

**MANAGEMENT OF FISHING IN THE
RAS MOHAMMED NATIONAL PARK
WITH SPECIAL REFERENCE
TO
THE FISHERY FOR *LETHRINUS
NEBULOSUS* (FORSSKAL, 1775)**

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To
Amany and Yara

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DECLARATION

I hereby confirm that all the research described in this thesis is my own unaided work, save form my University supervisor advised on the planning of the research and commented on the manuscript, advising in particular on English language. In addition assistance in identifying the crustacean organisms (in chapter five) by Dr. P. Hogarth, Biology Department, University of York.

Signed

.....

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CHAPTER ONE

**GENERAL
INTRODUCTION
&
STUDY AREA**

THESIS AIMS AND OUTLINE

The main object of this study has been to investigate a key fisheries-related issue critical to the management of the Ras Mohammed marine protected area, South Sinai, Egypt. Although this well known coral reef area is normally closed to all forms of fishing, there has been a traditional fishery to exploit spawning aggregations of the Spangled Emperor (local Arabic name 'Shour'), *Lethrinus nebulosus*, which occur annually during April to June around the headland of Ras Mohammed itself, and especially at one site, known to divers as Jackfish Alley. The fishery at this site was prohibited when the National Park was declared in 1983, but reluctantly reopened in 1991, following lobbying of central government by both Bedouin and sports fishermen. Consequently it became essential to gather sufficient data on the fishery, and on the stock of *L. nebulosus* which it exploited, to assess whether or not the fishery should be permitted to continue, and if so to develop a biologically-based management plan for it. This meant assessing whether the existing level of fishing effort was either optimal or sustainable which in practice involved investigating the effects of the current level of exploitation on seasonal yield, population structure, and reproduction process.

In addition, soon after the commencement of the study, an outbreak of Crown-of-Thorns starfish, *Acanthaster planci*, occurred, beginning at the very site on Ras Mohammed at which the fishery was concentrated. Since it had already been suggested (Ormond et al., 1988) that fishing, leading to reduced populations of key predatory fish, including in particular Emperors (Lethrinidae), is a contributory factor causing Crown-of-Thorns population outbreaks, the scope of research was extended, at the request of the National Park, to consider whether or not there might be a connection between the opening of the fishery and the outbreak of the starfish. Hence research was undertaken to investigate the origins of the outbreak,

to monitor the populations of the starfish, and to test how the populations might be controlled.

This thesis describes the results of this research. The different topics are covered as follows.

Chapter 1.

This present chapter includes firstly a review of the impacts of fishing on both the targeted populations and the ecological processes of the reef. These include effects on total yield, catch per unit effort, population size, catch composition and prey population release. Following this the chapter also includes an overview of knowledge of *A. planci* focusing on possible causes of population outbreaks, and evidence concerning them. Finally the study area is described with special emphasis on threats to its ecology and resources.

Chapter 2.

In this chapter the main fishery statistics collected for the *L. nebulosus* fishery at Ras Mohammed over 4 years are presented; these include changes in total yield, in catch per unit effort, and in population size structure. The size and species composition of the by-catch was also investigated.

Chapter 3.

In this chapter the reproductive behaviour and biology of the *L. nebulosus* stock are described. Possible factors influencing the fish to select Jackfish Alley as a spawning ground are discussed, and possible effects of fishing on the reproduction process considered.

Chapter 4.

In this chapter the age and growth parameters of *L. nebulosus* were investigated using different methods: measurements of growth rings in otoliths and in scales, and length-frequency analysis. These estimates of age and hence population structure were applied to various mathematical methods to estimate total, natural and fishing mortalities, and subsequently exploitation ratio.

Chapter 5.

This chapter describes the results of stomach content analysis of *L. nebulosus* caught on the spawning grounds, and hence describes the extent of their feeding and the variety of natural prey items consumed. These data were compared with the stomach contents of fish caught on a nearby control reef (Al-Konysa).

Chapter 6.

Describes the course of the Crown-of-Thorns starfish (*A. planci*) population outbreak that originated at Ras Mohammed and spread along much of the Egyptian Red Sea coast between 1994 and 1998. The population size and age structure on different infested reefs are recorded, and starfish movement (vertical and horizontal), reproduction, and feeding behaviour described. In addition, the starfish control programme initiated by the Ras Mohammed National Park is evaluated.

Chapter 7.

The final chapter provides a general discussion of conclusions arising from previous chapters, and in particular compares the effects of the Shour fishery on stock size and catch, and possibly on the reef ecosystem, with the economic and social benefits of the fishery. Implications for the management of the National Park are discussed.

CORAL REEF FISHERIES

The importance of coral reef ecosystems extends beyond their aesthetic beauty, species diversity and value to tourism: coral reefs produce up to 9 % of the total world marine fish production (6 million metric tons per year) (Smith, 1978). Indeed fishing must be the oldest form of human interaction with the coral reef ecosystem, and the survival of many coastal societies in tropical regions has long been dependent mostly on the production of coral reef fish which are typically the main source of protein. In addition fishing may provide many jobs in areas where employment opportunities are very limited. However, where well-developed reefs have a high value for conservation, for tourism, and for fisheries, there may be considerable conflict over resource use, which will require careful research and sensitive management to resolve.

A wide range of fishing methods is used in coral reef areas, but, because of the nature of the substrate, traditional manual methods employing hand-lines, traps, nets and spears, (rather than nets) tend to prevail. The selectivity of each method differs in relation to fish behaviour, so that each tends to target specific fish groups and size classes (Jennings & Lock, 1996). It has been well documented that hook and line fishing on reefs tend to target the top fish predators which, because of their size, are preferred food. Predators, because of their behaviour, will respond to the bait used in handline fisheries more than any other group (Munro & Williams, 1985). Studies of the selectivity of hand-lining on reefs have repeatedly shown that catches are dominated by Snappers (Lujanidae), Groupers (Serranidae), and Emperors (Lethrinidae) (Ralston & Polovina, 1982; Bertrand, 1988; Grant, 1981).

Such hand-line fishing has been documented to have significant effects on the abundance of large size classes in these predatory fish: an increasing reduction in

the contribution of the large size classes is expected as fishing effort is increased (Ralston & Polovina, 1982; Munro, 1983). Beinssen (1989) found that the average size of *Plectropomus leopardus* (Serranide) was about 13 cm bigger at unfished sites than at fished sites on the Great Barrier Reef. Similarly Craik (1981a) found that fish sizes were nearly twice as big in an unexploited population than in an exploited population on reefs in the Great Barrier Reef. Russ (1985), McCormick & Choat (1987), Polunin & Roberts (1993) and McClanahan & Muthiga (1988) also reported differences in fish size between populations of the same species on fished and on unfished areas. Furthermore, Koslow et al. (1988) has found that intensive fishing on reefs in Jamaica effects not only the abundance, but also the rates of recruitment and growth of not only target species, but also non-target species. Notably, the removal of the large size classes, due to the selectivity of the fishing method, leads to an increase in growth rate of the smaller fish, which so affects the size and age structure of the fish population.

Increased fishing pressure results of course in a decline in catch, and most early fisheries research on reefs has focused on the impact of intensive fishing on the sustainability of the fisheries. The effect of intensive fishing on fish populations can be detected initially by a reduction in catch per unit effort (CPUE) and eventually by a reduction in total catch. Alcala & Russ (1990) documented a clear reduction as a result of intensive fishing both in catch per unit effort and in population density of the most targeted fish species on a Philippine reef. Similarly, Koslow (1988) measured, after fifteen years fishing, an 82% decline in catches at heavily fished sites in Jamaica, and Craik (1981a) demonstrated that the catch per unit effort of coral trout (*Plectropomus leopardus*) in the Great Barrier Reef declined at the most intensely fished reefs.

In view of these effects it may be expected that targeting actively breeding stocks will further undermine the sustainability of such fisheries. It has been widely accepted that the protection of spawning aggregations is one of the most important policies that needs to be enforced in order to maintain any exploited fish population (Sadovy, 1994). In fact the impact of exploiting breeding stocks is not well documented for coral reef fish species, especially for top predators that are characterised by low rates of natural mortality, slow rates of population growth, long lives and late maturity. However Colin (1992) and Carter et al. (1994) concluded that breeding stocks of the Nassau grouper (*Epinephelus striatus*) have as a result of fishing effort being increasingly directed at aggregations of these fish occurring during spawning periods disappeared completely from some traditional spawning grounds in the West Indies and Belize.

Intensive fishing may also have an effect on the ecological balance and stability of coral reef ecosystem processes. In particular, selective removal of fish predators, or of other high trophic level species, may, as a result of predator-prey relationships, have large effects on the number and abundance of prey species. Where prey populations were previously controlled by predation at one or other life stage, removal of predators can result in population outbreaks of other species which as a consequence infest coral reef communities, and in some cases severely damage them (Russ, 1991). Thus McClanahan & Muthiga (1988) described how the removal of predatory fish from coral reef areas in Kenya resulted in a large increase in the numbers of sea urchins (*Echinometra sp* and *Diadema sp*), producing a decrease in algal biomass, an increase in calcium carbonate deposition as a result of bioerosion of the reef surface due to the feeding behaviour of the urchins, and significant coral mortality due to associated erosion of coral colonies. Similarly Endean & Stablum (1973), and Ormond et al. (1991) have argued that outbreaks of Crown of thorns starfish (*Acanthaster planci*) in Australia and

elsewhere in the Western Indo-Pacific have been precipitated by removal of key predators probably including Emperors (Lethrinidae) and Trigger fish (Balistidae), as well perhaps as the gastropod *Charonia tritonis*. The significance of fish predators was supported by data indicating that fish predators were significantly more abundant on component reefs of the Great Barrier Reef which had not experienced Crown of thorns outbreaks than on reefs which had been infested by them (Ormond et al. 1991).

CROWN-OF-THORNS STARFISH

The Crown of Thorns Starfish (*Acanthaster planci* Linnaeus 1758) has become one of the most studied invertebrates of coral reefs as a result of large-scale population outbreaks which have caused extensive damage to coral reef communities, in particular in Australia, Japan and Micronesia during several periods over the last 30 years (Moran, 1986). The species is widely distributed throughout the Indo-Pacific region, from the eastern coast of Africa to the western coast of central America, from the northern Red Sea to the southern section of the Great Barrier Reef (Moran, 1986). It primarily occurs in coral-rich reef habitat, at depths of up to 65 m. Early juvenile starfish feed on encrusting coralline algae, but after 6 months convert to feed on hard corals (Moran, 1990). They become mature at an age of two years (Lucas, 1974), and can live up to 12 years, reaching as much as 70 cm in diameter (Kenchington, 1977). Usually the starfish is relatively cryptic, occurring in low densities ranging between five and twenty individuals per square kilometre (Ormond & Campbell, 1974), but when population outbreaks occur, both the starfish and the coral mortality they cause may be very conspicuous.

The earliest starfish population outbreak was reported on Green Island in the Great Barrier Reef (Barnes & Endean, 1964) and this spread to engulf a high proportion of reefs in the central Great Barrier Reef. Soon outbreaks were reported from a wide variety of areas throughout the Indo-Pacific including Panama (Glynn 1973), Red Sea (Ormond & Campbell, 1974), Japan (Veron, 1992), Fiji (Zann et al., 1990) and Indonesia (Lane, 1996). However, the scale of outbreaks was highly variable, ranging from small-scale localised outbreaks of only a few hundred individuals (Endean, 1973; Ormond & Campbell, 1974; Lane, 1996) to widespread major outbreaks involving hundreds of thousand of individuals (Kenchington & Pearson, 1982; Moran & Death, 1992). The central section of the Great Barrier

Reef in particular has experienced three major starfish outbreaks since 1960 (Moran, 1986; Reichelt et al., 1990; Johnson, 1992; Stump, 1996). It is considered the most impacted area in terms of habitat destruction, with between 65 and 86 % of reefs being seriously affected by starfish populations.

As commented by Pearson (1981), the impact of the starfish population outbreaks on the coral reef ecosystem have probably been more extensive and dramatic than any other natural phenomena or man made interference. For example at Green Island up to 80 % of the hard coral colonies from the reef edge to 40 m were killed as a result of starfish predation (Pearson, 1981). On Tanguisson reef on the Island of Guam, Randall (1973a) found that only 1% of coral cover remained after a starfish outbreak. The effects of starfish infestation on a coral reef habitat can extend beyond a reduction in hard coral cover to a complete alteration in many of the ecological processes in infested reef areas (Moran, 1986). Most conspicuously a significant alteration in abundance and diversity of many coral reef biota has been observed after outbreak events (Endean, 1973b; Moran, 1986; Colgan, 1987; Williams, 1986).

Even through a considerable quantity of research has been carried out to investigate the causes of starfish population outbreaks, it has not been established until now whether or not outbreaks are an entirely natural phenomena or whether human activities have caused or at least influenced the size of the outbreaks. Indirect effects of intensive fishing, pollution, and terrestrial runoff of nutrients have repeatedly been proposed as possible anthropogenic causes for outbreaks. In particular, predation on *A. planci* by various marine animals has now been widely reported, and the suggestion made that starfish outbreaks might be due to decreased abundance of their predators. Thus Endean (1969) proposed that collection by shell collectors of the starfish-eating shellfish, *Charonia tritonis* had

triggered the starfish population outbreaks. Ormond & Campbell (1974) reported observation of *Arothron hispidus* (Tetraodontidae) and *Pseudobalistes flavimarginatus* (Balistidae) feeding on adult starfish on infested reef in the Sudanese Red Sea. Ormond et al. (1991) suggested that outbreaks of Crown of Thorns Starfish in Australia and elsewhere in the Western Indo-Pacific have been precipitated by selective removal of these and other predatory fish, including Lethrinidae, from the reefs. Endean (1976) studied the feeding behaviour of groupers in the Great Barrier Reef and found that remains of small starfish the gut of *Epinephelus spp.* Glynn (1977) found that feeding by the parasitic painted shrimp, *Hymenocera picta*, on *A. planci* was significant at Uvia Island in Panama. Conversely Sweatman (1997) studied the stomach contents of one hundred *Lethrinus sp.* caught on a reef heavily infested by large size-classes of starfish on the Great Barrier Reef, but no starfish remains were recorded.

Predation on starfish during their early life stages has also been investigated. Sweatman (1995), based on a field experiment, concluded that predation of juvenile starfish between 15 and 70 mm diameter by predatory fish was not an important factor. Conversely Keesing & Halford (1992a, 1992b), and Keesing et al. (1996) found that a significant mortality of post-metamorphic starfish was caused by epibenthic invertebrates. Similarly Lucas (1973 and 1974) observed predation on early post-metamorphic starfish by a small xanthid crab, the crab consuming all of the starfish that it could reach.

Increasing discharge from land of organic and inorganic substances also has been suggested as possibly causing starfish population outbreaks by increasing the survival rate of planktonic larval stage. Thus Lucas (1982) suggested that the density of phytoplankton on the Great Barrier Reef is not sufficient for most *A. planci* larvae to achieve complete development. Hoegh-Guldberg (1994) and

Ayukai (1992) however discovered that larval development of *A. planci* can be achieved using dissolved amino-acids as a source of nutrition. Brodie (1992) suggested that increasing nutrient levels in the Great Barrier Reef lagoon, caused by terrestrial discharges, might have increased larval food supply and thus starfish recruitment.

Edgar (1977) by contrast suggested that starfish population explosions are entirely natural and that recent human interference with coral reef ecosystems are not the causes of this phenomena. This suggestion has been supported by findings of high concentrations of starfish skeletal elements in sediment layers up to 10 m deep on fore- reef slopes along the Great Barrier Reef, suggesting that starfish outbreaks have occurred regularly during the last few hundred years. Further, Fabricius & Fabricius (1992) at Green Island, Australia measured concentrations of starfish skeletal elements in a deep layer aged at nearly 3 thousand years.

Thus the population dynamics of *A. planci* remain poorly understood. This is partly due to a failure to detect any exploding populations in their earliest life history stage. Ecological knowledge of these early stages between settlement and adulthood is poorly established. In laboratory experiments it was found that starfish larvae prefer to settle, metamorphose and live in dead coral rubble habitat until they reach 10 mm diameter after six months (Yokochi & Ogura, 1987). Johnson et al. (1991) hypothesised that Crown of Thorns Starfish larvae settle and metamorphose in deep water before moving into shallower depths, when they start feeding on hard corals. This hypothesis was supported by the results of surveying deep water habitats near infested reefs; the preferred rubble and coralline algal habitats were frequent around infested reefs, whereas deep water habitat around the uninfested reefs was mostly sand.

Based on population size and the scale of infested areas, starfish outbreaks have been classified into primary and secondary outbreaks (Potts, 1981). During all three outbreaks on the Great Barrier Reef a similar scenario was observed, in which small localised populations of starfish have been observed in northern area in the region of Green Island before the starfish spread southwards, infesting larger numbers of reefs after two to three years (Moran, 1986). *A. planci* is characterised by high spawning potential, in which each female may produce up to 65 million eggs during a spawning period (Moran, 1990). This feature suggests that successful spawning of a primary outbreak population and a subsequently high level of larval input to downstream reefs is the cause of secondary outbreaks (Endean, 1973).

Many attempts have been made to control starfish outbreaks. Zann & Moran (1988) reviewed the effectiveness of previous attempts, concluding that the effectiveness of control effort was affected by size of outbreaks, accessibility to infested reefs and availability of sufficient experienced participants. Controls were less effective for large outbreaks especially when insufficient man-power was available. Two main techniques were used in attempts to control starfish populations; manual harvesting and poisoning starfish underwater using copper sulphate. However, as emphasised by Zann & Moran (1988), there are possible undesirable side-effects of using copper sulphate in controlling starfish outbreaks, due to toxicity to other reef organisms.

STUDY AREA

The Red Sea Setting

Geologically, the Red Sea is part of the Syrian-African Rift system which separates north-east Africa from the Arabian peninsula. It extends for nearly 2100 km, with an average width of 280 km, and a depth in excess of 2000 m (Morcos, 1970; Braithwaite, 1987). Oceanographically the Red Sea is semi-enclosed, being separated in the south from the Indian Ocean by the Straits of Bab-al-Mandab, which is both fairly narrow (29 km) and very shallow (60 m) compared with the Red Sea proper. At the northern end, the twin Gulfs of Suez and Aqaba are fully enclosed save for the man-made maritime passage, the Suez Canal, built in the late 19th century, which connects the Red Sea with the Mediterranean, but is no more than 30 m in depth, and has an average width of only 370 m.

At the northern end of the Red Sea the twin Gulfs of Suez and Aqaba are separated by the mountainous Sinai peninsula, at the southern tip of which is the headland of Ras Mohammed. Despite their symmetrical location, the two gulfs differ significantly in their geological origin, morphology, environment and ecology (Siedler, 1969; Morcos, 1970; Gvirtzman & Buchbinder, 1975). The Gulf of Suez is a shallow depression which formed during the early Miocene (Friedman, 1972), and has an average depth of only 60 m, although it reaches about 90 m in its southern part. The bottom is flat and covered with thick layers of calcareous sediments and sandstone (Head, 1987). Surface water currents are caused by both the prevailing north wind and tidal oscillations. Because of the shallow depth and sandy bottom, water turbidity is very high (Morcos, 1970). The Gulf of Aqaba by contrast is narrow, varying between 14 and 26 km in width, but has steep sides which descend near its centre to almost 2000 m. Even at its narrow (6 km) entrance (The Strait of Tiran) water depth is about 250 meter. Surface water

circulation is generated by tidal water influx from the northern part of the Red Sea, as well as by prevailing north-east winds.

Climatically the Red Sea is surrounded by hot and arid continental land masses, with very low annual rainfalls averaging only 22 mm per year (Klinker et al. 1976; Allan & Morelli, 1971). As a result of the high air temperatures, low rainfall and high evaporation rates the sea is the hottest and most saline oceanic sea in the world, with water temperature exceeding 30°C in the central Red Sea during summer, and salinity averaging 40 ‰. Historically these severe conditions have contributed to limited human settlement along the coast, save that in the last fifteen to thirty years, supported by modern technology, very rapid development has occurred along many parts of the Red Sea coast, driven in particular by oil and tourism industries. The huge increase in human population has resulted in extensive stress and impact to the variety of sensitive coastal habitats, including, mangroves, seagrass beds and, in particular, coral reefs.

Mangrove stands are scattered in suitable locations along the coasts, although these are better developed in the south than in the north., and even these are poorly-developed by comparison with typical mangrove communities of the Indian Ocean. In the northern Red Sea only one species of mangrove, *Avicennia marina*, occurs, though in the south two others have been recorded, *Rhizophora mucronata* and (possibly) *Bruguiera gymnorrhiza* (Zahran, 1977; Price et al. 1987). The most northerly mangroves occur on the south-east coast of the Sinai Peninsula, where there is a small stand at Ras Mohammed and several much larger ones at Nabq, both however composed only of *A. marina*. (Por et al., 1977; Galal, 1999). Mangroves, in addition to exporting primary productivity to adjacent reef ecosystems, also provide food and shelter for the young of various commercial fish and shrimp species, such as the mangrove snapper, *Lutjanus argentimaculatus*.

Seagrass habitats are also widely distributed in bays and lagoons. All of the known tropical seagrass genera are recorded from the Red Sea. Among the ten species, the most typically dominant are *Halophila stipulacea*, *Halodule uninervis* and *Thalassodendron ciliatum* (Lipkin, 1977; Price et al., 1987). The number of species recorded decreases in the northern Red Sea and moving into the two Gulfs, with only one species (*H. stipulacea*) being found at the most northern tips, a decline in diversity which has been attributed to low water temperatures during the winter season (Lipkin, 1977). Like mangroves, seagrass beds have been identified as significant nursery grounds for various families of commercial fish, including both snappers (Lutjanidae) and emperors (Lethrinidae).

Most noted among Red Sea marine habitats however are well-developed coral reef formations which have been considered among the most spectacular in the world. Two morphological types of reefs are widespread. Fringing reefs which extend along almost all the coast line, especially in the north and central regions, except where the mersas (creek like inlets) and wadi (dry river beds) outflows reach the shore. There are also, especially throughout the central Red Sea, numerous offshore reefs, mostly complexes of patch reefs located several kilometres offshore, but also some atolls (such as Sanganeb in Sudan), and tower reefs, such as those in Egypt in the centre of the Straits of Tiran (Head, 1987).

On most reefs coral cover is relatively high, especially on the upper reef face, and approaching 200 zooxanthellate coral species from nearly 60 genera have been reported (Sheppard et al., 1992; Veron, pers. com.). The dominant genera include *Acropora*, *Montipora*, *Fungia*, *Porites* and *Favites*, which account for nearly 35 % of identified species (Scheer & Pillai, 1983). Among the best developed and most spacious of Red Sea reefs are those of south-east Sinai, especially those immediately south of the entrance to the Gulf of Aqaba. Over the stretch of coast

between Ras Nasrani and Ras Mohammed, deep water comes close inshore providing both ideal conditions for coral growth, and dramatic underwater scenery. Consequently this area, and the Ras Mohammed peninsula in particular, has developed a reputation among both marine biologists and divers as one of outstanding scientific interest and conservation value.

Threats to the Egyptian Red Sea habitats

Urban and coastal development. The tourist industry is one of the most important sectors in the Egyptian economy, and considered by some to be the largest element of the national income (Carr, 1990). Besides creating much new employment it drives considerable population redistribution (Sultan, 1993). Traditionally historical and antiquities-related tourism to Cairo and Upper Egypt dominated the market, but during the last fifteen years there has been a major shift towards other forms of tourism, especially marine-based tourism along the Red Sea coast. In South Sinai the number of hotel beds has expanded from 1030 in 1988 to 23,400 beds in 65 hotels in 1998; and this figure is expected to reach 160,000 within the next 20 years (Pearson & Shehata, 1998). Linked to this there has been an equivalent increase in the number of dive centres, diving boats, tourist employees and support urban population.

In many tropical coastal areas tourism-related development has led to extensive impacts affecting coastal and shallow-water marine environments (Salvat, 1987). In particular construction of coastal hotels and associated facilities (roads, airports) can destroy habitats directly where, for example, mangroves are felled or coastal reefs and lagoons infilled, or indirectly as a result of increased sediment loads or discharge of sewage, nutrients or other pollutants. Such impacts have caused significant deterioration of reefs along the mainland Red Sea coast around Ghardaqa. However effluent discharge, land-reclamation and coastal dredging

have not been permitted in South Sinai since the establishment and extension of the Ras Mohammed National Park, and are now also prohibited in along the mainland Red Sea coast.

Tourism also impacts coral reefs more directly. Divers and snorkellers unintentionally damage corals and other marine life by trampling on corals while walking on the reef flat, by accidentally kicking coral colonies while swimming, and by disturbing bottom sediment which then settles on nearby corals. It is now well established that at sites where diving pressure is intense coral cover may be reduced and hence the amenity value of these sites reduced (Hawkins & Roberts 1993; Davis, 1995; Medio, 1996). In South Sinai the growing conflict between conservation and recreational use has been of increasing concern. Steps have been taken by the Ras Mohammed National Park to regulate such effects: mooring buoys and other access points have been established giving a degree of protection to intervening areas. Also, at some sites, reef walkways have been constructed over the reef flat to give snorkellers access to the water beyond the reef face with minimum physical contact with reef top habitats. Medio (1996) found that these walkways result in a significant reduction in the amounts of physical damage to corals. Environmental awareness briefings can further reduce the accidental damage caused by divers (Medio et al., 1997).

Fishing. Fish provide one of the most important sources of high grade protein to Egyptian citizens, especially those living in coastal areas. According to FAO (1984) the total fishery yield of the Red Sea is low when compared to that of other areas, constituting only 0.07 % of total world yield. A range of different fishing methods are used. Purse seining and trawling by boats between 15 and 30 m in length, and powered by inboard engines of around 200 horse-power, are the most productive (Sanders & Kedidi, 1984). These methods were mainly employed in the

Gulf of Suez where the sea-bed depth and character were most suitable; but recently as a result of over-exploitation of this area some of these boats have been re-deployed to Foul Bay, which is in the south of Egypt and considered to be a relatively under-exploited fishing ground (El-Ganainy, 1997). The catches of these fisheries are dominated by mackerels (*Rastrelliger kanagurta* and *Trachurus indicus*), spotted sardinella (*Sardinella sirm*), lizardfish (*Saurida sp*). Annual yields are estimated at 11.4 and 1.5 thousand tons using purse seines, and 5 and 0.5 thousand tons using trawls, in the Gulf of Suez and in Foul Bay respectively (Sanders & Kedidi, 1984).

In other areas coral reef associated species dominate the fishery. This fishery is predominantly artisanal in nature, with local fishermen using gill and trammel nets in shallow reef areas, and long-lining and hand-lining in deeper ones (Galal, 1999). Fishing may be carried out by individuals or small groups of fishermen who reach the reef either from shore or using small boats, 7 to 15 m in length, with engines of around 50 horse power. The catch is dominated by groupers (37 %) and emperor (mostly *Lethrinus nebulosus*) (20 %). Sanders & Kedidi (1984) estimated the total yield of coral reef associated species from the Gulf of Suez and adjacent areas at 1.6 thousand tons. Based on this estimate he suggested that the total yield from the eastern coast of Sinai must be around 100 tons per year. However, given the greatly increased demand for fish by the tourist industry, and the rapid development of infrastructure, it is probable that the catch of fish from reef areas has increased considerably over the last 15 years, except in those parts of the National Parks which have been closed to fishing.

Shipping. Following the opening of the Suez Canal in the late 19th century, the Red Sea became a major shipping route, with thousands of tankers and cargo ships passing through the Straits of Bab-el-Mandab, Tiran and Gubal every years. The

main trade goods to and from the ports of the northern Red Sea are rock phosphate, potash, cement, chemical fertiliser, and oil. The large number of vessels are a significant source of pollution, which mostly takes the form of small-scale fuel spills, pumping polluted ballast-water and bilge water, or the disposing garbage in to the sea. However, the most significant impact to reefs in the Northern Red Sea in recent years has arisen from ships colliding with reefs. During the last ten years 8 major -impacts of this type have occurred in the Straits of Tiran region, resulting in an almost complete loss of coral cover over tens of thousands of square meters. In some cases physical damage was combined with either small-scale fuel spills, or the release of large amounts of phosphate or potash powder into the marine environment.

Pollution. Oil spillages and coastal mining are probably the main sources of pollution threatening the marine habitats of the northern Red Sea. Pollution by sewage and sewage effluent may occur locally but has only been significant around Eilat, where until recently the municipal systems discharged into the head of the Gulf of Aqaba. In Egypt, a substantial proportion of oil production occurs in the Gulf of Suez, and historically serious oil pollution, originating from oil wells and terminals, was described as affecting major sections of the Gulf of Suez (Wennink & Nelson-Smith, 1979; Dicks, 1987; 1984; Hanna, 1983). Subsequently the oil producers have become well-equipped with more advanced facilities, and oil spill accidents have become much less frequent. More recently the Egyptian Environmental Affairs Agency (EEAA), with technical and financial support of the European Union (EU), have established an Oil Emergency Centre in Sharm-el-Sheikh. This centre is well-equipped with in-shore and off-shore clean-up gear, including pick-up vessels, booms, skimmers, pumps, and absorbent materials.

Environmental Protection. With these various impacts in mind a series of conservation measures have been introduced by the Government of Egypt, with the intention of establishing a balance between the economic necessity of the country and the need to protect the environment. In 1983 the Ras Mohammed Marine Park was established, since when a network of terrestrial and marine protected areas (the Gulf of Aqaba Protectorates) had been declared (figure 1). These protected areas now include the entire coastal waters of the Egyptian Gulf of Aqaba, from the international offshore boundary to maximum high water level. In addition several terrestrial areas have been declared which now cover almost two thirds of South Sinai. According to the laws concerning protected areas and environmental protection (law 102 of 1982 and law 4 of 1992) all activities which may affect the natural habitats present within the boundaries of the protected areas prohibited, including fishing (except traditional fishing in permitted areas), hunting for wild animals, farming, introducing new species, and all forms of construction (including both buildings and roads).

Areas between these protected areas have been recognised as tourism development sectors in which a number of restrictions also apply: no permanent building is allowed within 30 meters of the high water mark, and impact or change to the coastline by either land-filing or dredging is prohibited. Because water resources in South Sinai are very limited, with most of the resorts depending on desalination of sea water, construction of water intake and brine water discharge pipes is permitted, subject to conditions ensuring that effluent discharge is via long-fall pipes at an appropriate distance from the reef, so as to avoid the hot saline brine impacting adjacent habitats.

The Ras Mohammed National Park, i.e. the peninsula of Ras Mohammed itself, was the first area to be protected. Besides the fringing coral reefs and coastal

Figure 1: Map of the South Sinai showing the boundaries of the Gulf of Aqaba Protected Areas (marked with yellow line).



waters, the terrestrial area of the Ras Mohammed peninsula is included in the protected area (see Fig 1), and no development is permitted here, except for a marine laboratory and visitor centre. Nevertheless, three critical management issues have arisen. First, the dive sites at the tip of Ras Mohammed, Shark reef and Yolanda Reef, are amongst the most heavily dived sites in South Sinai and appear to be showing signs of deterioration to the coral community. Second, the headland has been the site of a traditional fishery for Shour, *Lethrinus nebulosus*, that gather to spawn there, and after a period of closure, this was re-opened in 1991, and has been allowed to operate since. Third, and most recently, over the last few years there has been, beginning at the Ras Mohammed, a major outbreak of the coral-eating Crown-of-Thorns Starfish, *Acanthaster planci*. As mentioned above, this thesis describes a study of these latter two, possibly inter-related issues.

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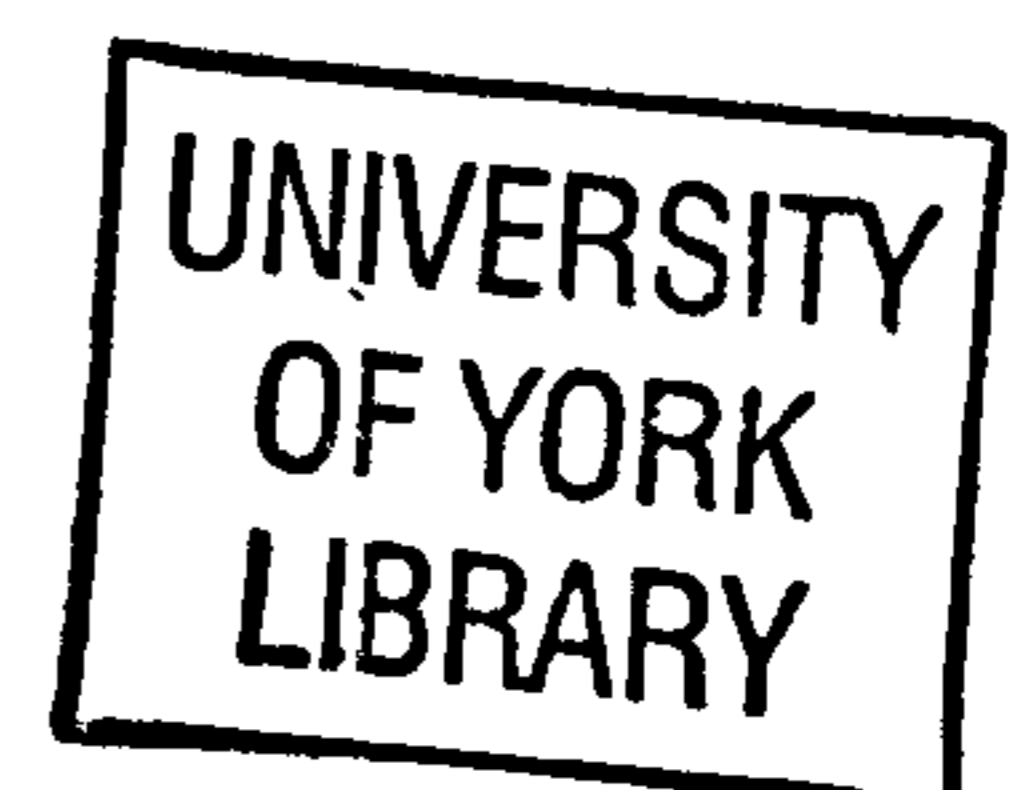
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CHAPTER TWO

**YIELD, EFFORT AND CATCH PER
UNIT EFFORT
OF THE
LETHRINUS NEBULOSUS FISHERY
AT
RAS MOHAMMED, RED SEA, EGYPT.**

ABSTRACT

Shour, *Lethrinus nebulosus* is amongst the most important commercial species caught from coral reef areas along the Egyptian Red Sea coast. The fish are known to aggregate to spawn at two sites in the northern Red Sea, one of these being at a site known as Jackfish Alley, within the Ras Mohammed National Park. The spawning aggregation at this site has been heavily exploited during the last 8 years. In this study the catch was monitored between 1995 and 1998. It was found that the catch peaks during the middle of the lunar cycle over two successive months between April and June. Between 1995 and 1998 a total of 72 tons of fish were taken, corresponding to approximately 42.7 thousand individuals. Over the same period the total seasonal yield catch and catch-per-unit effort declined by 40% and 50 % respectively. There was also a marked shift in population structure with a reduction in the proportional contribution of fish exceeding 50 cm. Further, fishermen interviewed reported that these figures represented a noticeable reduction in total catch and mean fish size compared with earlier years. In addition, a significant by-catch was found to be associated with the fishery, including a total of 30 species, dominated by Lethrinidae and Serranidae. The mean sizes of the most vulnerable species (*Variola louti*, *Cephalopholis miniata* and *C. hemistiktos*) were found to be smaller among fish caught on the spawning ground than among those caught on adjacent reefs.

INTRODUCTION

The effects of targeting commercially important species during spawning aggregation have been of increasing concern, and several authors have recently considered whether and to what extent such stocks may be exploited without risking a sharp decline in reproductive output and collapse of the exploited stock (Colin, 1992; Sadovy, 1996). It seems probable that all known spawning aggregations of commercially important species have been overexploited, in the sense fishing of spawning aggregations has contributed to exploitation of the whole stock beyond maximum sustainable yield (Domeier & Colin, 1997). Further, it has been argued that fish that form spawning aggregations are more vulnerable to over-exploitation than other stocks that spawn locally, since they aggregate in a predictable area and time every year in a way that encourages intensive fishing (Sadovy, 1994; Domeier & Colin, 1997).

From studies on different species it has been found that targeting spawning aggregations leads to various symptoms of overfishing, including declining catch (Bohansack, 1990), reduction in population mean size (Munro, 1983), alteration of sex ratio (Coleman et al., 1996), and in more extreme cases, a complete disappearance of the spawning aggregation from their traditional spawning ground (Colin, 1992).

In Egypt, fisheries are an important source of protein for many coastal communities. Yield from the reef areas is relatively low compared to that from major off-shore fisheries (Sanders & Kedidi, 1984), but is nevertheless significant in providing food and employment to many local artisanal fishermen. Further, over the last fifteen years there has been a dramatic development of the Egyptian Red Sea coastal zone, resulting in a many-fold increase in human population, local people as well as visitors. This in turn has resulted in a marked increase in demand

for local fish, and hence encouraged increasing fishing effort. It was in this context that the National Park management has been sympathetic to fully sustainable exploitation of natural resources within the protected areas.

The shour, *Lethrinus nebulosus*, is one of the most important commercial species in the Egyptian Red Sea. Older fisheries records show that the seasonal yield of this species has constituted up to 20 % of the total yield of reef associated species, with nearly 85 % of this amount being caught seasonally between April and June every year (Sanders & Kedidi, 1984). In the South Sinai region *L. nebulosus* aggregate to spawn during late-April to early-June every year, at a site known (to divers) as Jackfish Alley, on the east side of the Ras Mohammed headland. This spawning aggregation has been well-known and fished lightly since the early 20th century. According to fishermen's accounts, in the past all of the catch was salted and dried to be consumed later in the year, especially during the winter period, and two or three days fishing was enough to satisfy their requirement for the whole year. It is only recently, as a result of the increase in demand for fresh quality fish, that fishermen now fish in larger numbers and for a longer period, thus placing the stock under increasing pressure.

In view of concern at the sustainability of this stock, research was undertaken between 1995 and 1998 on the fishery on the *L. nebulosus* spawning aggregation. This chapter presents the basic fisheries data obtained from this study, and describes trends in seasonal total yield, catch-per-unit-effort, and population size structure. The likely effects of the current level of exploitation on the stock is discussed. In addition the by-catch of other species taken by the fishery was recorded, and possible implications considered.

METHOD

Study area

The area in which fishing is concentrated (and permitted) extends from the headland (known as the Shark Observatory) at Ras Mohammed, to a subsidiary headland, Ras Atar (or Attar), about 5 km to the north (figure 1). An extremely well-developed continuous fringing reef, sloping fairly steeply into deep water, extends between the Shark Observatory and Ras Attar. This area was examined both by snorkelling and Scuba diving, following which it was possible convenient to provide a more detailed description of the reef in terms of the following five partially distinct morphologically zones:

1- South of the Eel garden

The reef flat in this stretch is very narrow, (1 - 3 m wide), has a very low hard coral cover, and is dominated by filamentous algal turf. At the edge of the reef flat is a very steep reef face, characterised by extensive growth of soft corals and sponges. A sandy soft bottom begins to appear at 38 m. Fish diversity appears high compared with the other parts of the study area.

2- Eel Garden

The reef flat in this area has a sandy substrate towards the beach, and hard substrate nearer the reef edge. Small patches of seagrass (mainly *Thalassia hemprichi*) occur in the inner part, whereas towards the reef edge coral cover increases, dominated by branched coral colonies such as *Acropora*, *Stylophora*, and *Pocillopora*. The reef face descends steeply to about 7 m deep and has a high diversity of hermatypic hard corals. Below this a sandy slope descends gradually to 45 m; this is occupied by a large colony of garden eels (*Gorgasia* sp.), which live in individual burrows and feed on passing zooplankton. This colony, which

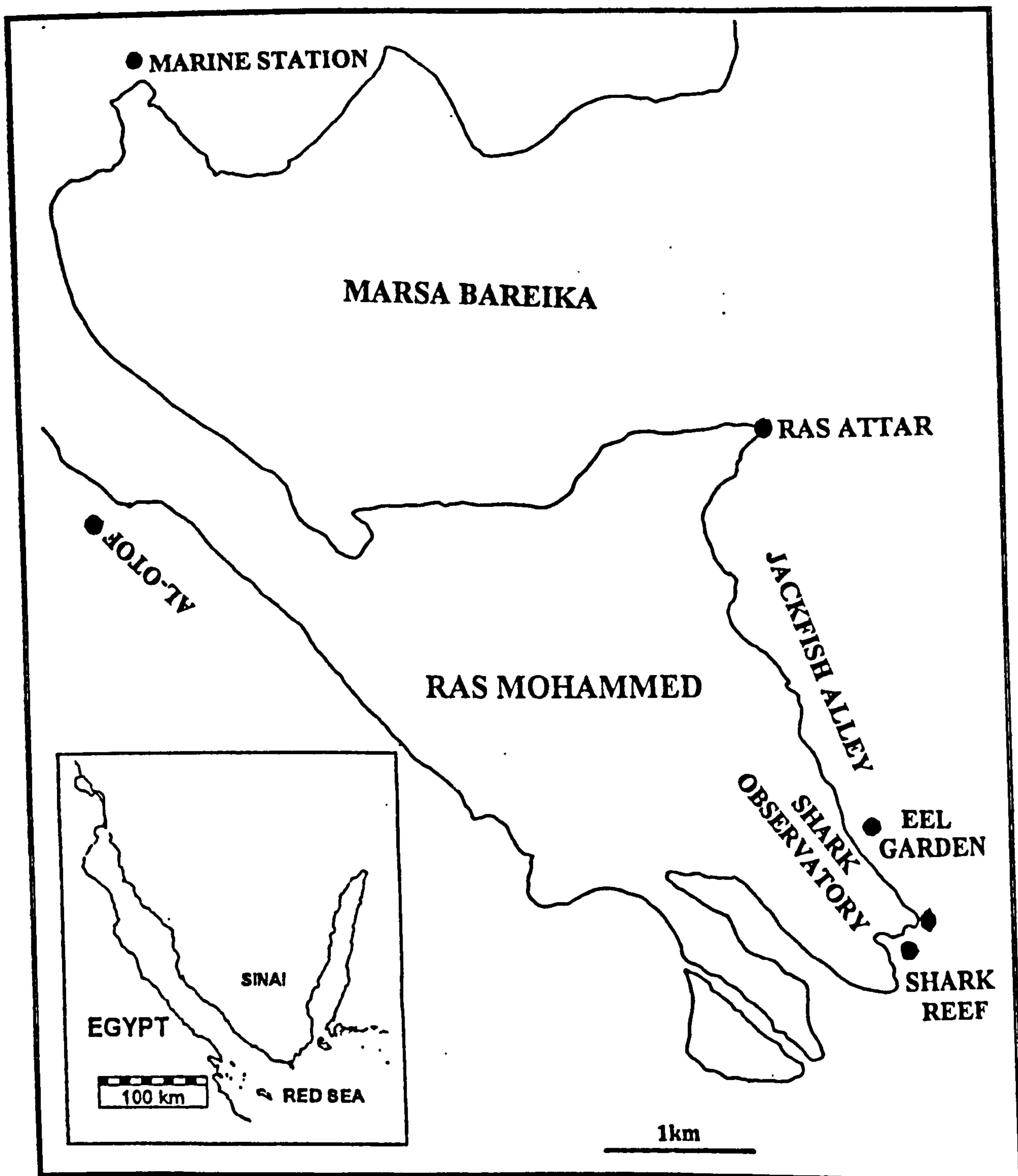


Figure 1: Map shows the location of the *L. nebulosus* fishing ground in the Ras Mohammed National Park at South Sinai, Red Sea.

contains more than 100,000 individuals, is thought to be the biggest of this species in the world (Clark et al., 1990).

3- North of the Eel Garden

Over an area extending about 400 m to the north, a wider reef flat has low coral cover towards the shore, but a higher coral cover nearer the reef edge. The reef face drops steeply to about 28 m, has a high hard coral cover, especially on its upper part, whereas on its lower parts dense stands of *Gorgonians* and large *Millepora* colonies appear down to about 20 m. Below this the reef has a more gentle slope, mainly covered by sand with scattered coral patches.

4- Jack Fish Alley

This section of reef has a wall-like reef face descending to 10 to 15 m and is occupied by dense coral growths. Below this a broad horizontal terrace develops, dominated by sometimes dense coral growths, which extends up to 500 m seawards before the reef slopes down again.

5- South of Ras Atar

Along this stretch the reef flat is mostly sandy, although towards the reef edge there is a high cover of calcareous algae. The reef is exposed to high rates of sedimentation because of the way in which winds drive sand over the high cliff which extends along the shore. The reef slope, which is covered by a thin layer of sand, has a relatively low hard coral cover. It appears that the high rate of sedimentation within this area may limit the abundance and diversity of hard coral growth.

In addition, the size and abundance of the most common species of the families Lethrinidae, Lutjanidae and Serranidae within the shore fishing ground and adjacent reefs were estimated, using underwater visual census method (UVC). At

each census, fish were counted and lengths were estimated to the nearest five centimetres within 200x10 m band transect at three depths (reef edge, 7m and 15 m).

Fishing permits and regulation

Four out of the thirteen dive sites in the Ras Mohammed National Park lie within the permitted fishing area for the shour fishery. These sites have been considered as not only the most popular dive sites in the Ras Mohammed National Park, but as amongst the best known dive sites in the world. These sites are used daily by diving centres in the Sharm el-Sheikh area. Restrictive fishing regulations were therefore issued by the Park authority to avoid any conflict between dive operations and fishing activities and to decrease the impacts of the fishing on the stability and aesthetic quality of these reefs. Fishermen had to have a fishing permit from the Park authority to be able to enter and fish inside the Park boundary during the shour season (April-July). A fishing permit form containing the fishing regulations was designed and distributed at the beginning of each fishing season among all the participating fishing boats. Skippers agreed an undertaking to respect the regulations. Permits were renewed every week. A translation of the fishing regulations is shown in table 1.

Table 1. Translation of Shour fishing season regulations as included in the fishing permit form.

- 1. Fishing is only permitted between Ras Attar and the south tip of the Ras Mohammed peninsula.**
- 2. Fishing is permitted only during the period from sunset to sunrise, and it is not allowed for any boat to be within this area before or after this period.**

3. Handline fishing is the only permitted fishing method, and boats should not have nets or any other fishing gear inside the Park boundary.
4. During the day time boats are only allowed to stay at Al-attof or Marsa Khoshbe, and all forms of fishing are not permitted at these day mooring sites.
5. Boat skippers have to report all fishing activities (catch and effort) to the Park on a daily basis.
6. Fishermen are allowed to catch only shour fish and all of the other species should be returned to the water immediately.
7. Boat skippers must provide any fish samples required for the research program.
8. The boat owner is responsible for any violation or damage to the Park resources by any of the boat crew.
9. on any violation of any of the above regulations this fishing permit will be terminated, and the boat required to leave the Park boundary on the same day.

Fishing methods and gear

Fishing was carried out from motorised boats ranging in length from 5 to 16 meters, boats smaller than 7 meters (dinghy) were fitted with outboard engines ranging between 10 and 25 horse power. Bigger boats were fitted with inboard diesel engines ranging between 20 and 115 horse power. All of the boats were fitted with ice storage boxes, size varied according to boat length, and capacity ranged between 0.5 and 15 tons. Boats ranging in length between 7 and 11 metres were the most common in the fishery. Many boats were accompanied by one or two small unmotorised canoes, mostly three to four meters long. About 90% of the fishing boats participating in the shour fishery came from El-Tor (100 km north, on the Gulf of Suez coast), and the remainder from Sharm el Sheikh (15 km away).

Fishing was only permitted during the night time and in accordance with park regulations. The fishing boats were not allowed to stay on site during the day, but had to move from day time mooring sites (at Marsa Bareika or El-Otaf) to the fishing ground every evening day about 1 hour before the sun set. Large fishing boats were moored at the fishing ground by placing a light small anchor over the reef edge, and a large anchor in deep (more than 50 m) water offshore of the reef. Small boats were moored either by tying off to the line between the large boats and the reef edge or to the back of the large boats. Fishing was carried out beyond the reef edge in depths of water ranging from 10 to 50 m. Hook-and-handline fishing was the only fishing method permitted. The handlines consist of 100 m. of nylon ranging in thickness between 80 and 120 (unit) terminating in a single hook ranging in length between 6 and 9 cm. A lead sinker is tied to the end of the fishing line, its weight being varied according to current strength. Various kinds of bait were used on the hook including, in increasing order of preference, strips of fresh fish flesh, salted sardine and squid. In addition a plastic bag containing a mixture of salted fish and squid and tied to a rope was dropped under each fishing boat in order to attract the *L. nebulosus* schools. These bags were pulled step by step once the fish came under the boat (when the fishing rate increases) so as to draw the fish groups up into shallower depths.

Effort and catch records

All fishing boat skippers were required (under National Park's fishing regulations) to keep a daily record of their fishing activity and catch. This was done by completing (whether they fished or not) a catch record form (figure 2) on which was entered the total weight of *Lethrinus nebulosus* caught, the number of fishermen fishing from the boat, and the time of starting and ending the fishing every day. The forms had space for 7 day's data and were collected at the end of each week. Before each fishing season all skippers were carefully briefed on how

رقم التصريح (ح)

استمارة تسجيل بيانات و كميات اسماك الشعور

الأسبوع السادس

ملاحظات REMARKS	عدد الصيادين MEN No.	وقت مغادرة الفرشه DEPARTURE TIME	كمية الشعور بالكيلو SHOUR IN kg	التاريخ DATE
—	٧	الساعة	٩٠ كيلو	الثلاثاء ٥/٢٠
—	٧	الرابعة	١٢ كيلو	الأربعاء ٥/٢١
X	+	+	+	الخميس ٥/٢٢
+	+	+	+	الجمعة ٥/٢٣
—	٦	الساعة	١٥٠ كيلو	السبت ٥/٢٤
—	٦	الساعة	١٥٠	الأحد ٥/٢٥
—		الساعة	١٥٠	الاثنين ٥/٢٦

Figure 2: A copy of the catch record form distributed among fishing boats to determine catch and effort (daily and seasonal) of the shour fishery in Ras Mohammed.

to complete the form, and correct completion of forms was monitored throughout the study period. Skippers were asked to fill in the form at the end of fishing every day, after they had stored the catch. Fish were stored in boxes, each of which could hold 25 kg. Catch was recorded as weight (kg) rather than as numbers, because the fishery is valued by weight. Recording only the number of fish could cause errors due to changes in size composition over the time. Further, estimating the catch by weight was easier for the fishermen who obtained their total catch by counting the number of boxes. The total daily catch and fishing effort of the whole fishery were obtained by summing the individual catches and effort of each boat. The total yield of each fishing season could then be estimated by summing the total daily catch of all the boats across the season. Daily catch per unit effort was estimated by dividing the total catch (kg) for each day by the total number of fishermen (Kg/men). The catch per unit effort for the whole season was estimated by dividing the total yearly catch by the number of permitted fishermen.

Size frequency

In addition to the record kept by fishermen, during each fishing season between 1994 and 1998, an average of 23 night visits were made (at 1 - 3 days intervals) to the fishing area. This was done both to ensure enforcement of the National Park's fishing regulations, and to collect more detailed data on the fishery. On these occasions fork length of all the *L. nebulosus* fish caught by a proportion (up to 6) of the boats was measured to the nearest millimetre, and thus fish assigned to 1 cm interval length classes. As a result, a total of 520, 580, 605 and 869 random *L. nebulosus* are measured during the 1995, 1996, 1997, and 1998 fishing seasons respectively. Size frequency of *L. nebulosus* population for each year over the study period were obtained and plotted histographically. On each occasion the boat skipper was interviewed and information on marketing of the yield, running

coast of the boat, fishing gear specification (hook size, bait type), number of fishermen, and the time spent fishing checked.

Species composition of the catch

On each night's visit all the by-catch from the boats being monitored was recorded, and identified to the species level, identification being based primarily upon Randall (1983). Fish lengths were estimated visually to the nearest 5 cm., The size structure and catch per unit effort data were compared with two other sets of data. Firstly, underwater censuses (UVC) were carried out along the nearby reefs. Secondly; a small scale fishing experiment was conducted at other unfished reefs inside the Park using the same fishing method that is used by fishermen. Also over the study period 13 fishing boats were spotted fishing outside the permitted fishing area (mostly at Shark Reef), and in these cases all the catch was identified and measured, fishing effort and time was estimated.

RESULTS

Effort, yield, and catch per unit effort

According to the Park fishing regulations the maximum number of fishermen permitted in each season is 200. The number of fishermen participated in the shour fishery was chosen as the unit in which to express the yearly and daily variation in fishing effort. The yearly effort varied through the study period. The fishing efforts were 163, 186, 80, 173 and 198 fishermen for the 1994, 1995, 1996, 1997 and 1998 respectively. The effort in 1996 was the lowest, largely because in that year many boats had some difficulty in getting the permit required from the Al-Tor Port Authority to move to Ras Mohammed. Daily fishing effort fluctuated within each season, the daily number of fishermen in each season varying between a maximum effort during the full moon days and a minimum (almost twenty fishermen per day) during the new moon days. This occurs because all the local fishermen know that the peak catch is taken during the full moon period. In each fishing season some permit holders did not participate in the fishery, either because their fishing boat needed maintenance, or because they became involved in another fishery (sharks or shell collection).

In total, nearly 72 tons of *L. nebulosus* were caught over the study period corresponding to about 42.7 thousand fish. However the total annual catch of this species declined by 40 % over the period between 1994 and 1998. In general the total catch declined gradually from 1994 to 1998 with the exception of the 1996 season, when the lowest yield was recorded, this is probably because, as explained above, the fishing effort in this year was lower than the effort in the other years. Other fish species were caught (as a by-catch) but in terms of weight, *L. nebulosus* dominated the catch, constituting more than 97 % of the total yield over the whole study period. Changes in the annual total yield of the *L. nebulosus* over the period between 1994 and 1998 in kilograms is shown in figure 3.

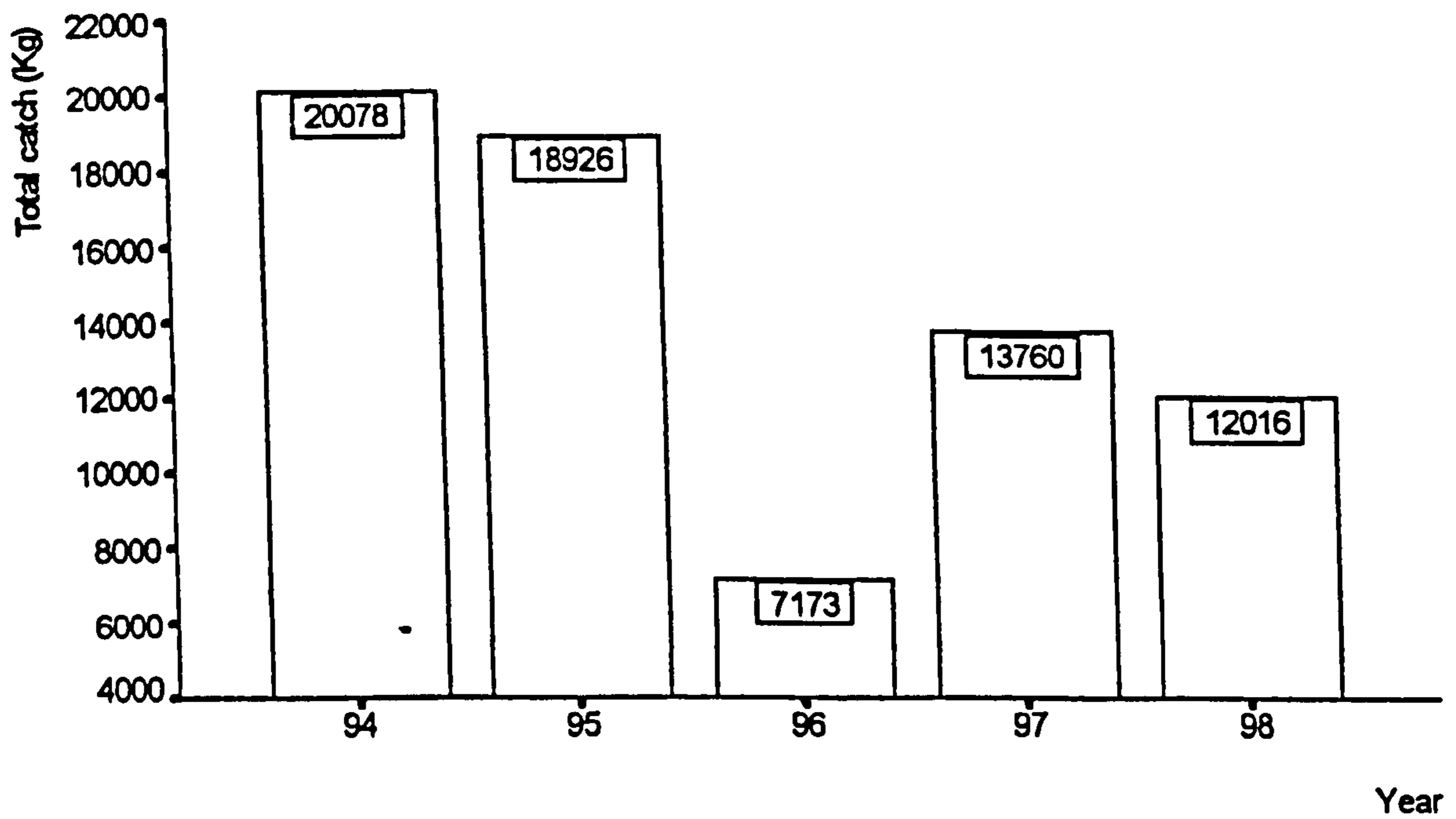


Figure 3: The change in the total annual catch of the *L. nebulosus* from the Ras Mohammed National Park between 1994 and 1998.

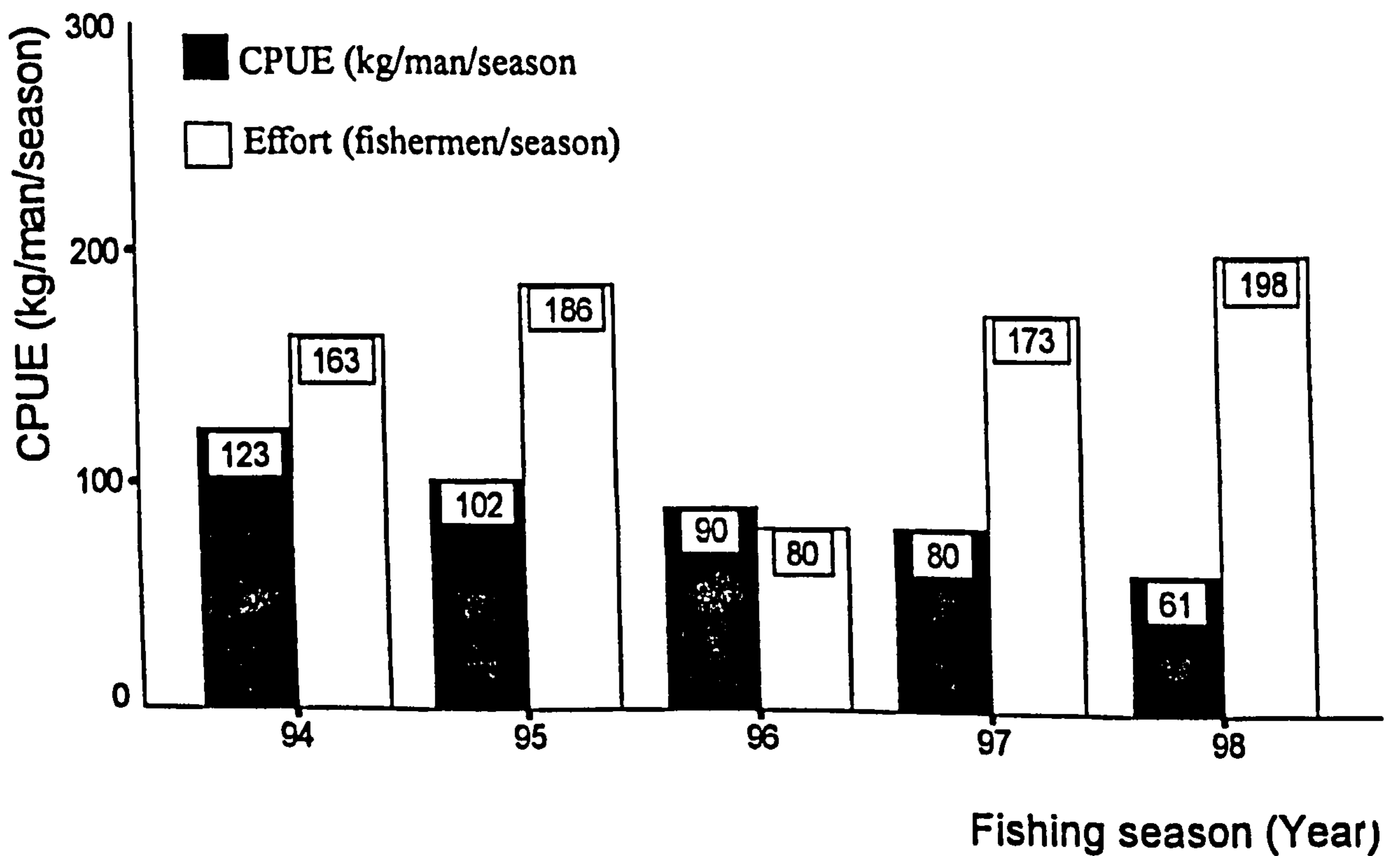


Figure 4: The changes in the annual overall catch per unit effort and in the maximum number of fishermen participating in the *L. nebulosus* between 1994 and 1998

Because of the fluctuations in both daily effort and daily total catch of *L. nebulosus*, the annual catch per unit effort for each year was estimated by dividing the yearly total catch by the maximum number of fishermen attending the fishery. There was almost no variation in this number during the peak fishing periods which accounted for the majority of the catches. The changes in the annual catch per unit effort and in the maximum number of fishermen attending the shour fishery are shown in figure 4. Generally, the yearly catch per unit effort has shown a similar pattern of declining yield to that observed in total catches. Overall the annual catch per unit effort declined by nearly 50 % between 1994 and 1998.

Fishing pattern

As previously mentioned it has been long known to local fishermen that there is a relationship between the lunar cycle and the yield of shour. A plot comparing daily total yield of *L. nebulosus* with lunar phases over the period between 1994 and 1997 (figure 5) revealed that in each fishing season there were two peaks in the *L. nebulosus* yield. Each of these peaks occurred during the period following a full moon day, and extended for 10 to 12 days. Usually yield rate began to increase gradually two days before full moon, and reached a maximum on the third day following full moon day, before declining toward the following new moon. The catches during these peaks periods constituted almost 95% of the total annual yield, since catches were very low during the periods between them.

It was also apparent that usually *L. nebulosus* yield during the first peak in each year was noticeably higher than the yield in the second peak. There was one exception: in 1997 only one large peak was observed, this occurring at the end of May, while a month early the yield was extremely low and estimated at only 250 kg. The start of the *L. nebulosus* season (the time of the first peak) varied between the 3rd week of April and the 1st week of May, this depending on the timing of the

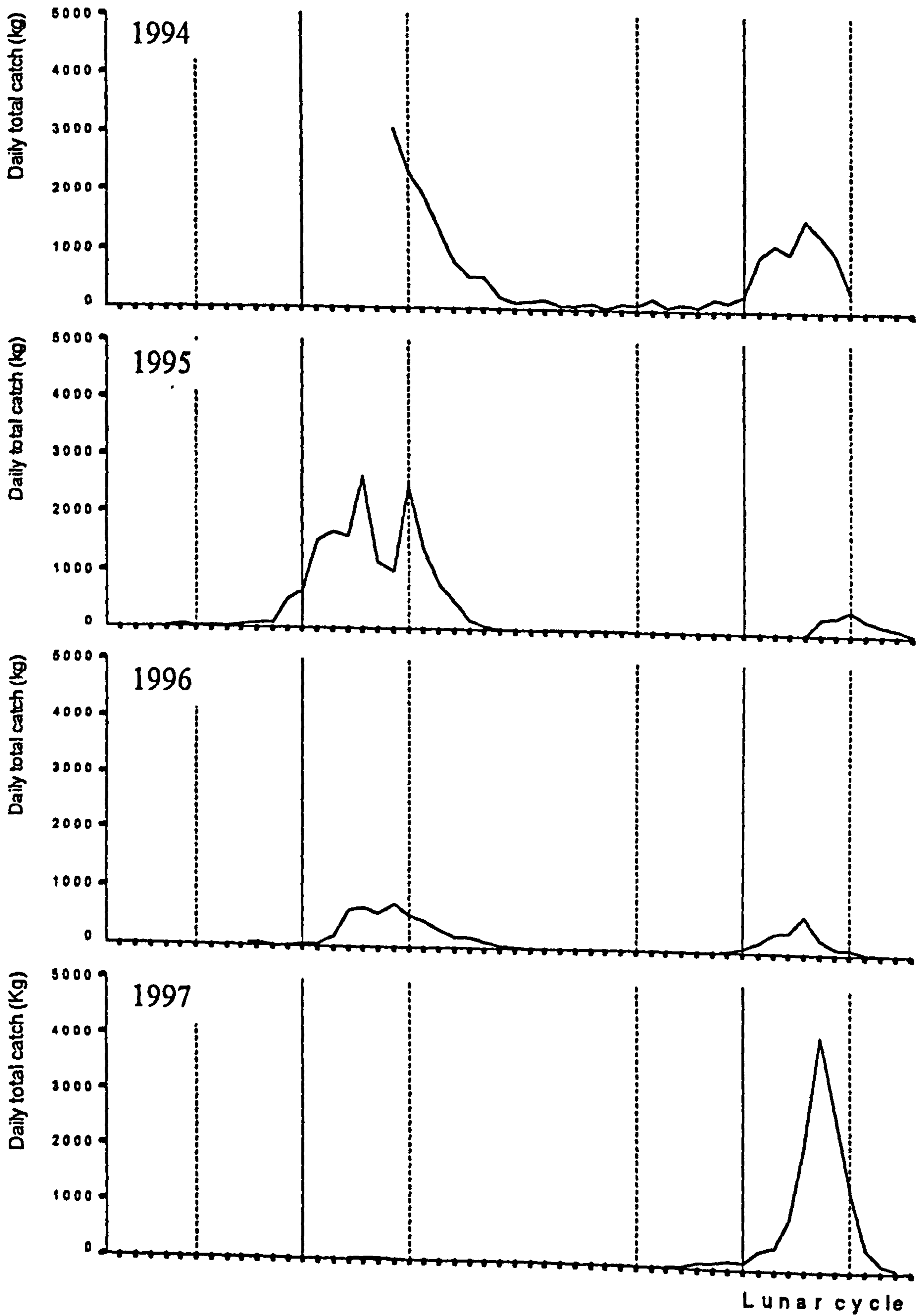


Figure 5 : Variation in the daily catches of *L. nebulosus* between 1994 and 1997; solid and dashed lines indicate full moon and half moon respectively.

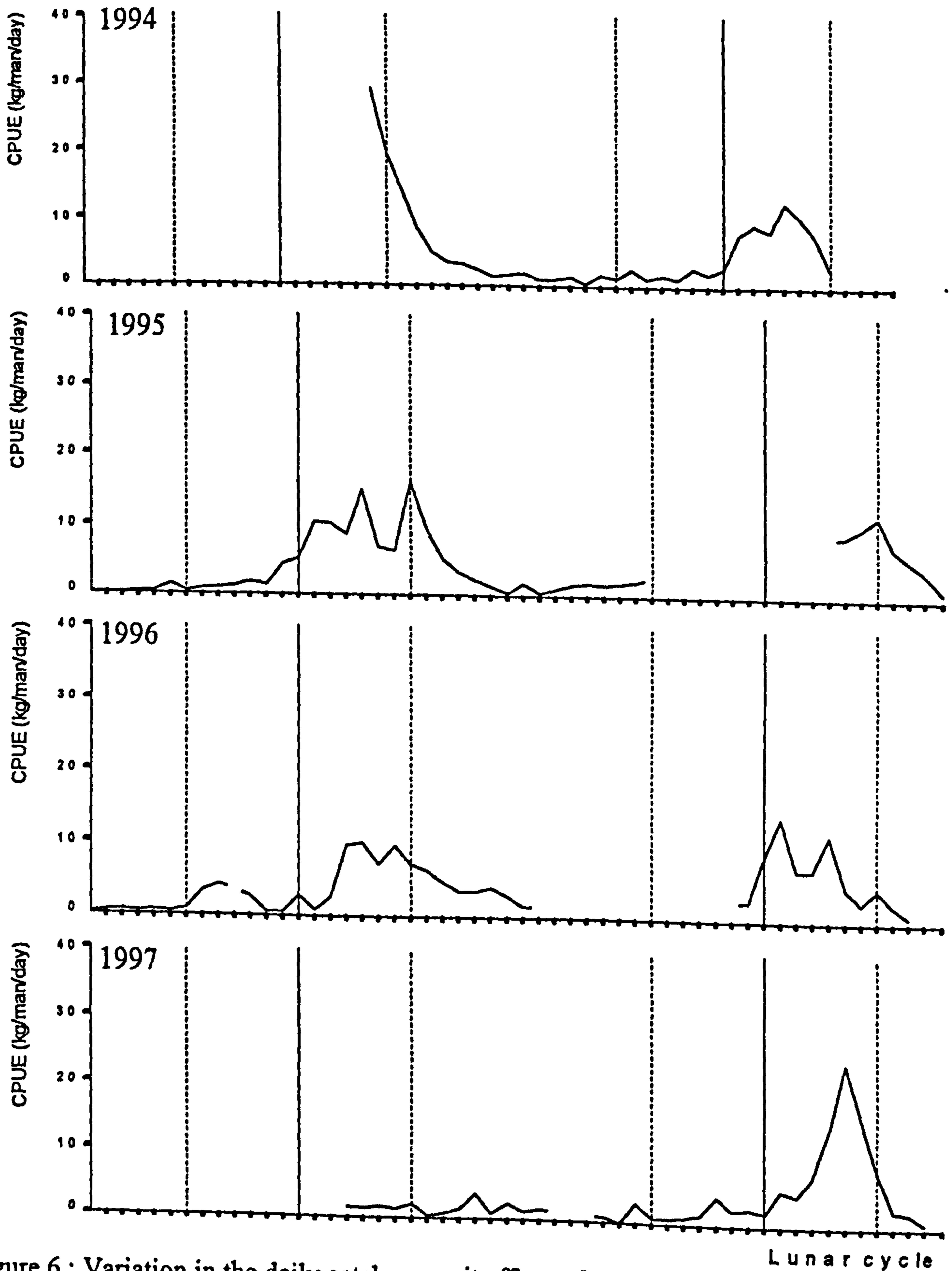


Figure 6 : Variation in the daily catch per unit effort of *L. nebulosus* between 1994 and 1997 fishing seasons; solid and dashed lines indicate full moon and half moon respectively.

full moon during this period. The maximum daily yield that was caught in one single day during the first peak periods were 3, 2.6, 0.7 and 0.3 tons in 1994, 1995, 1996 and 1997 respectively. A plot of daily catch per unit effort (figure 6) showed a similar pattern. Looking at variation in catch rate during the night, the *L. nebulosus* catch rate was always highest during the late evening period, between 20:00 and 24:00 hrs., although occasionally it was also high during the early morning periods, between 4:00 to 5:00 hrs..

Length frequency composition

The length frequency distribution of the *L. nebulosus* in each fishing season is shown in figure 7, and the percentage frequency of each size class in each year over the same period is shown in figure 8. The fork length ranged between 28 and 68 cm. The most frequent sizes were between 40 and 52 cm, these fish constituting 78 % of all the measured fish (N =2562). The largest fish was obtained in the 1995 fishing season and measured 78 cm in fork length. Fish smaller than 35 cm or larger than 59 cm were very rare within the catch and formed only 0.9 and 1.0 % by number respectively of the whole *L. nebulosus* catch.

Changes in the frequencies of the large and small size classes occurred between 1994 and 1998. In particular there was a reduction in frequency of fish larger than 50 cm, fish in this class constituting 17.9, 16.6, 13.1 and 12.3 % of the catch in 1995, 1996, 1997 and 1998 respectively. By contrast the percentage of fish smaller than 40 cm in fork length increased, constituting 10.1, 17.2, 22.6 and 18.6 % of the whole population in 1995, 1996, 1997 and 1998 respectively. Mean fork length for the entire sample (1995-1998) of *L. nebulosus* was 45.4 cm., but over the study period a slight overall reduction in mean fish size was recorded, mean fork length being 46.2, 45.4, 44.4 and 44.9 cm. for 1995, 1996, 1997 and 1998 respectively.

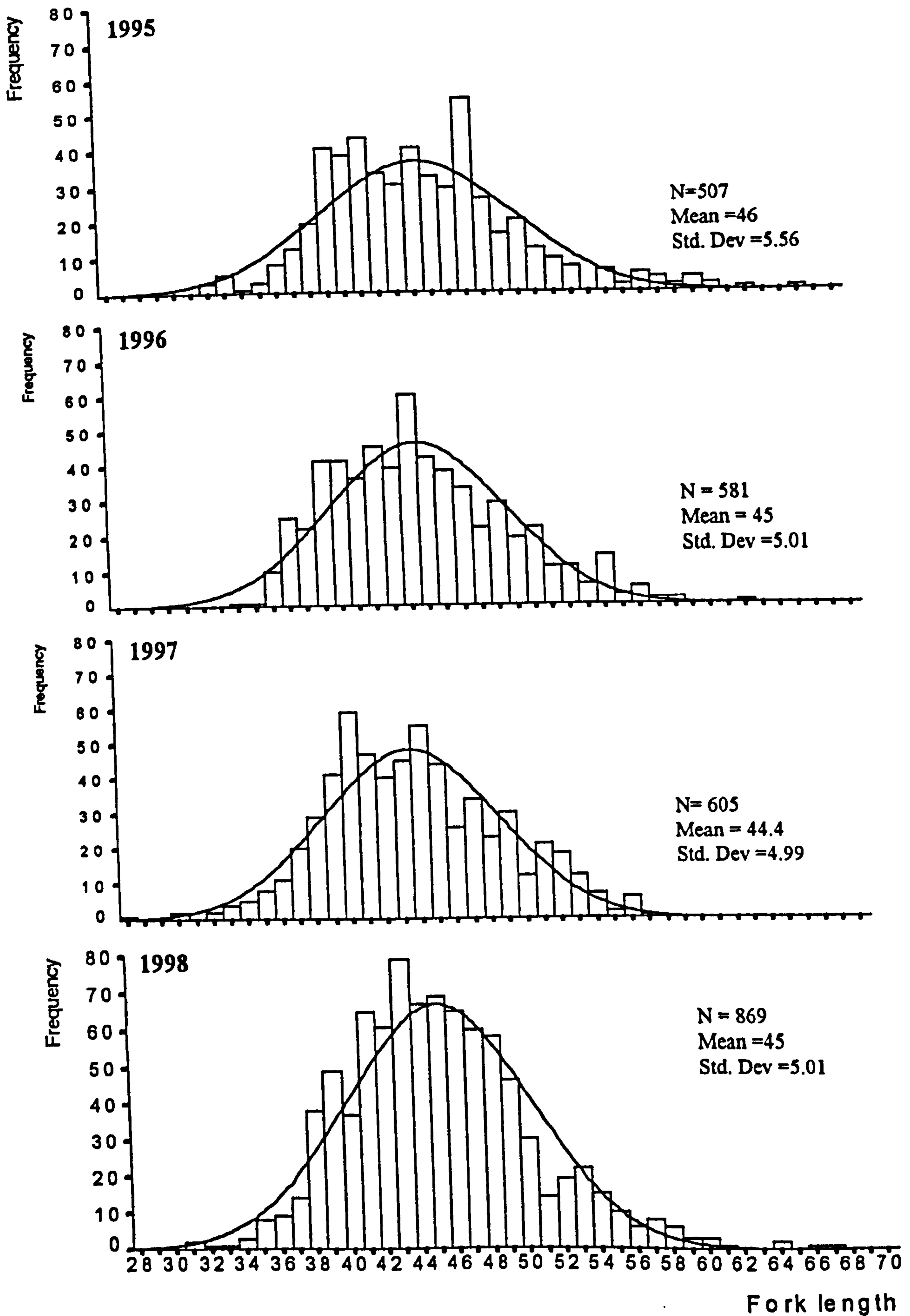


Figure 7: The length frequency distributions of *L. nebulosus* from seasonal fishery in the Ras Mohammed National Park between 1994 and 1998.

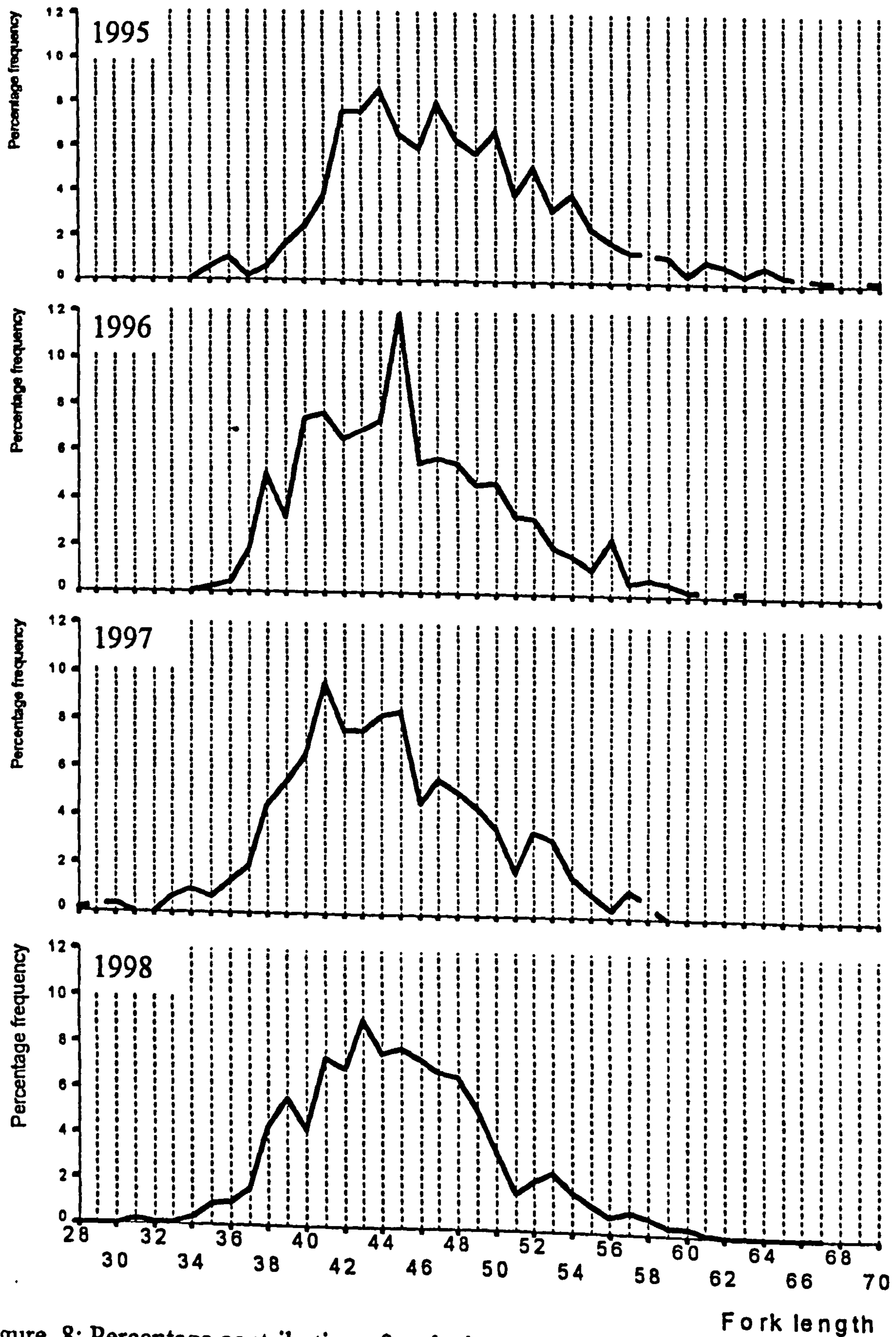


Figure 8: Percentage contribution of each size class to *L. nebulosus* caught at Ras Mohammed between 1995 and 1998.

Species composition

The by-catch of the shour fishery consisted of 30 fish species belonging to 16 families. The percentage frequencies of the recorded by-catch species and families are shown in figures 9 and 10. In term of fish number, four families dominated the catch: Lethrinidae, Serranidae, Sphyraenidae and Lutjanidae which constituted 40, 23, 7.8 and 7.2 % of the by-catch respectively. *Lethrinus xanthochilus* was the most frequent species, accounting 24% of the total number of fish. Apart from the grouper *Epinephelus fuscoguttatus*, the reef associated fish species were mostly small in size ranging in total length between 7 cm to 25 cm. In terms of weight, however, the by-catch was dominated by two other fish families: Carangidae and Carcharhinidae. The number of the recorded species varied between years, with totals of 25, 24 and 19 fish species being recorded over the 1995, 1996 and 1997 respectively. However, the same families remained dominant: the Lethrinidae, Serranidae and Lutjanidae. the differences were remarkably within the other species.

A total of 13 fishing boats was recorded fishing outside the boundary of the permitted fishing area during the study. The catch obtained by these boats revealed that the catch per unit effort outside the permitted area was nearly 9 times higher than the catch per unit effort inside the fishing ground. In addition, the mean fish size of the most common by-catch species was higher outside the *L. nebulosus* fishing ground. For example the mean total lengths of *Cephalopholis miniata*, *C. hemistiktos* and *V. louti* were 38, 30, and 40 % larger outside as compared to inside the *L. nebulosus* fishing ground. The catch from outside the fishing area was much less diverse than that from inside it. Also the dominant species were different, being in descending order *C. miniata*, *C. hemistiktos*, and *Variola louti*. Generally, the fishing rate of the by-catch species was lower during the peak periods for catching *L. nebulosus*.

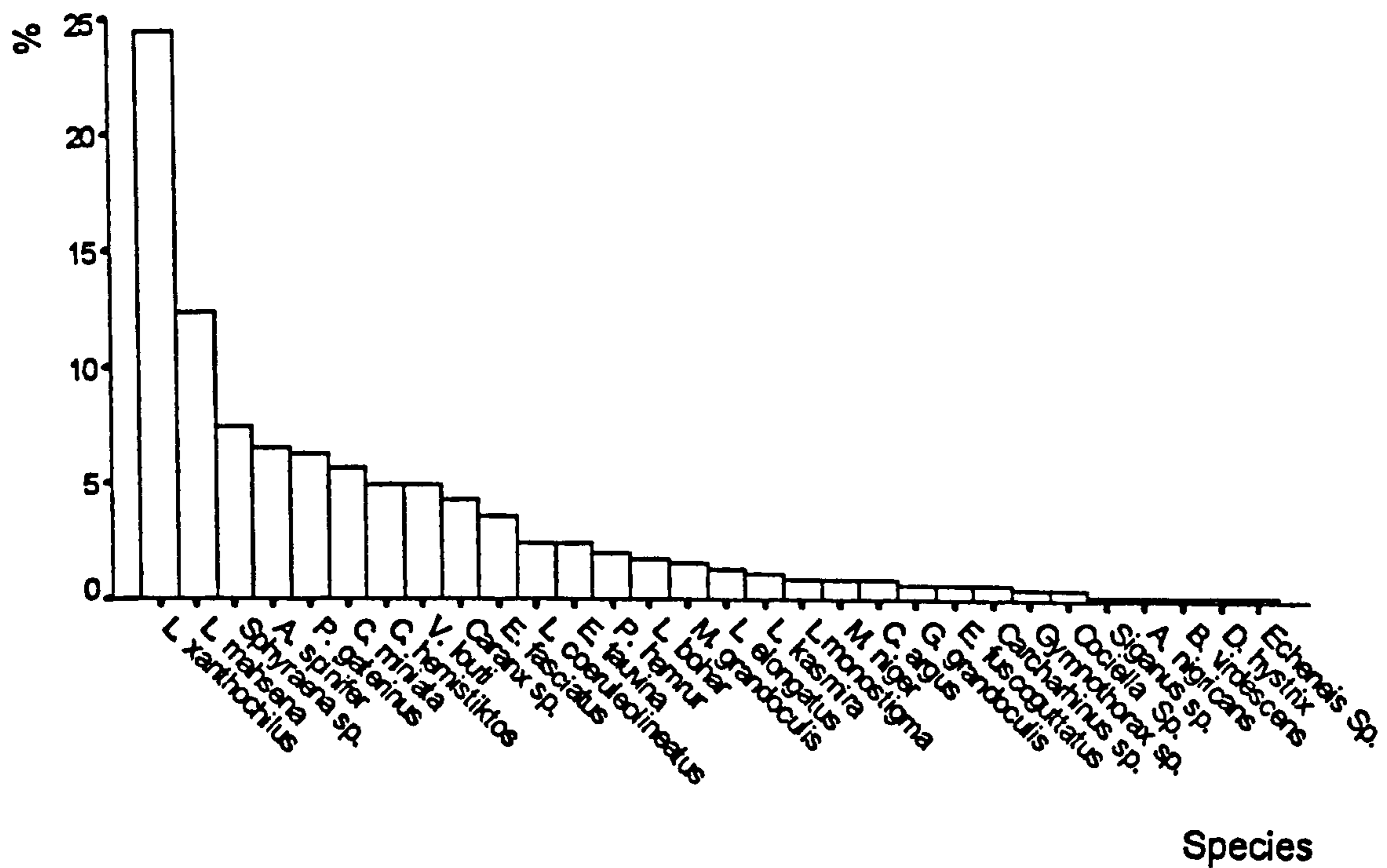


Figure 9: The relative frequencies of different fish species in the by-catch between 1995 and 1997, species being arranged in descending order of abundance.

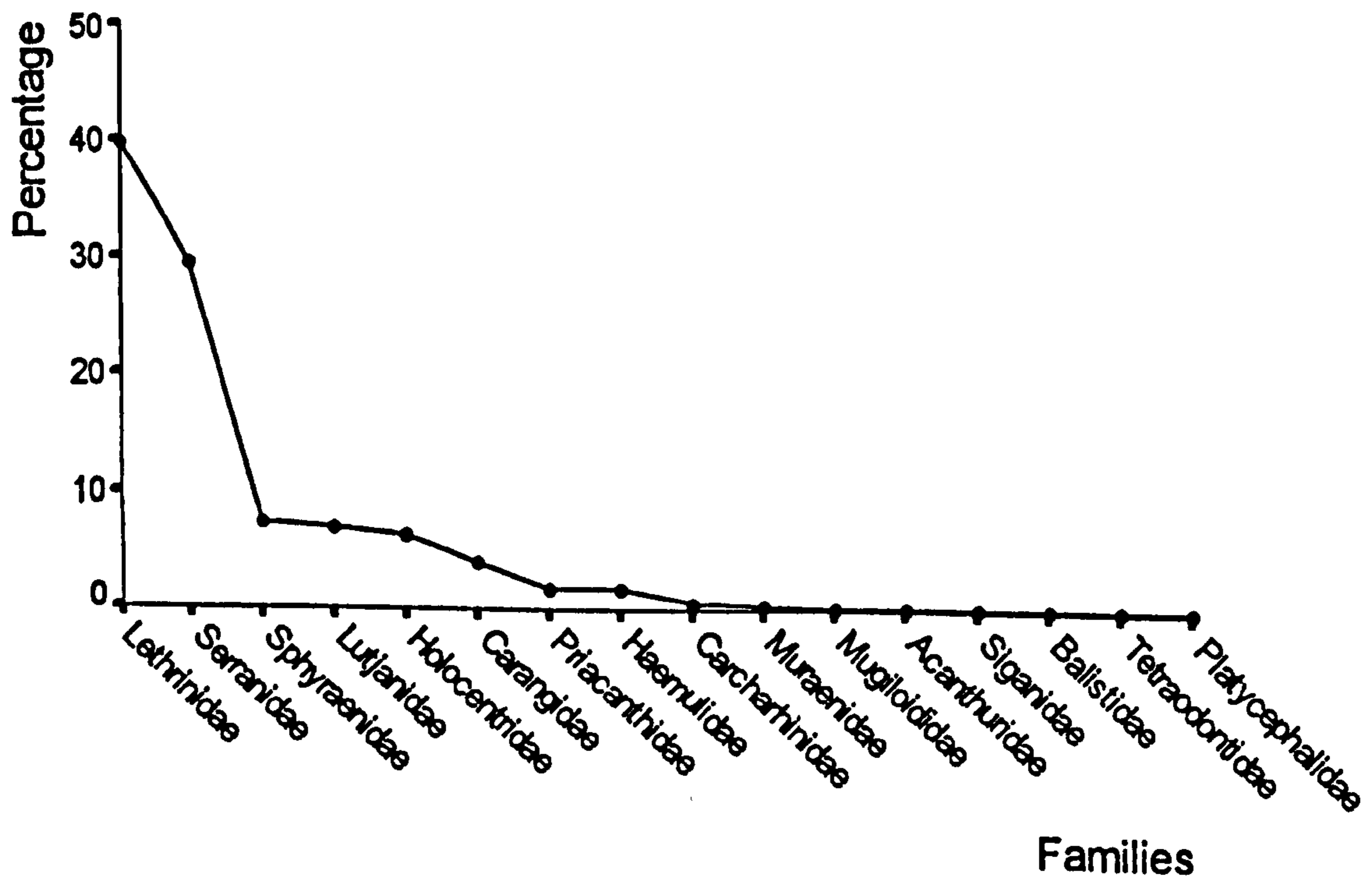


Figure 10: The relative frequencies of fish of different families in the by-catch associated with shour fishery between 1995 and 1997.

During the 1997 fishing season fishermen were asked to return all by-catch species to the water immediately. This was done in order to decrease the impact of the *L. nebulosus* fishery on reef fish abundance and diversity, and so on the aesthetic beauty of the reef. However, it was found that most of these fish when returned to the sea, remained on the surface, because of problems associated with an expanded air bladder. In fact very few fish were observed to eventually descend to the bottom; also during the season most of the by-catch is consumed by the fishermen, so this arrangement was cancelled.

Marketing

Most of the *L. nebulosus* yield was sold fresh on a daily basis, by sailing the fishing boats to either the Marsa Khoshby or the El-Konysa landing sites. *L. nebulosus* was sold to the local fish retailer for almost 7 Egyptian pound (2.1 \$) per kg. Some large boats however accumulated and stored the catch until the end of the season; this portion of the catch was sold to fish retailers from Suez or Cairo for a higher price (10 Egyptian pounds per kg.). The retail price of the *L. nebulosus* in the South Sinai market declined during the spawning period from 16 pounds per/kg at other time of the year to 10 pounds per/ kg. These prices are for the whole fish, which is the traditional form in which it is sold in the area. According to Egyptian fishing authority regulations, 20 % of the total fish catch of any licensed fishing boat must be sold to Government retailing centres; fish were sold to these centres at lower prices (5 Egyptian pounds per kg), and retailed to the customers for 7 Egyptian pounds per kg.

Total and net benefit.

According to the interviews with fishermen during the spawning season the running cost of the fishing boats including fuel, ice for fish storage, and living expenses onboard amounted to nearly 27 % of the fish price. Based on this figure,

the net benefits of the *L. nebulosus* fishery at the Ras Mohammed National Park each year during the period 1994 to 1998 were 114.3, 107.8, 40.8, 48.3 and 68.4 thousand Egyptian pounds respectively. Also, the average net income per fisherman from the *L. nebulosus* fishery was 701, 579, 511, 453 and 346 Egyptian pounds in each year during the same period.

DISCUSSION

Total catches and catch per unit effort

The spawning grounds of *L. nebulosus*, as well as of many other fish species, along the Egyptian Red Sea coast have been well known for a long-time to most fishing communities. For *L. nebulosus* two spawning grounds are known in the northern part of the Egyptian Red Sea: one at the southern tip of Ras Mohammed ($27^{\circ} 44' N$ and $34^{\circ} 16' E$), and the other on eastern side of Um-Gumar Island in the north western Red Sea ($27^{\circ} 21' N$ and $33^{\circ} 55' E$). A third site is known in the southern Egyptian Red Sea near to Ras Benas. All three spawning populations have experienced different levels of exploitation since the early 1900s (pers. com.). However, during the last ten years there has been increasing exploitation at the spawning ground as a result of increasing demands for fish resulting from the rapid development of tourism in the northern Red Sea. According to interviews with fishing boat skippers, the Ras Mohammed *L. nebulosus* spawning ground is the most heavily exploited among the three, followed by Um-Gumar and then Ras Benas (in descending order of level of exploitation). The level of exploitation of each breeding stock appears to be influenced mainly by how far the fishing ground is from the market, and the sea conditions during the spawning season.

A decline in total catch and as well as in catch per unit effort is the typical response of any reef fishery to exploitation, particularly if the fishery targets same population or operates over most of the relevant habitat, (Craik, 1981a; Gaut & Munro, 1983; Munro & Williams 1985; Ferry & Kohler, 1987 and Koslow et al., 1988). In this study the total catch and catch per unit effort of the *L. nebulosus* both declined remarkably in only five years, by 40 % and 50 % respectively. However if fishing is too intense, catch and catches per unit effort will continue to decline, rather than leveling of as they should do at optimum sustainable yield. The continuing decline in the total catch of *L. nebulosus* suggests they may be

being over-exploited. A collapse in fish population as a result of heavy fishing from its well-known spawning grounds has been documented in many coral reef areas throughout the world, especially, for species with a high commercial value. Colin (1992), Carter et al., (1994) and Aguilar-Perera & Aguilar-Dvila (1996) observed that Nassau grouper (*Epinephelus striatus*) breeding stocks have disappeared completely from some traditional spawning grounds in the West Indies and on the Belize coast as a result of increased fishing effort directed at these populations during the spawning periods. Similarly, Domeier & Colin (1997) documented that the spawning aggregation of *Plectropomus leopardus* at Elford Reef, Australia, almost disappeared as a result of heavy fishing pressure. These comparisons suggest there may be undesirable consequences of targeting the *L. nebulosus* breeding stock at Ras Mohammed. In summary, targeting the breeding aggregation of any fish stock is not a recommended policy, since it threatens the sustainability of future catches, especially for those species that are characterised by very low population growth.

Length frequency

Russ (1991) and Jennings & Lock (1996) have demonstrated that each fishing method tends to target specific size classes, and subsequently affects the size structure of the fish population. It is well-known that hand-lining in coral reef areas targets the larger size classes in the fish population (Craig, 1981a, and 1981b; Bohnsack, 1982; Gaut & Munro, 1983; Koslow et al., 1988 and Beinssen, 1988). Ralston (1990) in Hawaii measured a significant reduction in mean size of lutjanid fish sizes targeted by a handline fishery. Similarly Craig (1981a), Ayling & Ayling (1986) and Beinssen (1988) found that the mean size of *Plectropomus leopardus* (Serranidae) was smaller on heavily fished reefs than on others along the Great Barrier Reef.

The size structure of the *L. nebulosus* population throughout the study period suggests that *L. nebulosus* recruit to the Ras Mohammed breeding stock only when they reach about 35 cm in fork length. The age determination work described in chapter three indicates that this size corresponds to fish at four years old. This conclusion is confirmed by work on reproduction in this species (see chapter three) which confirms fish only came into breeding condition at this size. Inspection of the frequency of the large fish in the catch across the study period shows a clear reduction in the frequency of the large size classes. This suggests that exploitation of the *L. nebulosus* breeding stock in the Ras Mohammed National Park during the last 7 years has driven the population structure towards the smaller size classes. This suggestion is supported by earlier work on *L. nebulosus* in the northern Red Sea which documented a maximum size for *L. nebulosus* of 85 cm (Sanders & Kedidi, 1984).

The appearance of immature fish smaller than 35 cm and the increasing proportion of fish smaller than 40 cm within the catch during the study period are clearly consequences of increasing the fishing effort on the breeding stock over the last 5-7 years. Similarly Ralston & Kawamoto (1985) in Hawaii observed that age at first capture of *Pristipomoides filamentous* (Lutjanidae) declined from 4 to 1.8 years as a result of five years of intensive exploitation by handlining.

Species composition (by-catch)

In terms of weight and discarding sharks and jacks the catch per unit effort of the by-catch species from the spawning ground was estimated at 0.04 kg/man/hour. This catch per unit effort is in fact relatively low compared to that from neighbouring reef areas. From adjacent reefs, Shark reef, the inner part of Ras Attar and the south part of Marsa Bareika the catch per unit effort was 0.7 kg/man/hour, and from the Gordon Reef and Ras Gamylla in the strait of Tiran,

which may be considered as effectively unfished areas, the catch per unit effort was estimated at 1.7 kg/man/hour. It is also low compared to that reported from reef areas in some other parts of the world. Thus Watson et al. (1996) estimated the yield from fished and unfished Kenyan reefs to be 0.6 and 1.3 kg/man/hour respectively. Higher yields up to 4 kg/man/hour have been reported from Caribbean and Seychelles reefs (Kawaguchi, 1974; de Moussac, 1987; Dalzell & Preston, 1992). Based on surface water area, the allowed fishing ground in the Ras Mohammed National Park was estimated to be 0.8 km². This area has been used by nearly 180 fishermen per day in every fishing season since 1991, this level of fishing within such a small area presumably explains the low by-catch yield.

The by-catch yields from unfished reefs near Ras Mohammed were dominated by groupers (Serranidae) which constituted up to 75 % of the total by-catch. Further, the mean fish size of most recorded fish species was larger in the unfished areas than in the fished area in Ras Mohammed. This indicates that fishing in the *L. nebulosus* breeding ground has also affected both the composition and the individual sizes of the reef fish community as whole. Russ and Alcala (1989) similarly reported a significant reduction in abundance and richness of many coral reef fish populations as result of intensive fishing in an area which was protected for ten years in the Philippines.

In the 1995 fishing season, three sharks averaging about 160 kg in weight were recorded within the by-catch. From underwater observation at other times of year, sharks, especially the large size classes, were very rare within the fishing area, suggesting that these sharks may be attracted to Ras Mohammed during the spawning season to feed on the Shour fish. This is supported the fact that on once the shour had been hooked they were sometimes attacked by shark before the fish could be landed. Subsequently, sharks became the target of some fishermen, who

used special fishing gear (steel wire and large hooks) to capture them. But the sharks were not targeted for their trading value but just to stop them interrupting the fishery. From the 1996 season however this shark fishing was banned.

Targeting a spawning aggregation of any fish stock is not a recommended policy since typically it adversely affects the sustainability of the fishery for that stock taken as whole. This is especially the case for those species that are characterised by low individual or population growth. The current level of exploitation of the *L. nebulosus* breeding stock appears to be unsustainable. The decline in total catch and catch per unit effort by 40 and 50 % respectively over such a short period should be taken very seriously by the Park management. Not only may allowing the current level of fishing in the future lead to further reduction or a complete disappearance of fishery, but, reducing the *L. nebulosus* breeding stock to a lower level will risk future spawning and recruitment, leading to the collapse of the fishery for this valuable species over a wide area and throughout the year.

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Appendix

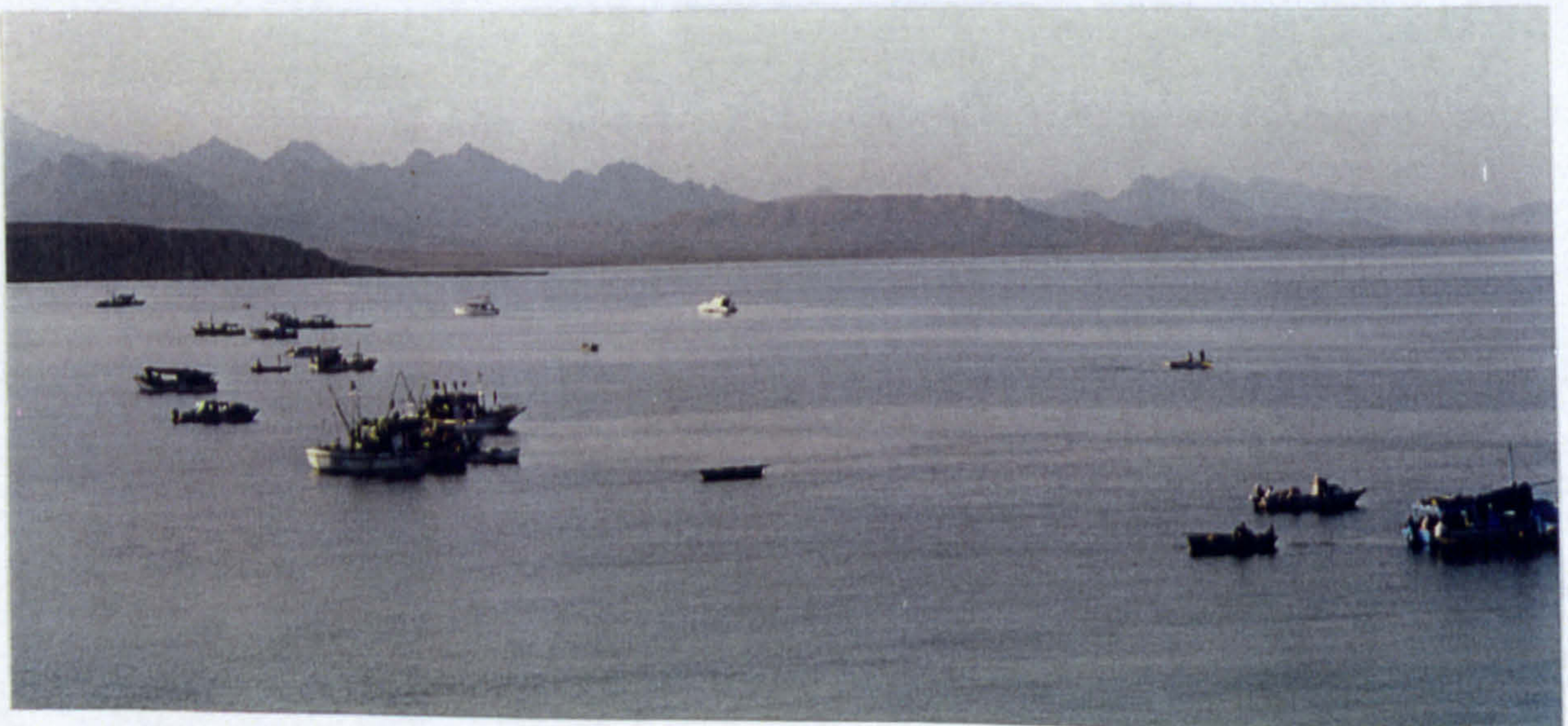


Figure 1. Photographs show the fishing boats, (top) parking at Marsa Bareika during the day time, (centre) anchoring in the fishing ground, (bottom) overview of Jackfish Alley reef during the shour fishing season.

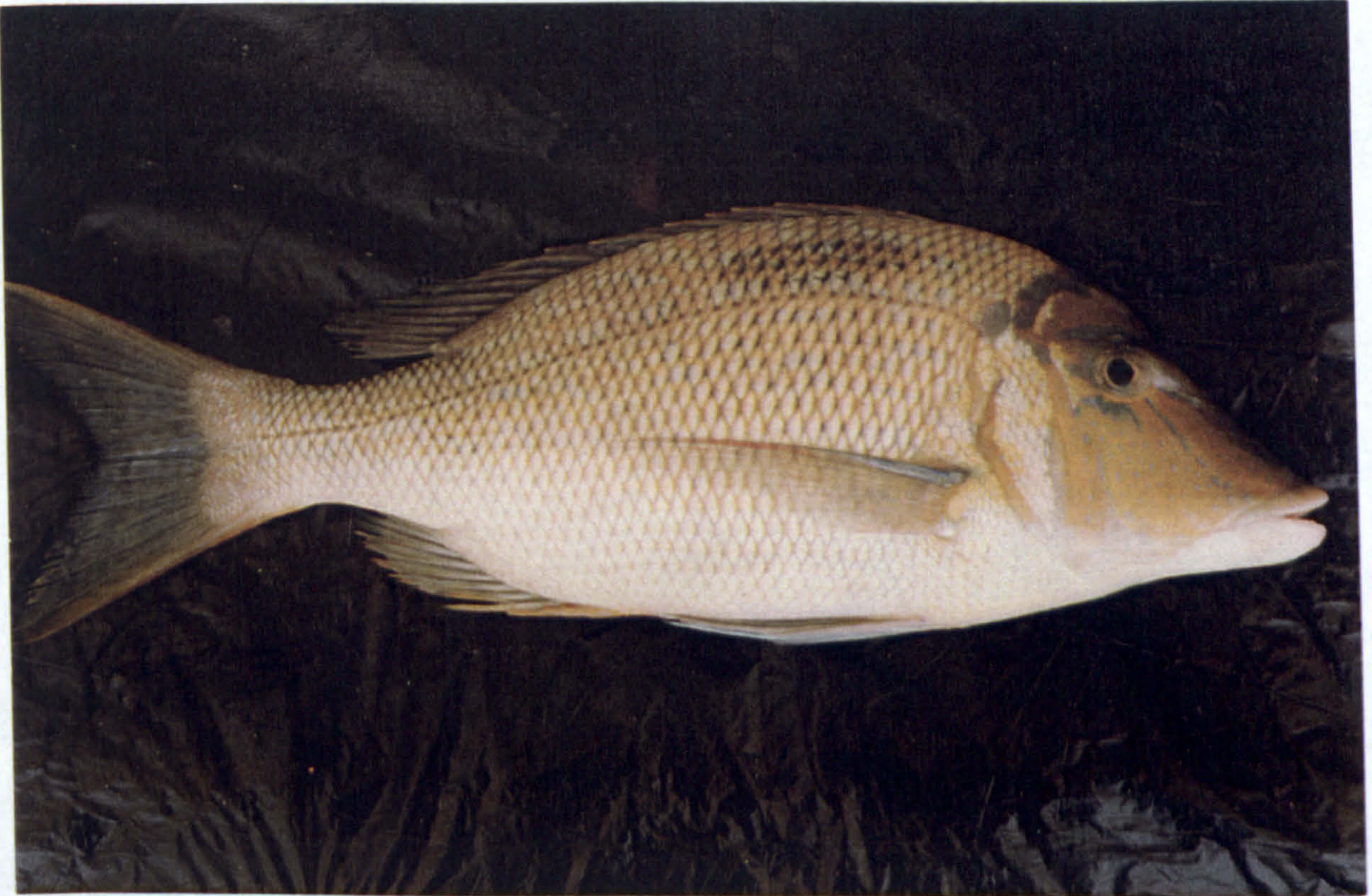


Figure 2. Photos show (Top) Shour, *Lethrinus nebulosus*, (bottom) fish boxed for sale at Marsa Bareka landing site

CHAPTER THREE

**OBSERVATIONS ON
THE REPRODUCTIVE BEHAVIOUR
AND BIOLOGY OF THE
LETHRINUS NEBULOSUS
SPAWNING AGGREGATION AT RAS
MOHAMMED, RED SEA, EGYPT**

ABSTRACT

The reproductive behaviour and biology of Shour, *Lethrinus nebulosus*, spawning close to the southern tip of Ras Mohammed, was investigated between 1995 and 1998. The spawning site, called Jackfish Alley, is unusual for the area in that it possesses a wide coral-covered reef terrace extending seawards at a depth of 10 – 25 m. Macroscopic and histological examination revealed a strong correlation between gonad development and feeding rate. It is suggested that the habitat features allowing feeding over the spawning period may be key to the choice of Jackfish Alley as the spawning ground. Analysis of ova diameter frequency and gonad condition suggests that *L. nebulosus* is a multi-spawner species, and spawn during two short periods of time within two successive lunar cycles, between mid-April and Early-June. Evidence suggests that the fish become sexually active during the full moon period, with spawning starting on the third day after the full moon, and continuing for 6-8 days. Equations were determined relating mean gonad weight, gonad index and fecundity to body length. The mean absolute fecundity was estimated at 920,434 eggs/fish, with the maximum measured being 4.7 million eggs. Ova exceed 0.45 mm in diameter when they are released. the Sex ratio was found to vary slightly with fish size. The size at first maturity for males was 35 cm and for females 37 cm, corresponding to four years of age. Fish less than 35 cm fork length were rare in the fishery, and no fish were observed less than 28 cm. Sexes were completely separate and there was no indication of hermaphroditism.

INTRODUCTION

The period of time and the extent of the area over which coral reef fish spawn has been reported to vary greatly; some fish spawn once a year at a specific site and time, while others spawn more frequently over a wide area or throughout their range (Robertson, 1991). Spawning aggregation is one of the more extraordinary reproductive tactics used by a minority of coral reef fish species; large numbers of fish from across a very large area come to a specific site at specific time on a yearly basis in order to spawn. This phenomena has been documented for many coral reef fish species, especially for groupers and snappers: *Epinephelus striatus*, (Smith, 1972; Colin, 1992; Carter et al., 1994 and Aguilar-Perera & Aguilar-Perera, 1996), *E. guttatus*, (Colin et al., 1987; Shapiro et al., 1993a & 1993b Sadovy et al., 1994;), *Plectropomus areolatus*, (Johannes, 1988).

The factors that influence breeding coral reef fish to use a specific area as a spawning ground have been the subject of a great deal of discussion. Repeatedly it has been hypothesised that fish aggregate to spawn at a specific site and time in order to benefit from certain oceanographic features during spawning (Johannes, 1978a; Barlow, 1981; Doherty et al., 1985). The pattern of water currents during or following spawning may influence larval survival by carrying fertilised eggs to areas with lower predation levels or more food resources (Johannes, 1978; Doharty, 1985 and Lobel & Robinson, 1988). However Colin (1992) argued against this hypothesis after finding no significant movement of the water masses around an *E. striatus* spawning ground for one week after the spawning event, while Shapiro et al. (1988) suggested that fish aggregate at a specific area in order to escape from predators during the spawning period.

Robertson (1991) suggested that the timing of spawning in tropical areas is related to temperature rather than any other environmental factor. Brown et al. (1994) and

Tucker et al. (1993) found a strong correlation between the timing of yearly spawning aggregating of *E. striatus* and changes in surface water temperature. Domeier & Colin (1997) demonstrated that fish in spawning aggregations are more likely to spawn when tidal currents occur around dusk. By contrast Shapiro et al. (1993a), Samoilyis & Squire (1994) and Aguilar-Perera & Aguilar-Perera (1996), found a strong correlation between timing of spawning and the lunar cycle, in which fish in spawning aggregations were sexually active during the full moon days. However Lobel (1978), Colin & Clavijo (1988) and Colin & Bell (1991) have suggested that correlation between the timing of spawning and any environmental or physical stimulus are primarily a tactic for synchronising reproduction.

All of the documented spawning aggregations that have been discovered by fishermen, have subsequently experienced an increased level of exploitation (Domeier & Colin, 1997). Commercially valuable species that form spawning aggregations are more vulnerable to over-exploitation than species that do not, since they aggregate at a specific area and time every year (Olsen & LaPlace, 1979; Carter et al., 1994; Sadovy et al., 1994). The effects of targeting spawning aggregations on population size vary according to exploitation level, but usually include declines in total catch, catch per unit effort, and mean fish size. Continued severe exploitation can lead to a dramatic complete disappearance of the breeding stocks from their traditional spawning ground (Colin, 1992). Smith (1972) estimated the population size of *Epinephelus striatus* at their traditional spawning ground in Bahamas waters at 150,000 fish. Subsequently Colin (1994) estimated the breeding population size of *E. striatus* in this same area at no more than 2000-3000 fish along. Furthermore, one of the *E. striatus* breeding populations disappeared completely from its traditional spawning ground.

Contrary to an older view, both fish egg production during spawning seasons and subsequent recruitment success may be strongly correlated (Rothschild, 1986). Targeting spawning aggregations disturbs the recruitment process more than might be expected because the quantity of eggs produced is reduced in greater proportion than the number of fish removed, as result of the selective removal of large size classes which produce proportionally more eggs than smaller fish. Further, where there is sexual dimorphism or sex change, population sex ratio may be altered as a result of selective removal of either sex, and this in turn may lead to failure of the recruitment processes. For example Coleman et al. (1996) found that the percentage frequency of *Mycteroperca microlepis* males within a spawning aggregation declined from 17% to 1% over a 20 years period as a result of increasing fishing pressure during the reproductive period. Thus the population became sperm-limited as result of selective removal of male individuals. Conversely, Coleman et al. (1996) measured no significant change in population sex ratio of *Epinephelus morio*, which does not aggregate to spawn.

The shour, *L. nebulosus* (Forsskal, 1775) is one of the most valuable and extensively exploited species among the Lethrinidae. It has a wide range of distribution throughout the Indo-Pacific, being recorded in the Red Sea, Persian Gulf, East Africa, southern Japan and Australia. Usually the juvenile stages, inhabit either seagrass beds or mangrove swamps before moving to coral reef areas thereafter fishing (Fish base, 1997). They feed on echinoderms, molluscs and crustaceans. Because of their carnivores feeding habits, *L. nebulosus* is vulnerable to handline fishing (Fish base, 1997). Despite the ecological and economical importance of the *L. nebulosus*, few studies have focused on their biology and population dynamics. However Morales-Nin (1988) studied the age and growth of *L. nebulosus* in New Caledonia using otolith analysis, and Ezzat et al. (1992) investigated age and growth in Arabian Gulf waters using fish scales. Ebisawa

(1990) investigated *L. nebulosus* reproductive strategy in Okinawan waters; he described them as multiple spawners, which release several batches of eggs over a long period of time, and spawn in aggregations with no relationship to the lunar cycle. He also concluded that they were protogynous and exhibited juvenile hermaphroditism.

Along the Egyptian Red Sea coast, *L. nebulosus* is the most valuable food species in terms of total value of catch among the Lethrinidae; it is fished throughout the year using almost all fishing methods, however, due to its feeding habits, it is most vulnerable to handlining. According to local fishermen, *L. nebulosus* aggregates to spawn every year at three well-known reef sites in the Egyptian Red Sea coast, These spawning aggregations have been exploited since at least the early 1900s, but, as a result of increasing demand for fish during the last ten years fishing effort on these breeding stocks has greatly increased.

The most important spawning ground of *L. nebulosus* in term of population size and fish production is a reef site known to divers as Jackfish Alley in the Ras Mohammed National Park. Several thousands of fish aggregate every year during the period between late April to early June, but to date no information is available on their actual spawning or other behaviour associated with this event.

This chapter, describes work carried out in order to reveal details of *L. nebulosus* reproductive biology during the spawning aggregation. This was done by investigating changes in gonad development during the spawning season, including changes in gonad weight, gonad index, fecundity, ova diameter frequency and histological appearance. In addition, the overall population sex ratio and its change in relation to fish size was recorded.

METHODS

Aggregation behaviours

The *L. nebulosus* spawning behaviour at Ras Mohammed was investigated by regularly surveying the spawning ground using SCUBA gear and underwater scooters. In the 1997 spawning season two dives were conducted every day over the peak fishing period, one in the early morning and the other before dusk. In each dive the area between Shark Reef and north of Jackfish Alley was surveyed at depths of 25 and 10 meters. When *L. nebulosus* schools were observed, a record was made of the number of fish, dominant size, direction of movement, and depth. Also, the characteristics of the spawning ground were recorded, this including dimensions, topography, depth and the dominant associated benthic marine biota.

Sampling

In all, 1226 *L. nebulosus* were collected between 1995 and 1997. 886 specimens ranging in fork length between 28 and 68 cm, were collected from the Ras Mohammed spawning stock. In 1997 particular care was taken to collect on a daily basis, during the peak fishing period, samples representing a wide range of sizes. In addition a total of 340 *L. nebulosus* specimens were obtained from the Al-Konyasa fishing ground. This fishing area is the nearest all year fishing ground to Ras Mohammed, being located 30 km north of Ras Mohammed in Gulf of Suez ($27^{\circ}56'$ N and $33^{\circ}53'$ E). These specimens were collected seasonally over the period May 1996 to May 1997, and included immature size classes with fork lengths between 10 cm and 30 cm, that were not observed in the catch from the stock breeding at Ras Mohammed.

Fish specimens were studied in fresh condition within a maximum of two hours after removal from the water. Each specimen was weighed and measured to the nearest gram and 0.5 cm of fork length. A cut was made along the ventral side of

each specimen and all of the internal organs removed. Gonads were separated carefully from other organs, and weighed to the nearest gram. Fish sexes were determined visually for large mature gonads, and using a light microscope for fish with smaller gonads. A small portion from each gonad was fixed in aqueous Bouin's solution for 48 hours and then preserved in 70 % ethyl alcohol for subsequent fecundity estimates and histological studies.

Length at first maturity

Lengths at first maturity of *L. nebulosus* were estimated based on both the external appearance and microscopic examination of testis and ovaries. Males were considered fully mature when their testes were white in colour, occupied more than half of the body cavity and released milt when pressed between fingers. Immature male gonads were reddish in colour, small in size and showed no sign of milt developed inside. Females were considered fully mature when their ovaries were cylindrical in shape, swollen, yellow to orange in colour, occupied more than half of the body cavity, and developed eggs constituted the bulk of the gonad tissue. Immature female gonads were almost transparent in colour, small in size and showed no sign of developed eggs inside. The percentage frequencies of mature fish were calculated for each size class, and size at first maturity was considered to be that at which when the percentage frequency of mature gonads constituted 50 %.

Gonad index (G.I).

Condition and degree of development of the *L. nebulosus* gonads were monitored throughout the spawning season. Results were expressed in form of mean population gonad weight and of gonad index (G.I) for which individual gonad weight was converted to percentage of total fish weight using the following formula:

$$G.I = GW / TW * 100$$

Where G.I is the fish gonad index.

GW is the fish gonad total weight.

TW is the fish total weight.

Correlation was sought between mean gonad index and mean fork length of each size class. Variation in mean gonad index throughout the spawning period was also investigated.

Fecundity.

238 female *L. nebulosus* specimens were used to investigate variation in fecundity with size. The specimens represented a wide range of fish sizes, ranging in fork length between 31 and 62 cm. The fecundity estimate was based on counting the density of well-developed yolked eggs in each female ovary. This was done by processing a small portion from each female ovary (representing almost 1% of the total ovary weight) as follows: 1) the ovarian wall was carefully removed, 2) excess liquid was dried using filter paper, 3) the tissue was weighed to the nearest 0.0001 gram, 4) the sample was squashed very gently over a one mm. sieve to separate eggs from other ovarian tissue, 5) eggs were suspended in exactly one litre of water, 6) and then the number of ripe eggs (exceeding 0.32 mm in diameter) was counted in 5 ml³ five times for each sample. The number of eggs in each ovary specimen was estimated by multiplying the mean number of eggs in 5 ml³ by 200, and the absolute fecundity for each fish specimen estimated using the following formula:

$$F = G.W / W' * N$$

Where F is the absolute fecundity.

G.W is the total gonad weight.

W' is the weight of the sample.

N is the number of eggs in the sample.

Relative fecundity (number of eggs produced per unit fish weight) was also estimated (egg per gram) using the following formula:

$$F' = N / T.W$$

Where **F'** is the relative fecundity.

T.W is the fish total weight.

N is the total number of mature eggs in female ovary.

Changes in the mean absolute and relative fecundities with *L. nebulosus* fish length were then assessed.

Ova diameters.

To further investigate *L. nebulosus* spawning strategy, daily variation in ova size was also recorded. This was done by measuring the ova diameter frequency distribution of 167 female specimens, this representing a wide range of fish sizes, throughout the entire spawning period. A small portion was randomly selected from each ovary, and ova suspended in a small volume of water using the same procedure as previously described for preparing samples for fecundity estimates. Up to 120 random ova from each sample were measured using a compound microscope fitted with measuring eyepiece scale. Data from each day were pooled to examine change in ova size during the season. The overall ova diameter frequency distribution of *L. nebulosus* population was also obtained.

Histological study.

The changes in *L. nebulosus* gonad structure during the spawning period were also investigated histologically. Gonads from a total of 157 fish (134 females and 23 males) were used. Sections were obtained using the following procedure: 1) a small portion of preserved gonad was dehydrated using an ascending graded series of ethanol (10, 30, 50, 70, 90 100 %), 2) dehydrated tissue was cleared in an ascending graded series of xylol (10, 30, 50, 70, 90 100 %), 3) cleared tissue was embedded in paraffin wax and sectioned transversely at 5-7 μm thickness using a microtome, 4) the stained sections were cleared using another graded series of xylol and ethanol respectively, 5) the section was stained with haematoxylin followed by eosin, 6) the stained sections were dehydrated in another graded series of ethanol and then passed through three changes of xylol (50, 75, 100 %), 7) finally, sections were mounted in BDX.

Spawning behaviour.

As described in chapter two, the catch rate of *L. nebulosus* usually starts to increase at the full moon to reach a maximum four days later, before declining gradually towards the new moon. This fishing pattern is assumed to reflect the feeding habits of the fish during the spawning season. The relationship between this fishing pattern (feeding habits) and actual spawning was investigated by tracking daily changes in gonad structure (ova diameter, histological appearance, and gonad index). Variation in gonad condition was related to the peak fishing day, referred to as day zero, the previous and following days were numbered negatively (-) and positively (+) respectively.

Parasite infection.

During dissection of the *L. nebulosus* gonad it was noticed that the female's ovaries are frequently infected by an unidentified nematode worm. For each infected fish specimen an estimate of the level of infection was obtained, based on

infected fish specimen an estimate of the level of infection was obtained, based on the size of the worm and the percentage area that was occupied by the parasite. The worm was isolated from same fish specimen, measured and preserved in 70 % alcohol for taxonomical identification. The effects of infection on the *L. nebulosus* absolute fecundity and spawning process were also investigated.

Changes in the spawning potential

The effect of the selective removal of large size classes on the *L. nebulosus* overall yearly spawning-potential was investigated. Yearly number of eggs produced by a proportion of population was estimated using the following calculations: 1) the percentage frequency of females in each size class was estimated (based on the population sex ratio). 2) This was multiplied by the number of eggs a single female would produce (based on the fish length- fecundity relationship). 3) then the results were summed together.

RESULTS

1. Spawning ground characteristics

The *L. nebulosus* aggregate to spawn at Jackfish Alley, which can be categorised as a relatively extensive well-developed fringing reef. The reef flat is approximately 50 meters wide, with a sandy substratum occupied by seagrass bed in its inner part. Moving toward the reef edge the bottom becomes rocky with coral cover ranging between 7 and 10 %. The most frequent coral species along the reef edge are *Pocillopora*, *Acropora*, *Stylophora*, *Millepora* and *Favia*. The reef slope descends steeply to 15 meters, and possesses a high hard coral cover, averaging 60 %. This zone is dominated by *Pocillopora*, *Seriatopora*, *Stylophora*, *Millepora* and *Porites*. From the bottom of the reef slope a wide coral terrace extends approximately 500 meters seaward, and varies in depth between 15 and 25 meters. The bottom of this coral terrace is mostly occupied by branched hard coral colonies, occupying up to 55 % of the area. The substratum is soft, composed of sand, gravel and coral rubble. This coral terrace ends at a drop off which descends steeply to great depths. The upper zone of this contains less coral cover, estimated at 25 %. At this drop-off large *Gorgonia* sp. colonies were frequent. A cross-section through the aggregation ground is shown in figure 1.

2. Aggregation behaviours

The Jackfish Alley Reef is well known as a traditional spawning ground for three of the commercially important fish species along the South Sinai coast; *Lethrinus nebulosus* (Lethrinidae), *Lutjanus bohar* (Lutjanidae) and *Caranx* sp (Carangidae). In addition to these three species, *Plectropomus gaterinus* (Haemulidae) was also observed in high density aggregations along the reef slope, this population estimated to be between 7 to 9 thousand fish during the end of May. *L. nebulosus* appeared at the breeding ground almost 15 days before the full moon day, with fish swimming in groups that ranged in number between 25 and 50 individuals,

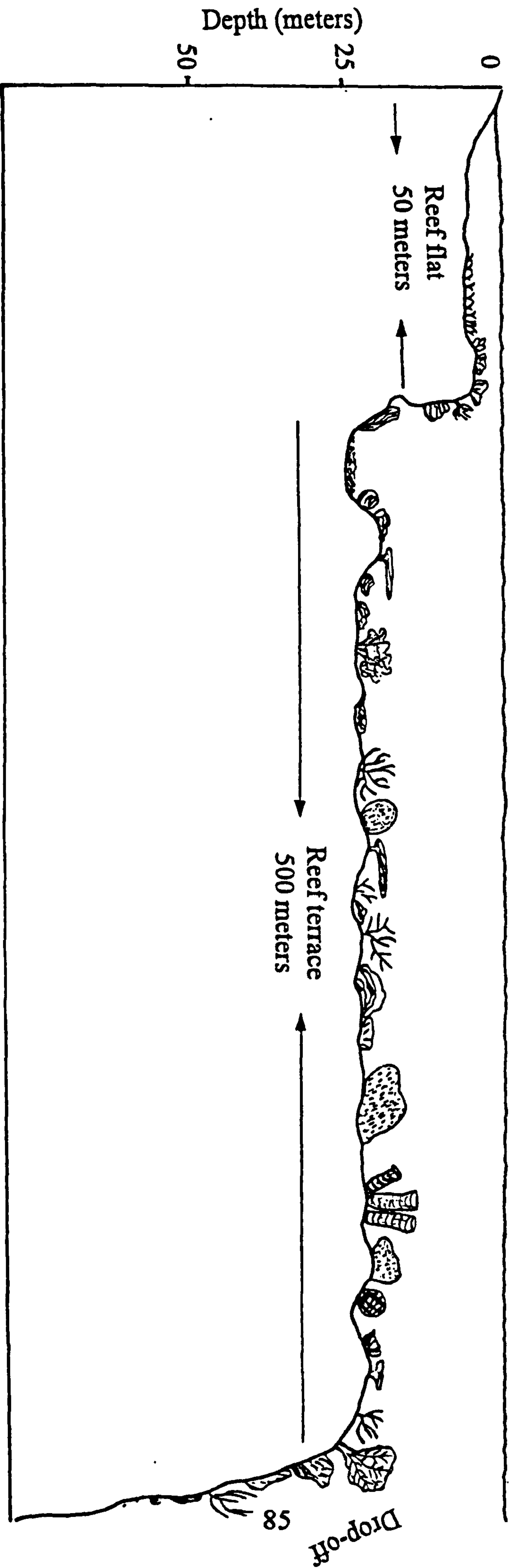


Figure 1: Cross section through the Jackfish Alley Reef (the *L. nebulosus* spawning aggregation ground), showing the main topographical features.

each group being composed of a wide range of fish sizes. At this stage fish were mostly seen moving along the base of the reef slope between Shark Reef to the south and the northern edge of the Jackfish Alley Reef. Later the number of fish in each group increased markedly reaching up to 150 fish. Occasionally a group estimated at approximately 700 fish was observed during the early morning period at the drop off of Shark Reef, away from the reef face. However in none of the underwater surveys, was chasing between individuals or release of gametes among the aggregated fish observed. It was however noticeable that the *L. nebulosus* within the spawning aggregation were slightly darker in colour with more distinctive blue lines around the heads than in fish during the rest of the year at their normal density.

3. Gonad investigation

3.1 Gonad morphology

Both female and male *L. nebulosus* gonads are composed of two elongated lobes, which occasionally are unequal in length. These lobes totally separate anteriorly but connect together posteriorly into a single gonoduct. In mature specimens gonads occupied more than half of the body cavity. In the large size classes (> 42 cm) gonads were found to be attached to the body cavity only by the gonoduct, and no attached fat bodies were observed inside the body cavity. By comparison in smaller sizes gonads were attached all along the body cavity by mesenteries, and attached fat bodies were frequently seen. Ovaries were cylindrical in shape with a smooth surface, and yellow to orange in colour with many blood veins running in their walls. Testes were flattened and multilobular in shape with a smooth surface that is almost white in colour and few blood veins in their surface. The most frequently observed male and female gonad forms are shown in figure 2.

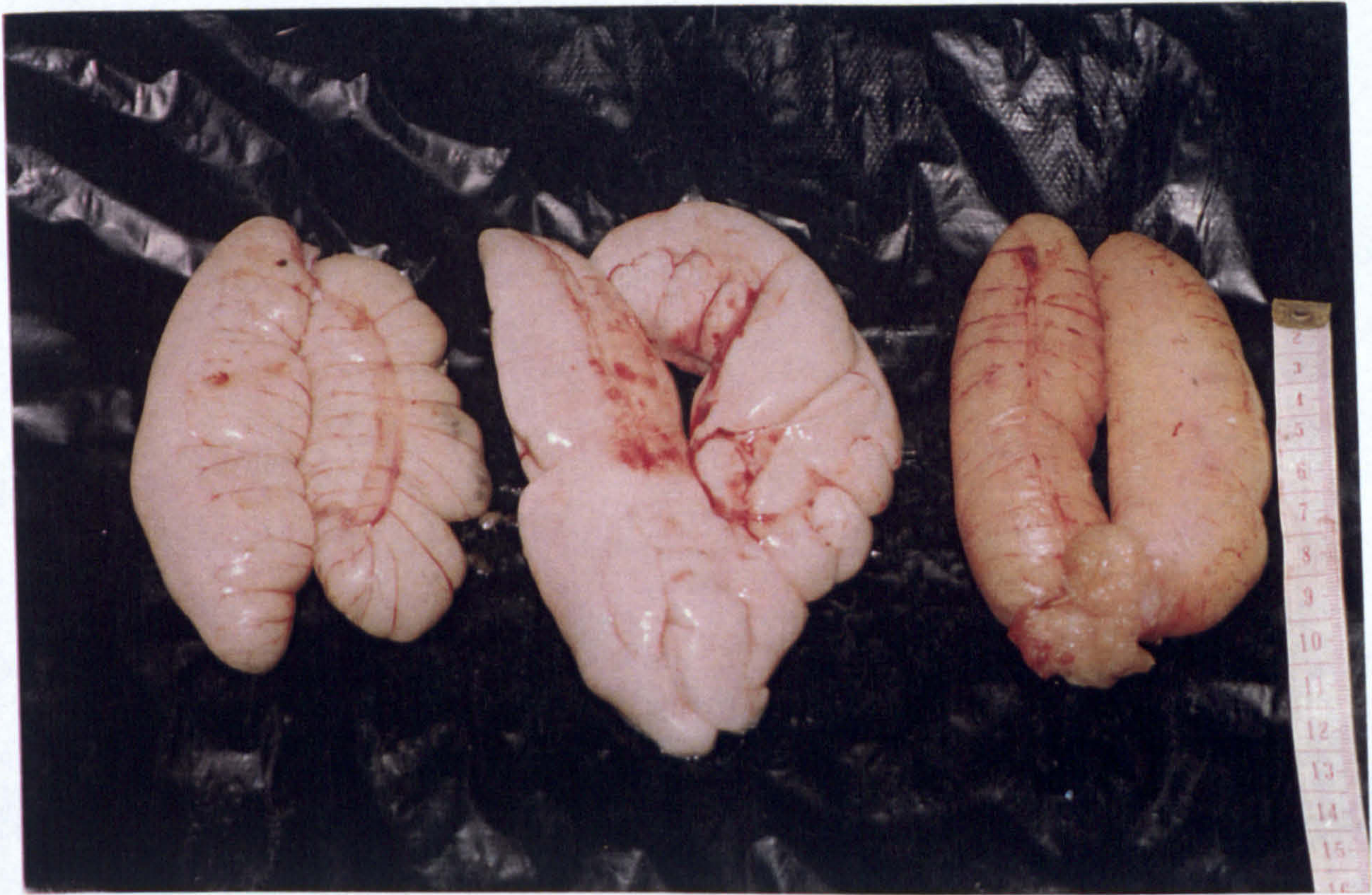


Figure 2. Photograph shows the typical appearance of a ripe *L. nebulosus* male testis (middle) and female ovaries (left and right).

3.2. Gonad weight

The relationship between mean gonad weight and fork length is shown in figure 3. Sizes that are represented by less than five fish specimens and fish gonads that were classified as spent were not included in this estimate. This rule was also applied to the following analysis. Mean gonad weight increased significantly with body size. Female gonad weight was always greater than males for any size class. For the entire population the mean gonad weights were 72.5 and 49.3 grams for females and males respectively. The relationship between mean gonad weight and fork length was best described by a linear equation, for which the correlation coefficient was highly significant ($R_{sq} = 0.97$, $P < 0.001$), and the relationship was described by the following equation:

$$F.L = 34.06 + 0.17 * (G.W)$$

Where F.L is the fish fork length.

G.W is the fish gonad total weight.

3.3 Gonad index

The gonad index of *L. nebulosus* during the spawning season varied between 0.5 and 11.4, with a mean of 3.8 %. Fish for which the gonad index was lower than 1% were either not fully mature or were entirely spent. These constituted nearly 12% of the studied specimens. The mean gonad index increased with fish length (Figure 4), a relationship best described by the following quadratic equation:

$$F.L = 35.03 + -2.41 * (G.I) + 1.49 * (G.I)^2$$

Where G.I is fish gonad Index.

FL is fish fork length.

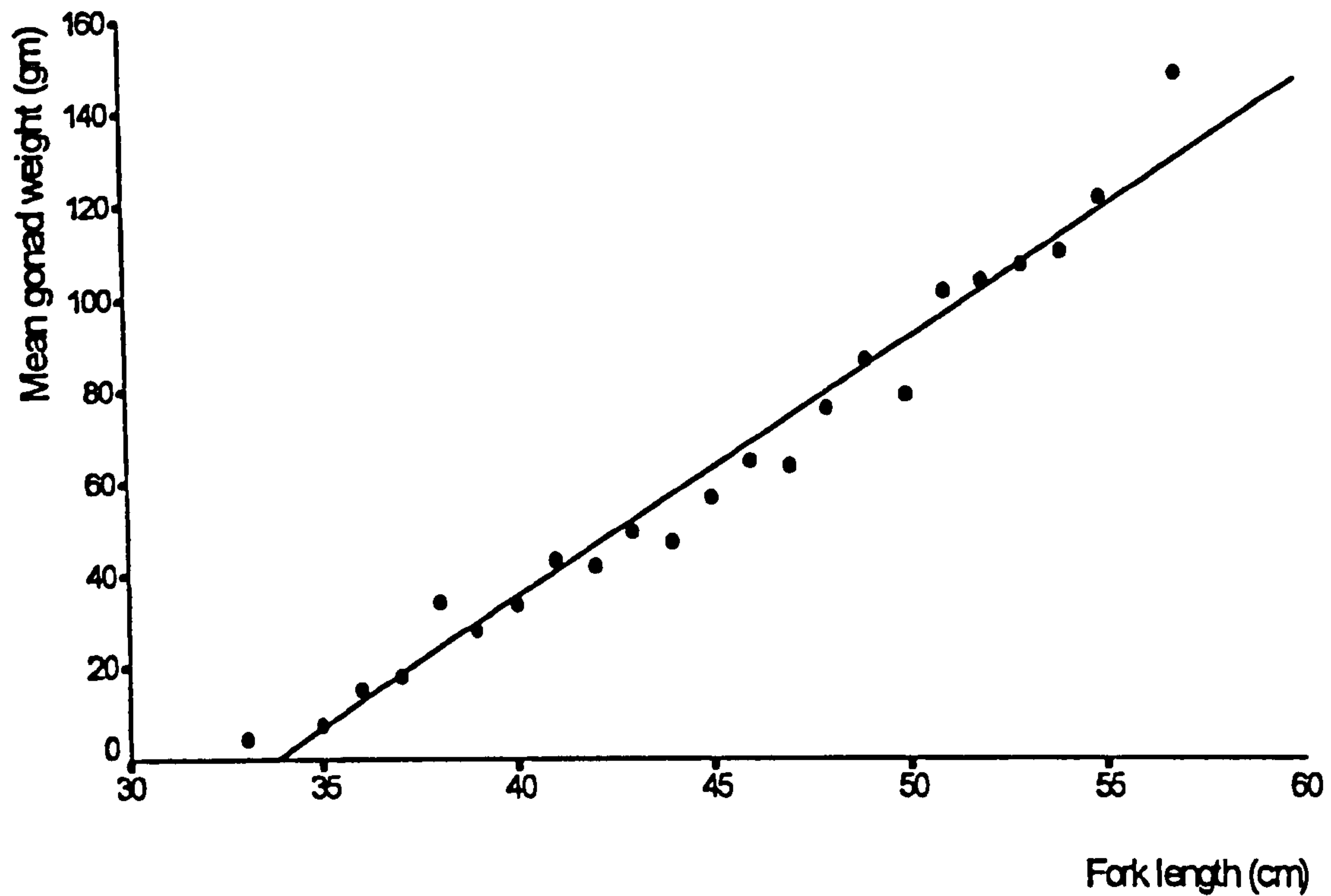


Figure 3: The relationship in *L. nebulosus* between the mean gonad weight and fork length. Each point is the mean gonad weight of 5+ specimens in the particular size class.

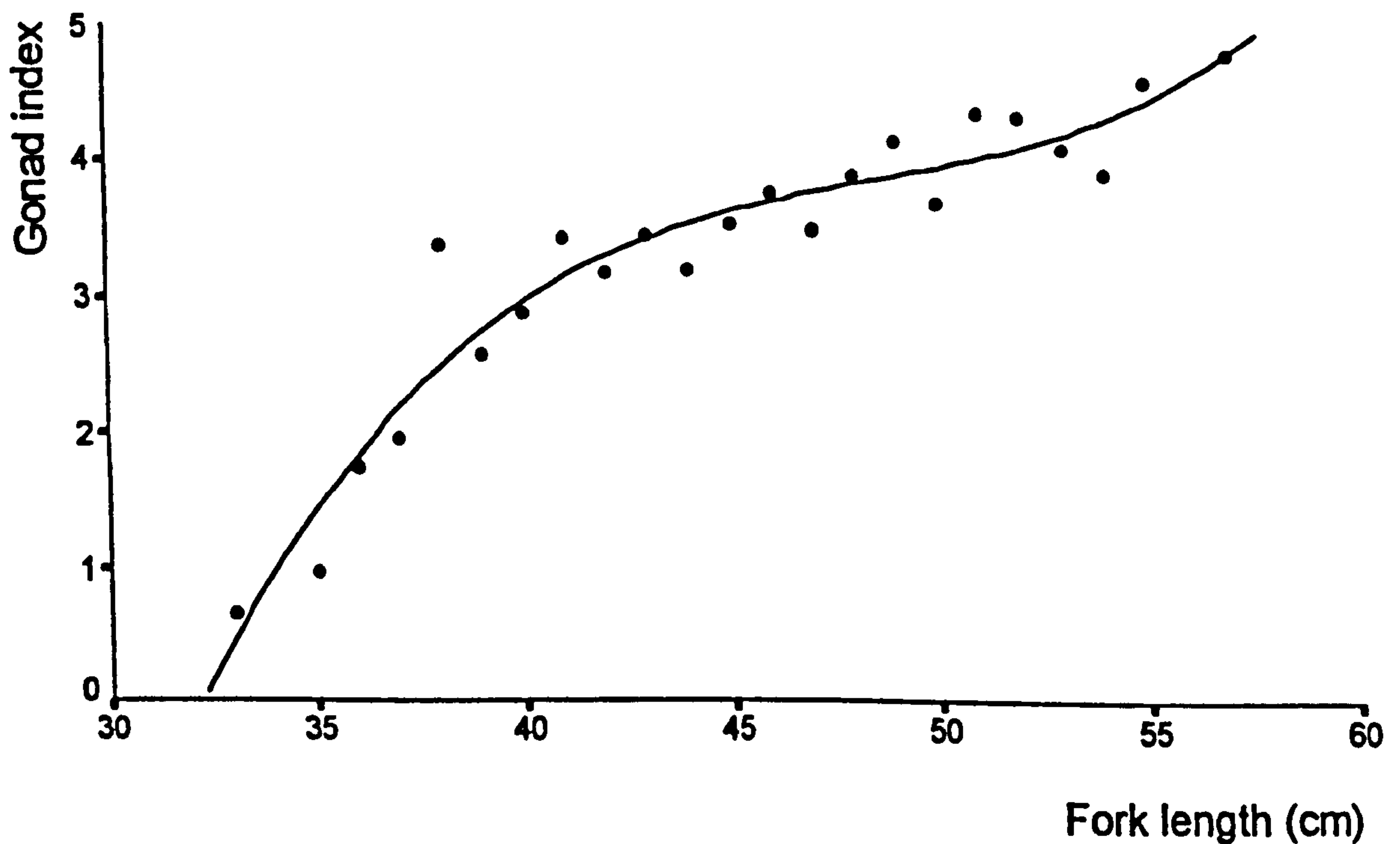


Figure 4: The relationship in *L. nebulosus* between mean gonad index and fork length. Each point is the mean gonad weight of 5+ specimens in the particular size class.

3.4 Fecundity

3.4.1 Absolute fecundity

A total of 238 *L. nebulosus* female specimens ranging in fork length between 31 and 63 cm. were used in fecundity estimates. All specimens came from the Ras Mohammed breeding stock. The mean absolute fecundity of these fish was 920,434 eggs/fish. The absolute fecundity of the smallest mature female (36 cm) was estimated at 374,747 eggs; its ovary weighed 35 grams and its gonad index was estimated at 3.93. The lowest absolute fecundity was 2710 estimated for a fish which measured 42 cm in fork length and had an ovary weighing 8 grams and a gonad index estimated at 0.54. The highest absolute fecundity was estimated at 4,723,030 eggs in a fish which measured 62 cm in fork length and had an ovary weighing 282 gram and a gonad index estimated at 6.22. The absolute fecundity of the largest fish (63 cm) was estimated at 1,210,435 eggs, its gonad weighed 116 grams and its gonad index was estimated at 2.70.

The relationship between mean absolute fecundity and fish fork length was highly significant (figure 5). The relationship is best described by a linear relationship ($R_{sq} = 0.94$, $P < 0.001$) represented by the following equation:

$$F = (-3.*10^6) + 84035.3 * (FL)$$

Where F is absolute fecundity

FL is fork length.

L. nebulosus absolute fecundity increased significantly with gonad weight (figure 6). This relationship was best described by a linear equation with a correlation coefficient of 0.92.

$$F = -103604 + 15050.4 * (GW)$$

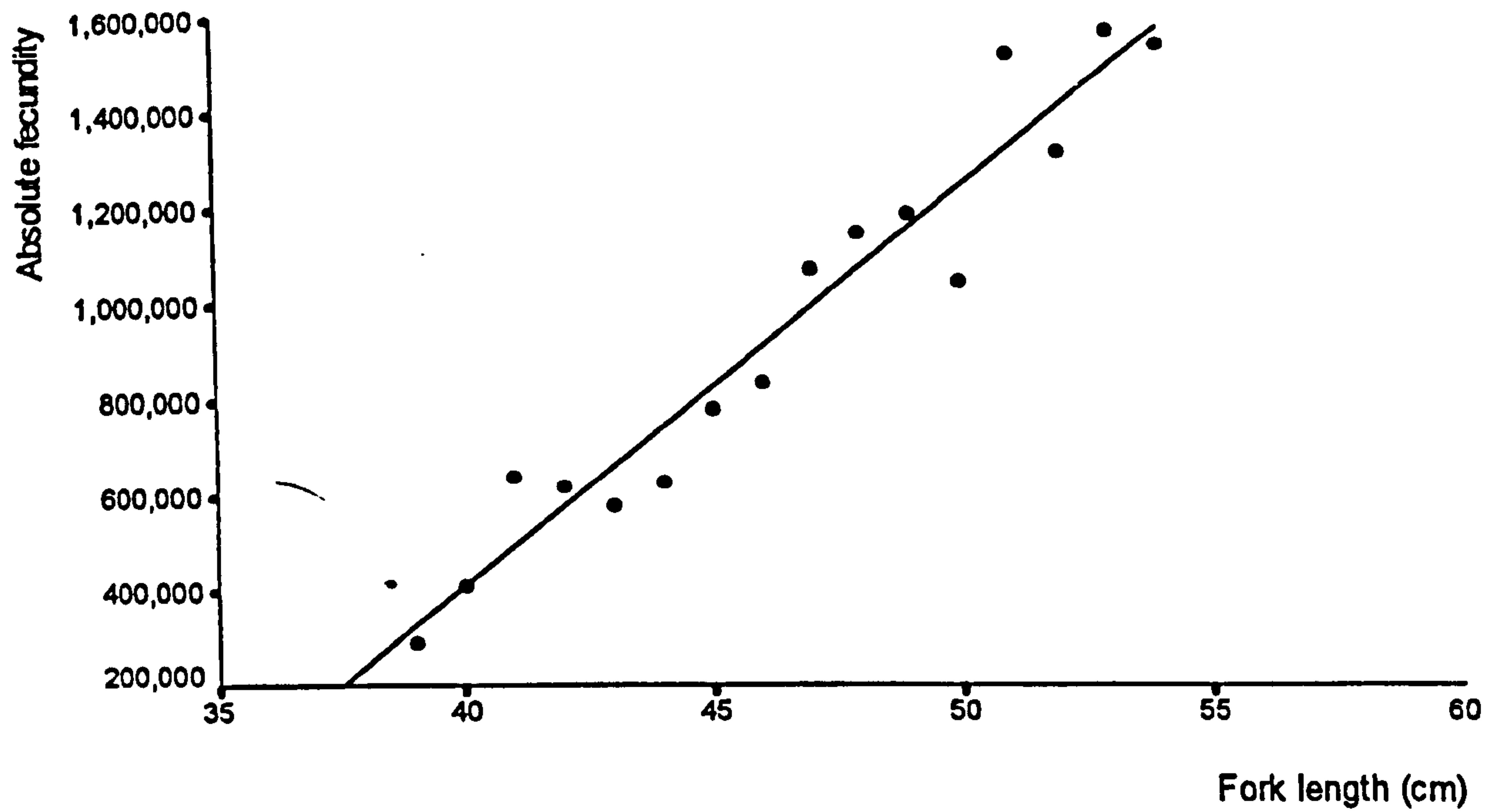


Figure 5: The relationship in *L. nebulosus* between mean absolute fecundity and fork length. Each point represents the mean values for fish in that size class.

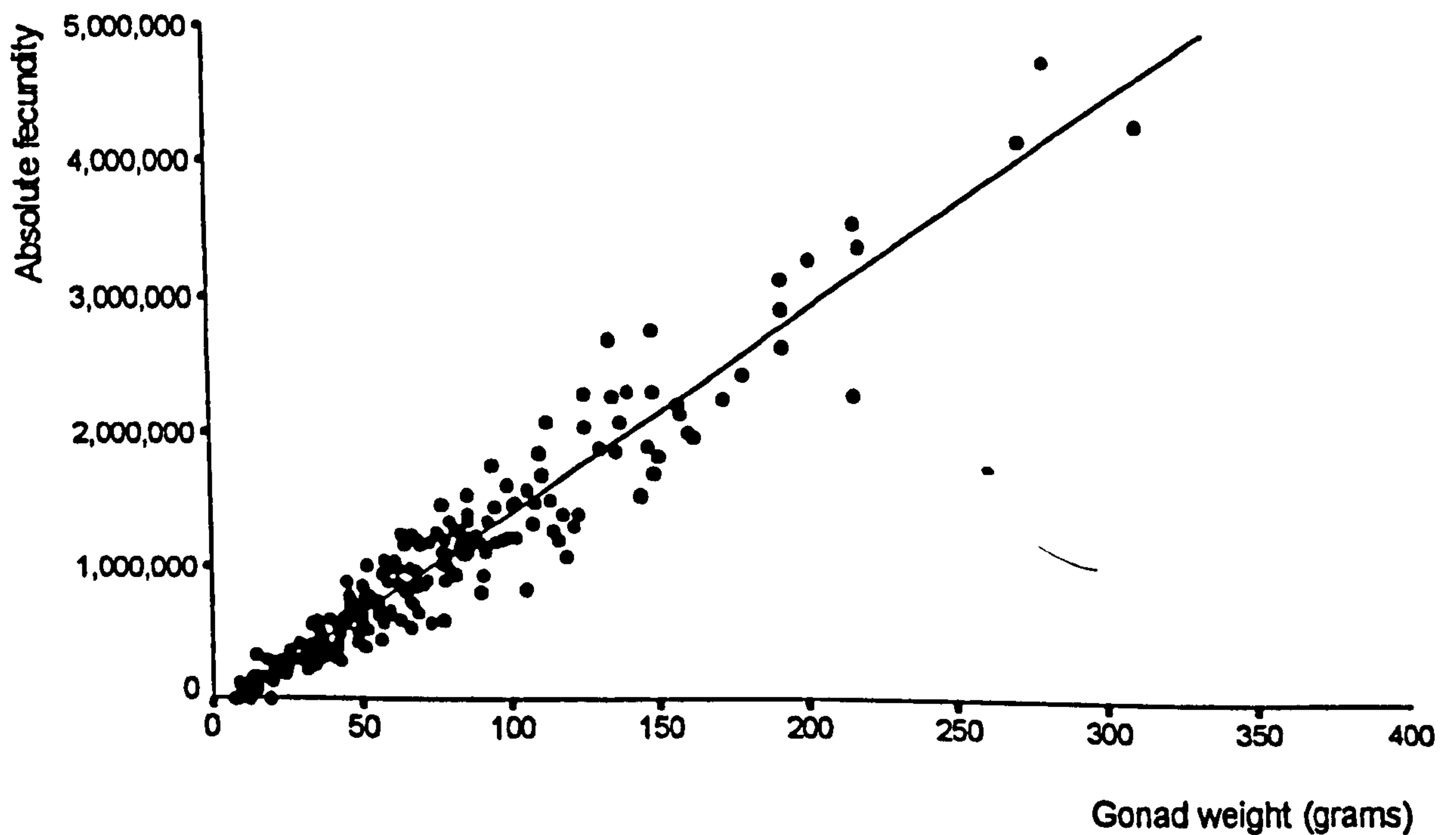


Figure 6: The relationship in *L. nebulosus* between mean absolute fecundity and gonad weight.

Where F and G.W are the fish absolute fecundity and gonad total weight respectively. In addition it was found that 29.3 % of female gonads infected by nematode worms, for those the mean absolute fecundity was 27.1 % lower than uninfected fish. Whether or not these worms prevent the egg release can not concluded since no histological study was carried out for infected fish from late spawning season.

3.4.2 Relative fecundity

L. nebulosus relative fecundity averaged 484 eggs per unit of fish weight (gram). The relationship between relative fecundity (egg/gm) and fish total weight (figure 7) was best described by a cubic regression equation, for which the correlation coefficient was significant ($R_{sq} = 0.85$, $P < 0.001$).

$$F' = -1105.6 + 2.45 * TW + -.0012 * TW^2 + 2.0^{-07} * TW^3$$

Where F' is relative fecundity

TW is fish weight.

3.5 Ova diameter frequency

In total 17.3 thousand ova from 149 *L. nebulosus* female specimens were measured. Ova diameter ranged between 0.02 and 0.64 mm, but ovaries were dominated by ova whose diameter ranged between 0.32 and 0.55 mm.; constituting 66.3 % of the measured ova. Overall ova measurements appeared to fall in to several different size classes (figure 8): ova of 0.19 mm and less diameter, another of 0.21-30 mm diameter, and third of 0.32 diameter and above. This feature suggests that the *L. nebulosus* breeding stock spawns in two or more pulses within one season with the different size of eggs becoming mature during different time of the spawning period. Further, it is seems likely that the *L. nebulosus* ovary is ready to spawn when their most advanced ova exceed 0.45 mm in diameter.

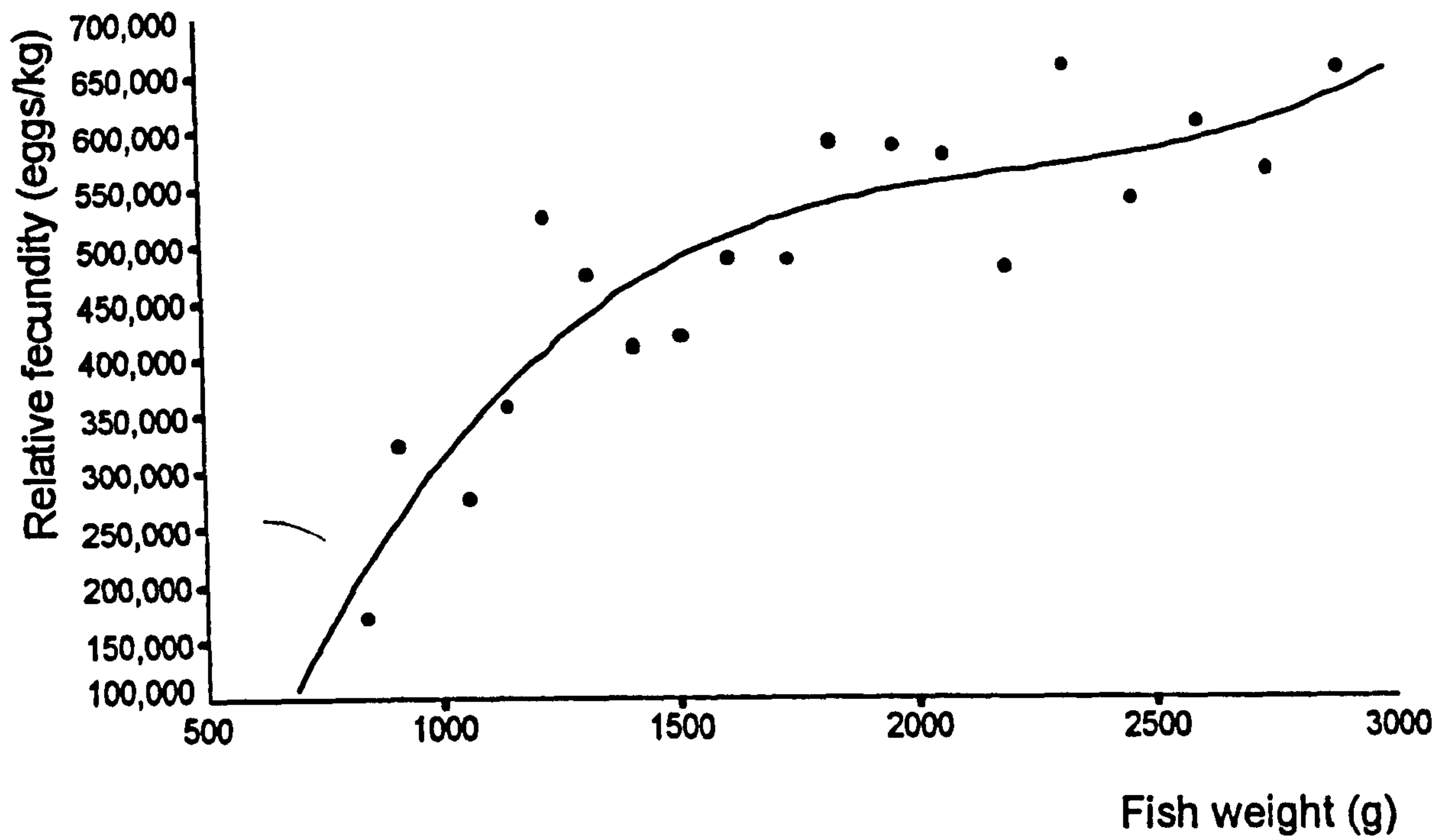


Figure 7: The relationship in *L. nebulosus* between the mean relative fecundity and fish weight.

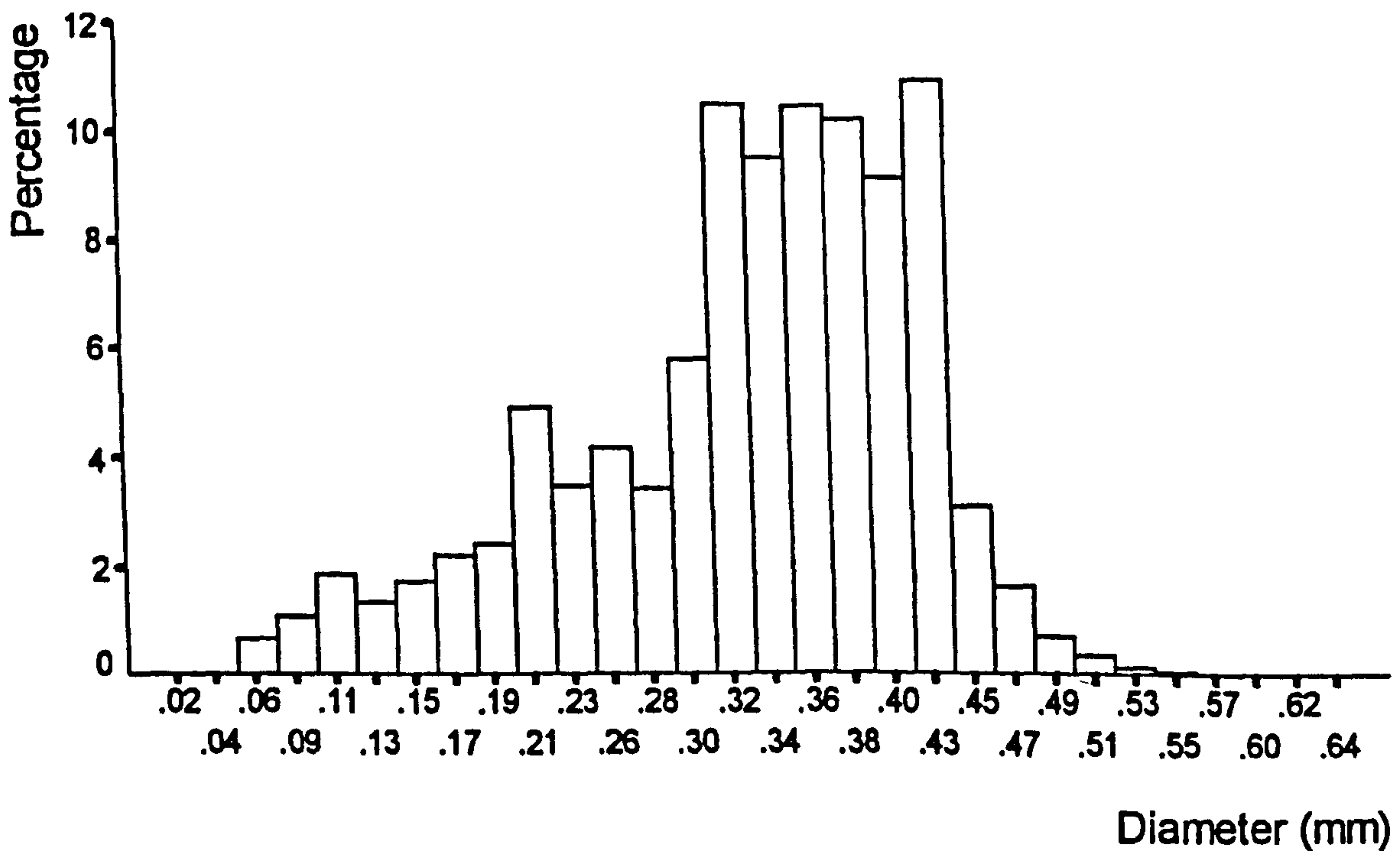


Figure 8: The percentage frequency of ova of different size in female *L. nebulosus*, based on measurements taken directly from ovarian tissue.

3.6 Gonad histology

3.6.1 Ovaries

Histological examination of the *L. nebulosus* ovaries during the spawning season revealed that their ovary is of the asynchronous type, in which each ovary contained almost all of the oocyte development stages at the same time. According to Wallace and Selman's (1981) criteria, *L. nebulosus* oocytes could be classified to nine different development stages. This categorisation is based on the appearance and development of the oocyte inclusions: cytoplasm, nucleus, nucleolus, yolk vesicle and yolk granules. Based on histological observation, the pattern of change in oocyte features through the oogenesis process in *L. nebulosus* were as follows:

1- Oogonia (figure 9a): this is the simplest observed form of oocyte in the oogenesis process. Cells at this stage were circular in shape, averaged 0.009 mm in diameter, appeared in aggregates, and were connected together with lamellar epithelium cells. No developed nucleus was observed at this stage, only dark spots, which appeared to be strands of chromatin, scattered throughout the cytoplasm. All cell inclusions were weakly basophilic. Oogonia were observed through the whole spawning season in small fish ranging in size between 31 and 40 cm.

2- Chromatin nucleolus stage (figure 9b): oocytes at this stage were semi-circular in shape, averaged 0.021 mm in diameter, and were encircled by epithelium cells. Chromatin strands aggregated at the centre of the oocyte, occupied the majority of the oocyte, and constituted up to 65 % of the oocyte. The chromatin area was less basophilic than other oocyte inclusions.

3- Early perinucleolus stage (figure 9c), oocytes at this stage showed two growth phases. To begin with the oocyte was irregular in shape, averaging about 0.033

mm. in diameter and had a nucleus with only one large nucleoli located at the periphery of the oocyte. Then, as the oocyte increased in size to a mean of 0.072 mm in diameter, the nucleus moved towards its centre. Multiple nucleoli appeared at the periphery of the nucleus. The cytoplasm at the early perinucleolus stage was strongly basophilic with less basophilic particles scattered in its inner layer. The early perinucleolus stage was observed in all fish size classes throughout the entire spawning season.

4- Late perinucleolus stage (figure 9d): at this stage oocytes increased further in size averaging 0.13 mm in diameter. They appeared circular in shape and were surrounded by layers of follicle cells. The nucleus was now positioned in the centre of the oocyte and constituted up to 51 % of the oocyte diameter. The nucleolus had decreased markedly in size compared with the previous stage and was now located at the periphery of the nucleus. The cytoplasm had become less basophilic, but had an intensely staining area in its inner zone.

5- Yolk vesicle stage (figure 9e): further increase in oocyte size occurred at this stage which averaged 0.18 mm. in diameter. The oocyte was still circular in shape, with no changes in nuclear features compared to the previous stage, but the nucleus now occupied only 33 % of the oocyte. The first phase of the vitellogenesis process was observed at this stage. This took the form of very tiny yolk vesicles appearing in the outer zone of the cytoplasm.

6- Primary yolk globule stage (figure 9f): at this stage oocytes averaged 0.24 mm in diameter, while small yolk globules had appeared in the outer layer of the cytoplasm. No change was observed in the nucleus compared with the previous stage.

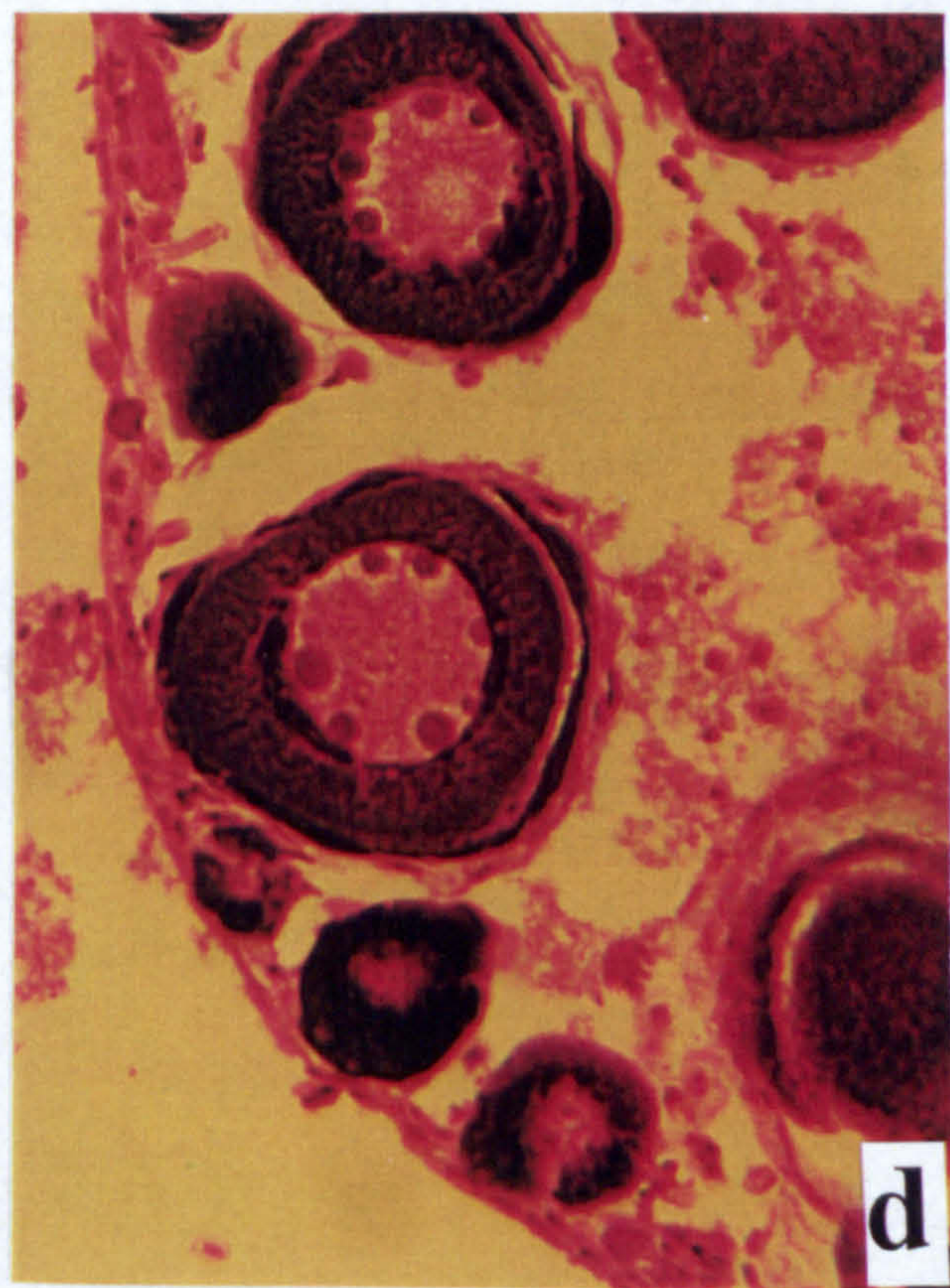
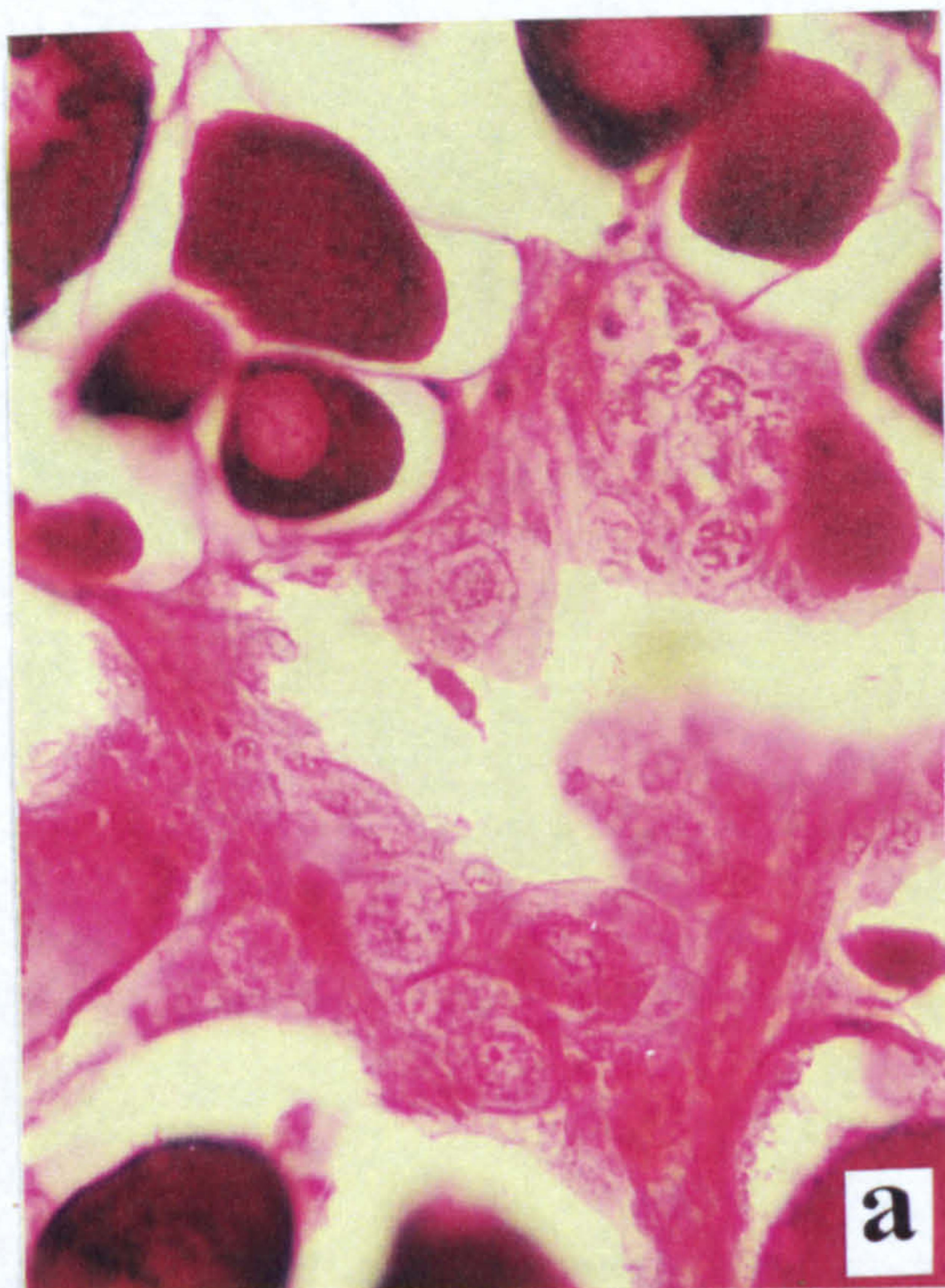


Figure 9. Development stages of oogenesis in shour, *L. nebulosus*. 9a. Oogonia stage; 9b. Chromatin nucleolus stage; 9c. Early perinucleolus stage; 9d. Late perinucleolus stage.

(continue)

7- Secondary yolk globule stage (figure 9g): oocytes at this stage had increased further in size and now averaged 0.35 mm in diameter. Yolk globules had increased in size and density, and were spread throughout the cytoplasm. The nucleus had also increased in size compared with the previous stages, and so still constituted 33 % of the oocyte. Yolk vesicles had now appeared around the nucleus.

8- Tertiary yolk globule stage(figure 9h): oocytes now averaged 0.43 mm in diameter. The yolk globules had become larger and now occupied most of the oocyte. The yolk vesicles continued to enlarge and eventually fused together around the nucleus forming one mass. The nucleus now decreased extremely in size and almost disappeared at the most advanced phase of this stage.

9- Maturation stage (figure 9i): this is the most advanced stage but the least frequently observed stage throughout the spawning season. At this stage the oocyte lost its circular shape and became partially elongated. The yolk globules were now fused together forming one mass, and within this mass a small crescent-shaped object was observed near to the periphery of the oocyte. This object was more basophilic than the fused yolk and appeared to be the germinal vesicle migrating toward the oocyte periphery.

3.6.2 Testes

In males the spermatogenesis was very active, and various growth phases were observed. In the early spawning period testes were dominated by spermatogonia and spermatocytes, with only occasional clumps of sperm. During the mid spawning season testes containing all stages of spermatogenesis were observed, and sperm sinuses full with mature sperm were developed (figure 9k). In the late spawning season testes were almost void of sperm (figure 9l).

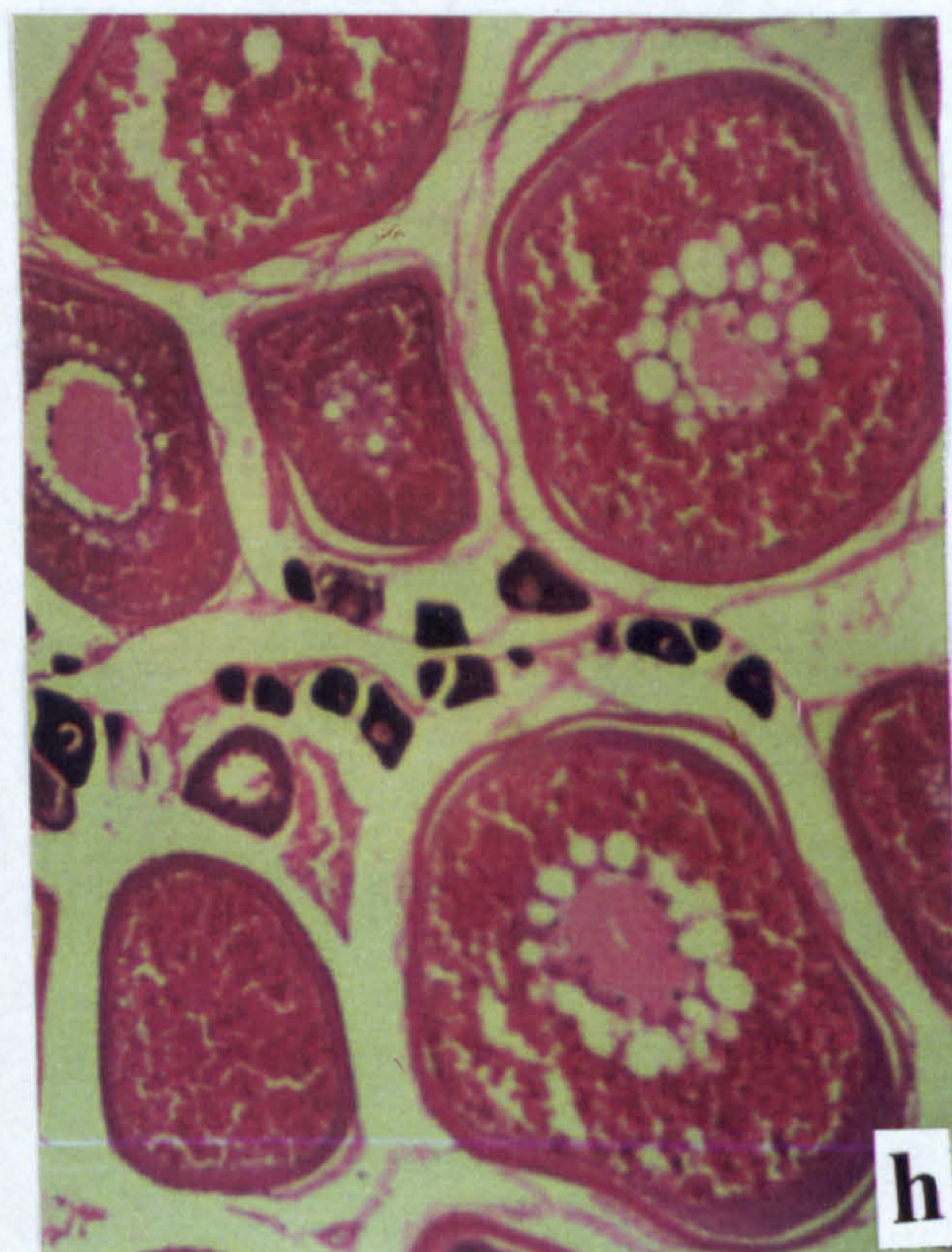
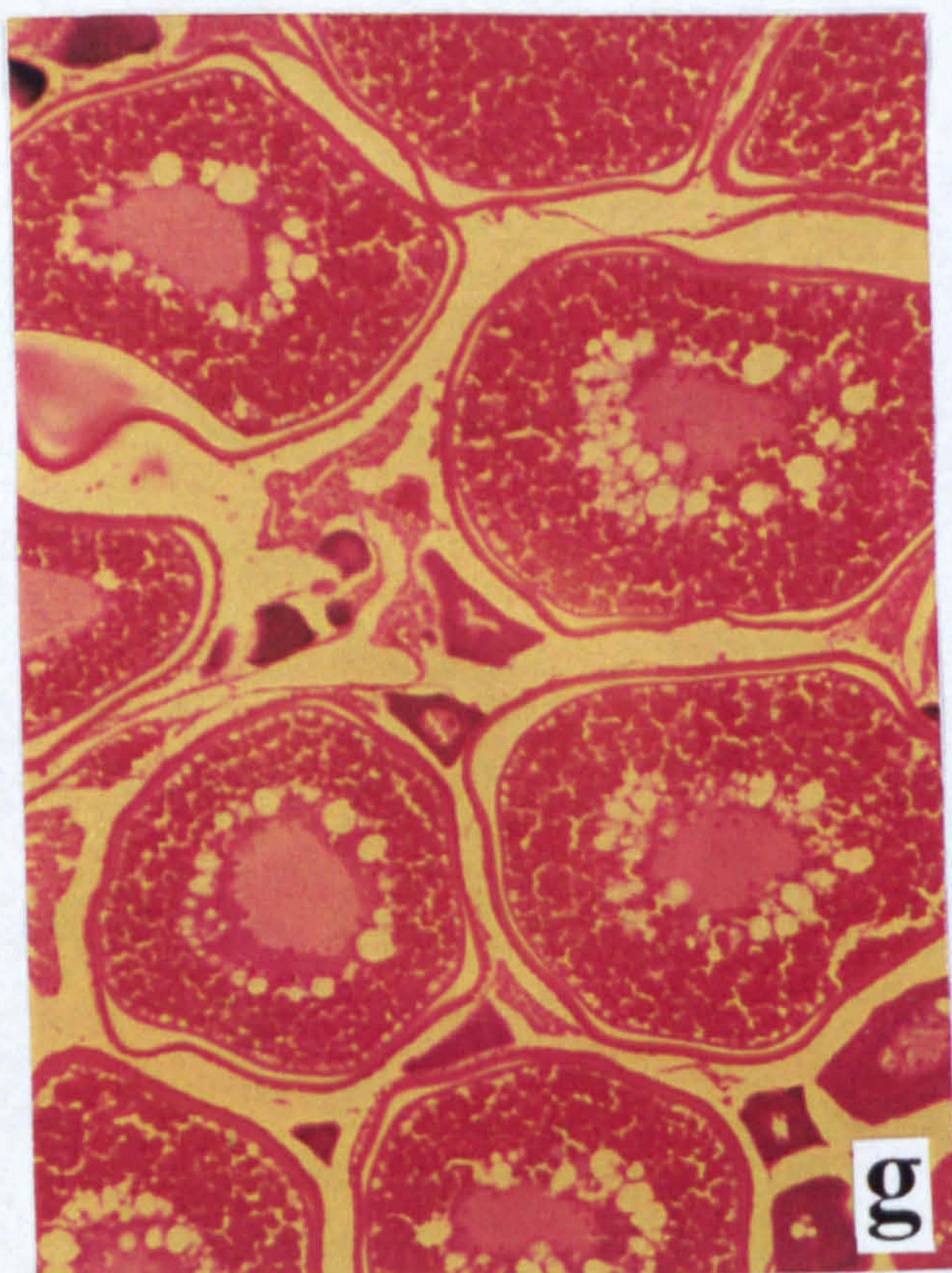
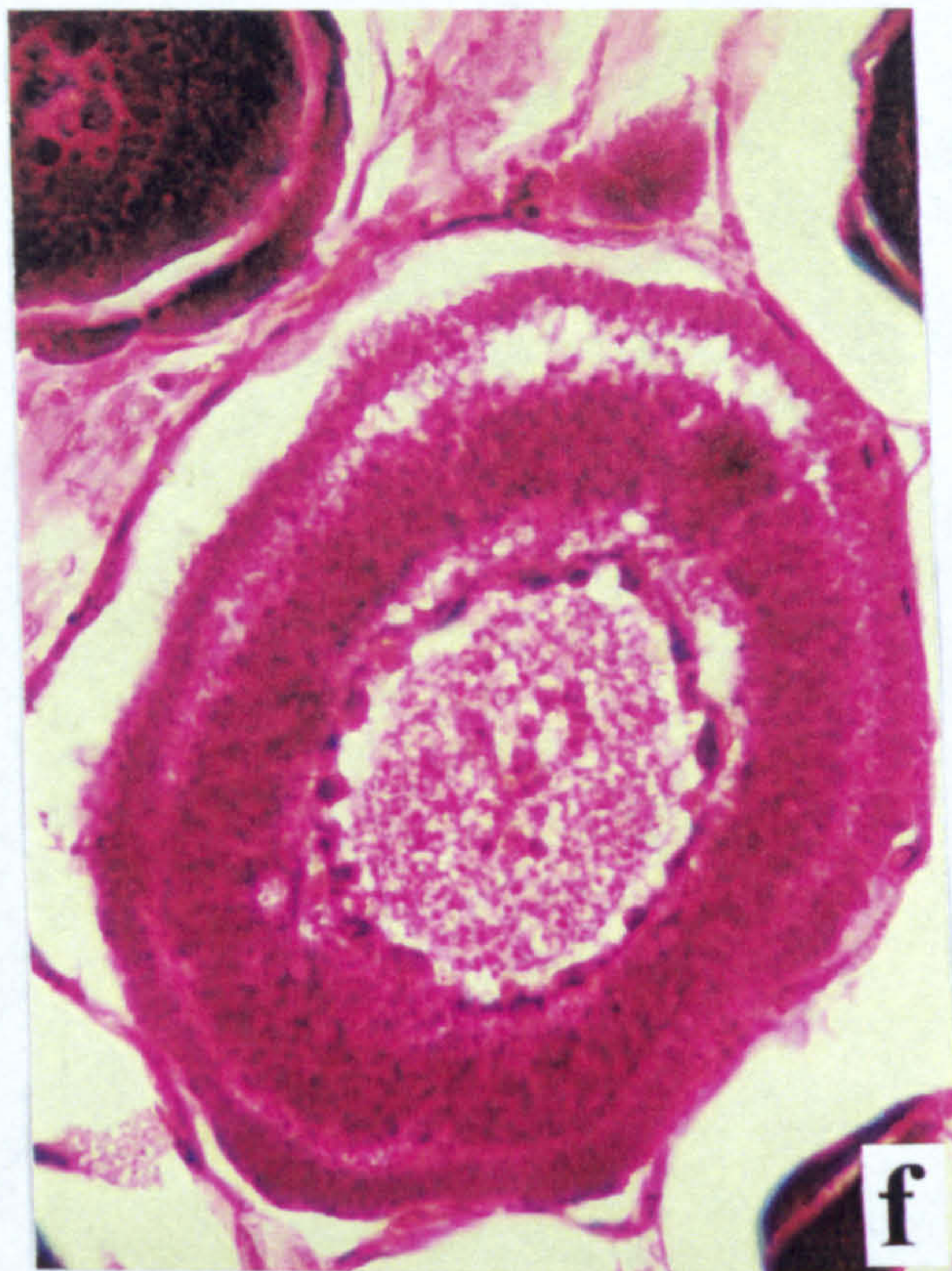
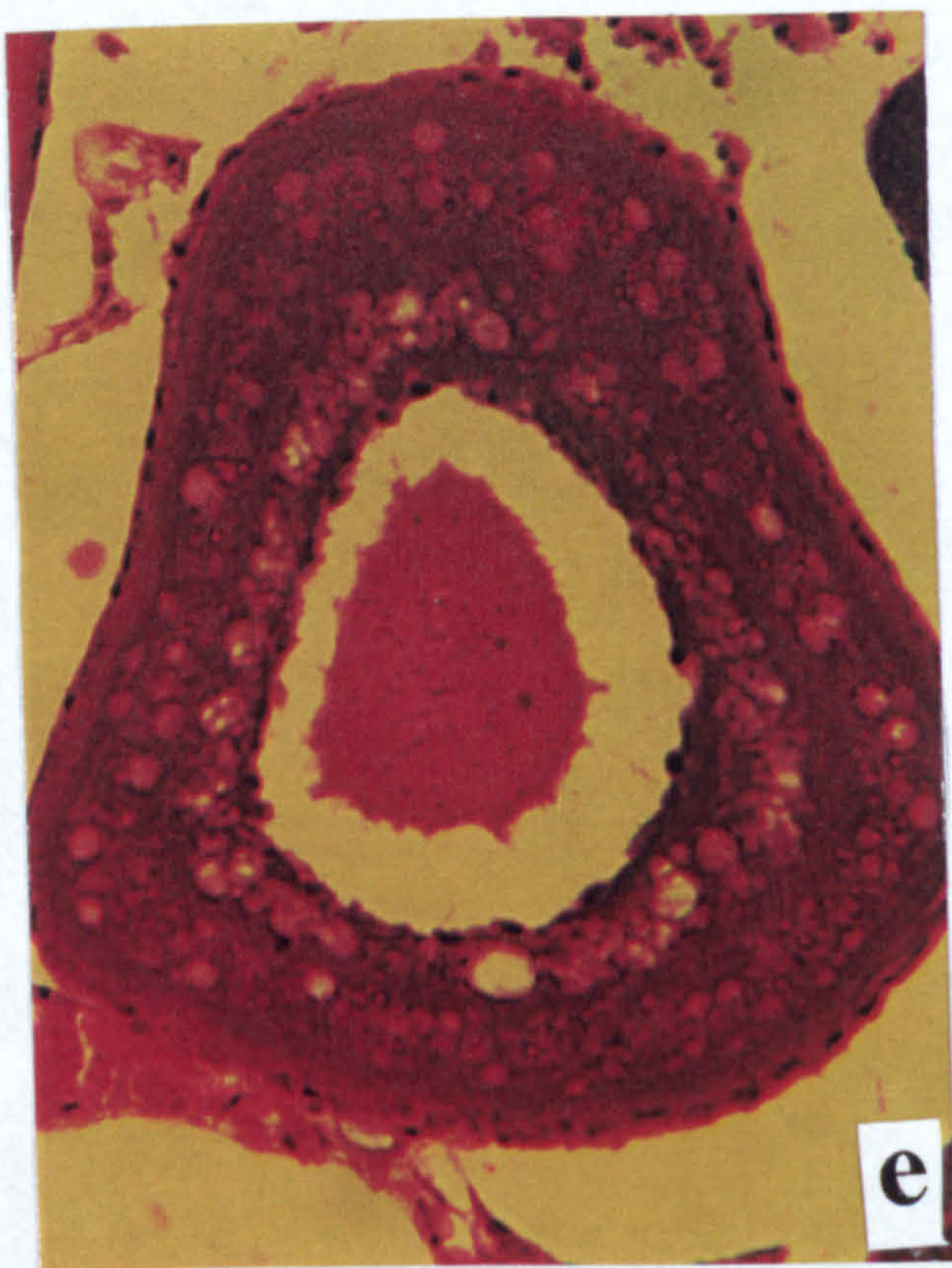


Figure 9. Development stages of oogenesis in shour, *L. nebulosus*. 9e. Yolk vesicle stage; 9f. Primary yolk globule stage; 9g. Secondary yolk globule stage; 9h. Tertiary yolk globule stage (note the beginning of fusion at the oocyte periphery).
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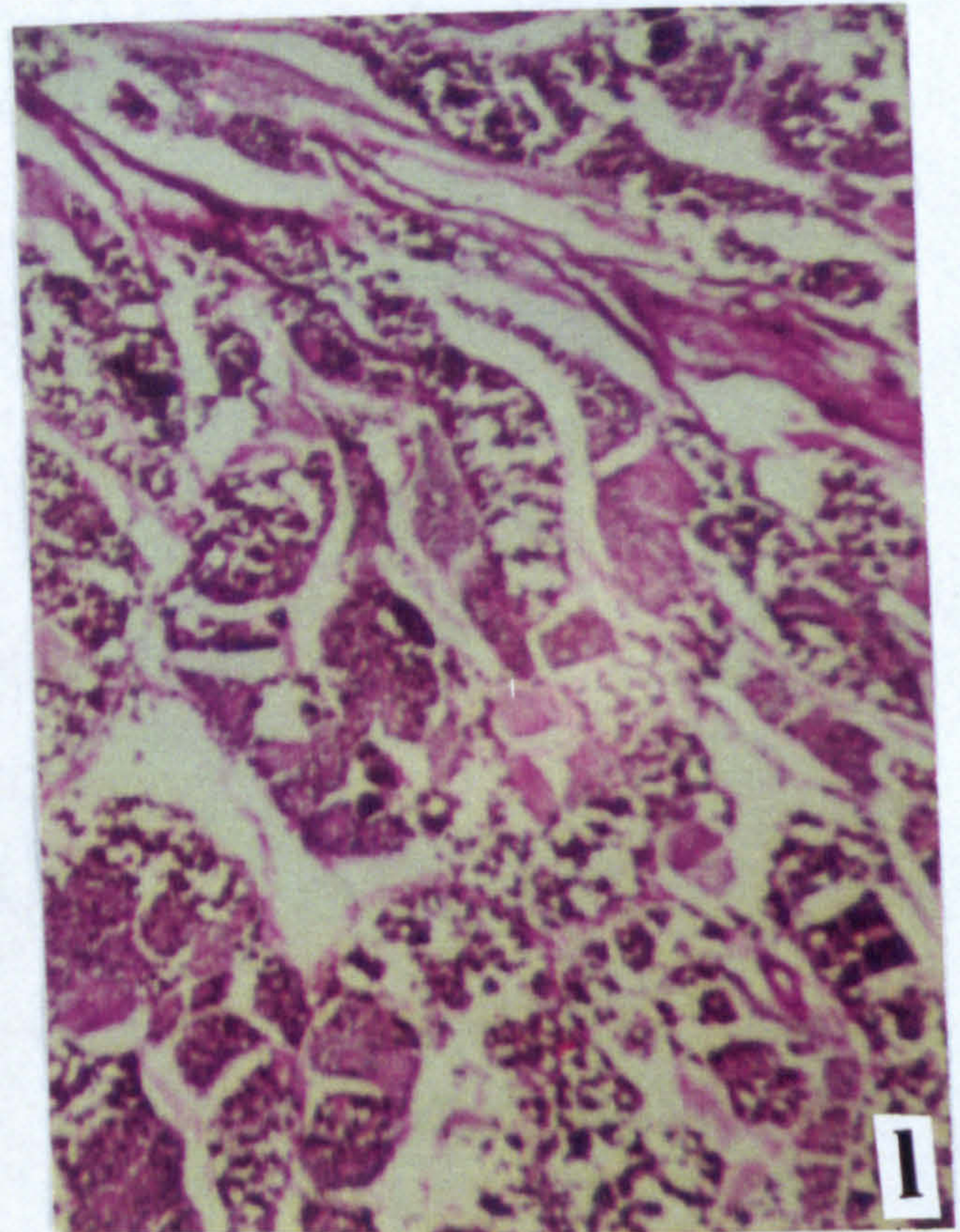
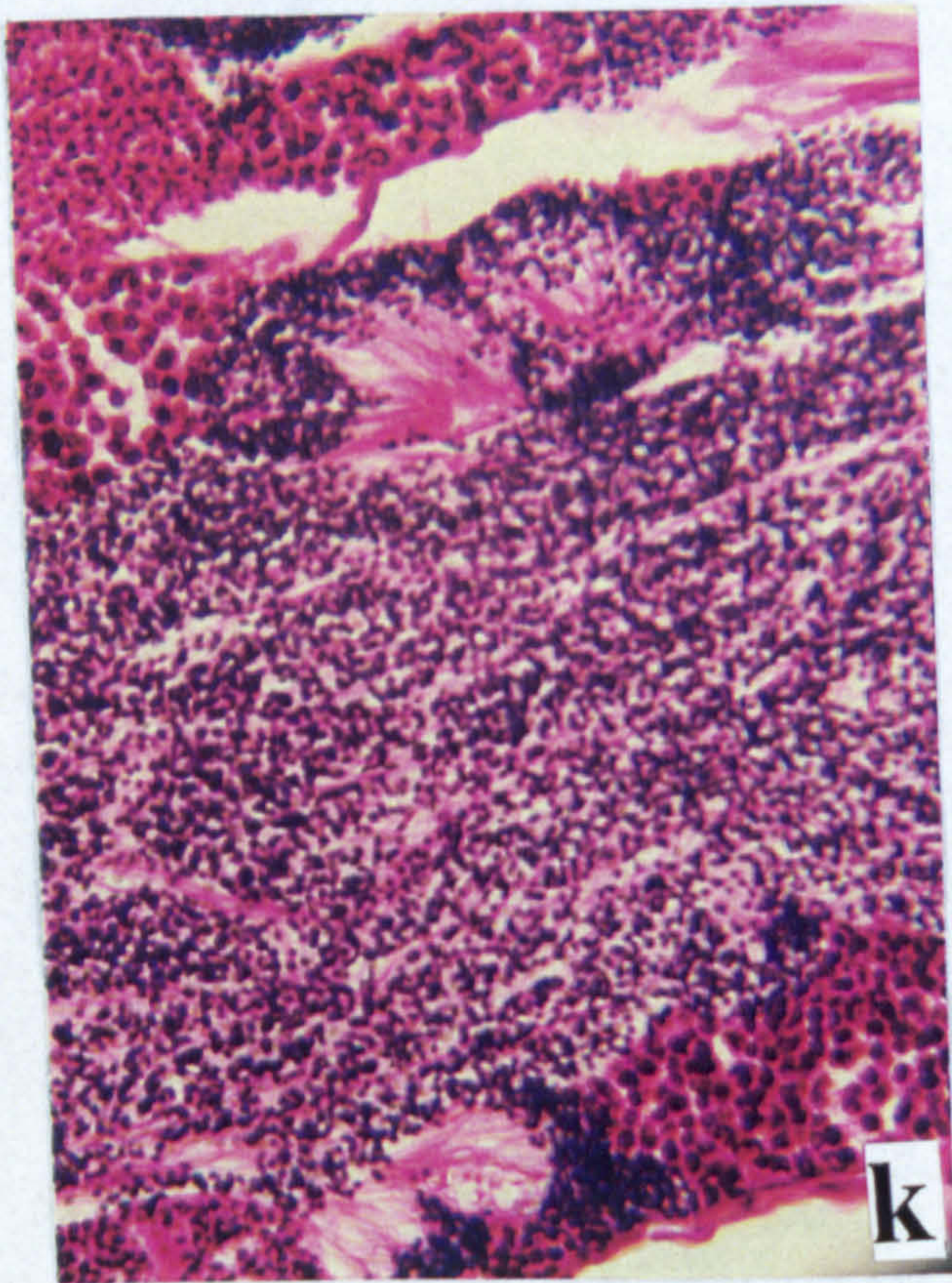
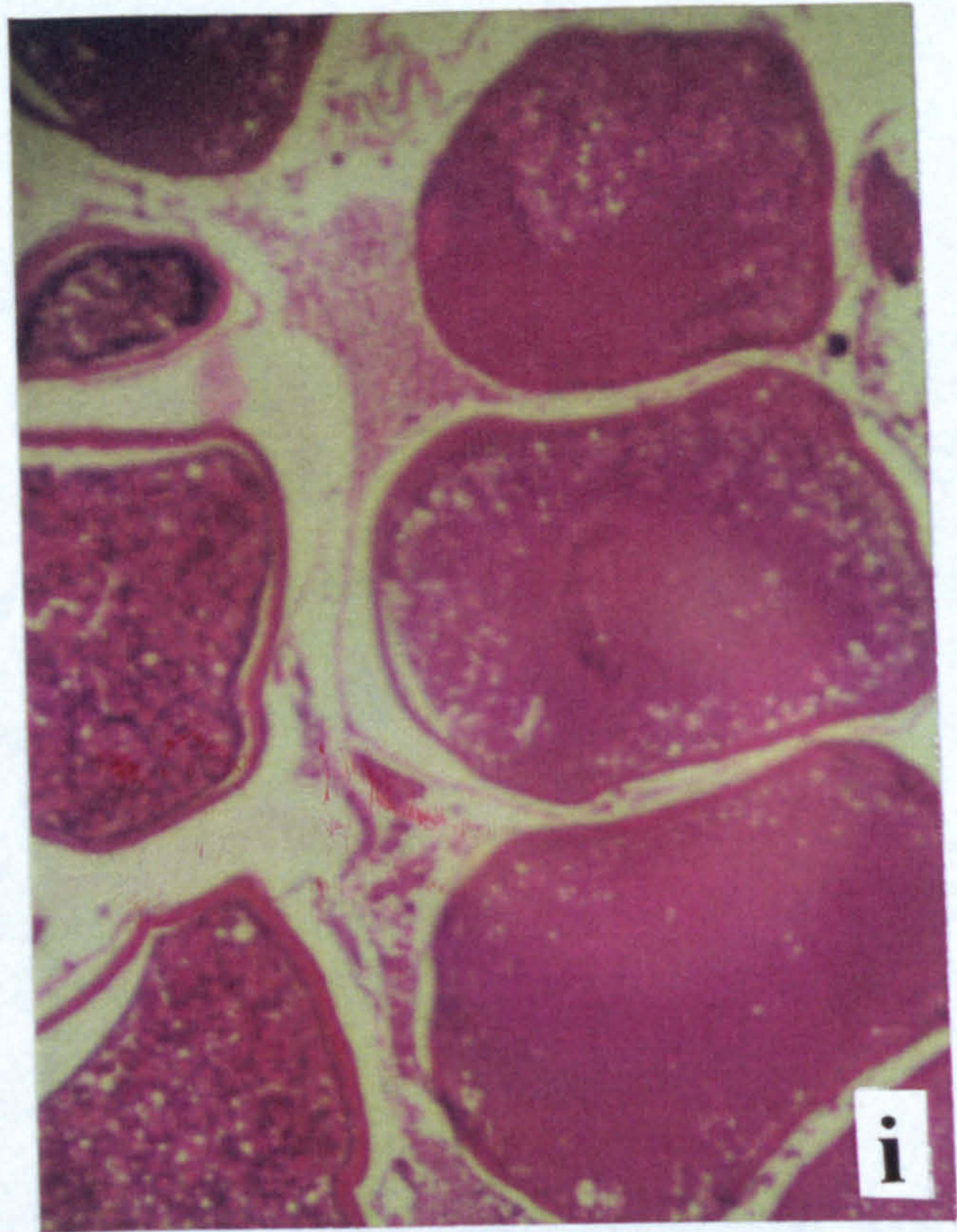
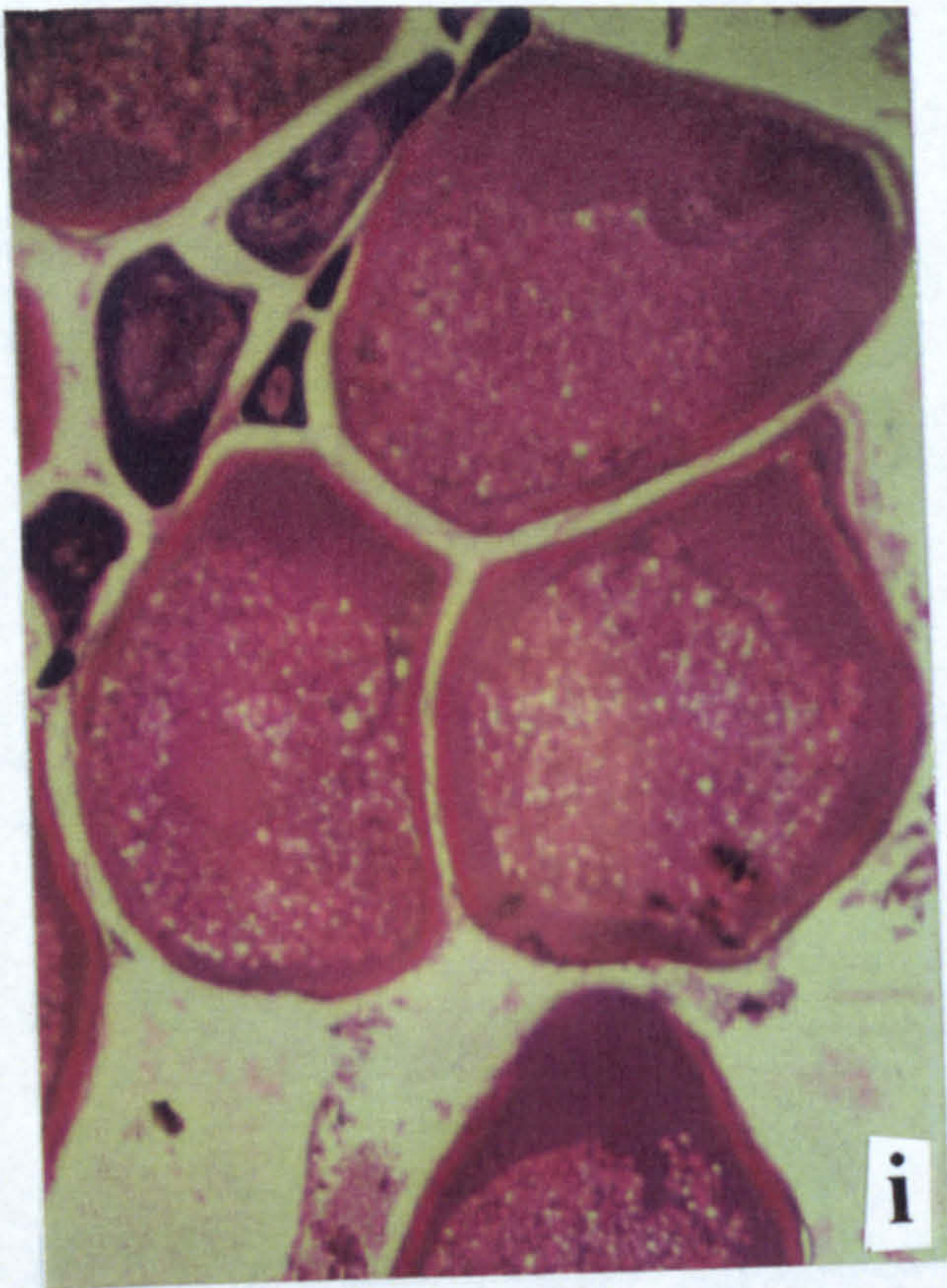


Figure 9. (top) Development stages of oogenesis in shour, *L. nebulosus*. 9i. (left and right) ripe stage (note the almost complete yolk fusion). (bottom) 9k. Testis section showing germ cells at advanced stage; 9l. Testis section from the late spawning period showing no sign of developed sperm.

4. Sex ratio

Variation in the percentage frequency of *L. nebulosus* sexes within the catch was investigated. Over the entire sample, males accounted for 8.6 % more fish than females. However the apparent of sex ratio varied markedly with fish length (fig. 10). Males exceeded the number of females and constituted up to 61 % among the small size classes (33 to 45 cm in fork length). Conversely, in the larger size classes females outnumbered males constituting nearly 65 % of individuals. For the entire population the mean fork length of females was 46.5 cm., while for males it was 43.5cm.. The largest female specimens measured 63 cm and largest male 58 cm.

5. Length at first maturity

No indication of gonad development was observed in any fish smaller than 31 cm in fork length. Thus, these size classes may be considered as immature fish. Fish ranging in fork length between 31 and 36 cm were either developing gonads or were in some cases fully mature. The smallest observed mature fish specimens were 33 and 36 cm in fork length for males and females respectively. Almost 50 % of the males and females specimens were fully mature at sizes 35 and 37cm respectively, the percentage frequency of mature individuals rising rapidly with body length thereafter (fig. 11). Referring to the estimated age at length study in chapter four, it is clear that in the northern part of the Red Sea both sexes of *L. nebulosus* become sexually mature at an age of 4 years.

6. Spawning behaviour

The *L. nebulosus* spawning behaviour at the Ras Mohammed breeding ground clearly reflected changes in gonads condition. Marked changes were observed in oocyte diameter frequency distribution, gametogenesis and gonad index. These changes in gonad condition were strongly correlated with the fishing pattern based

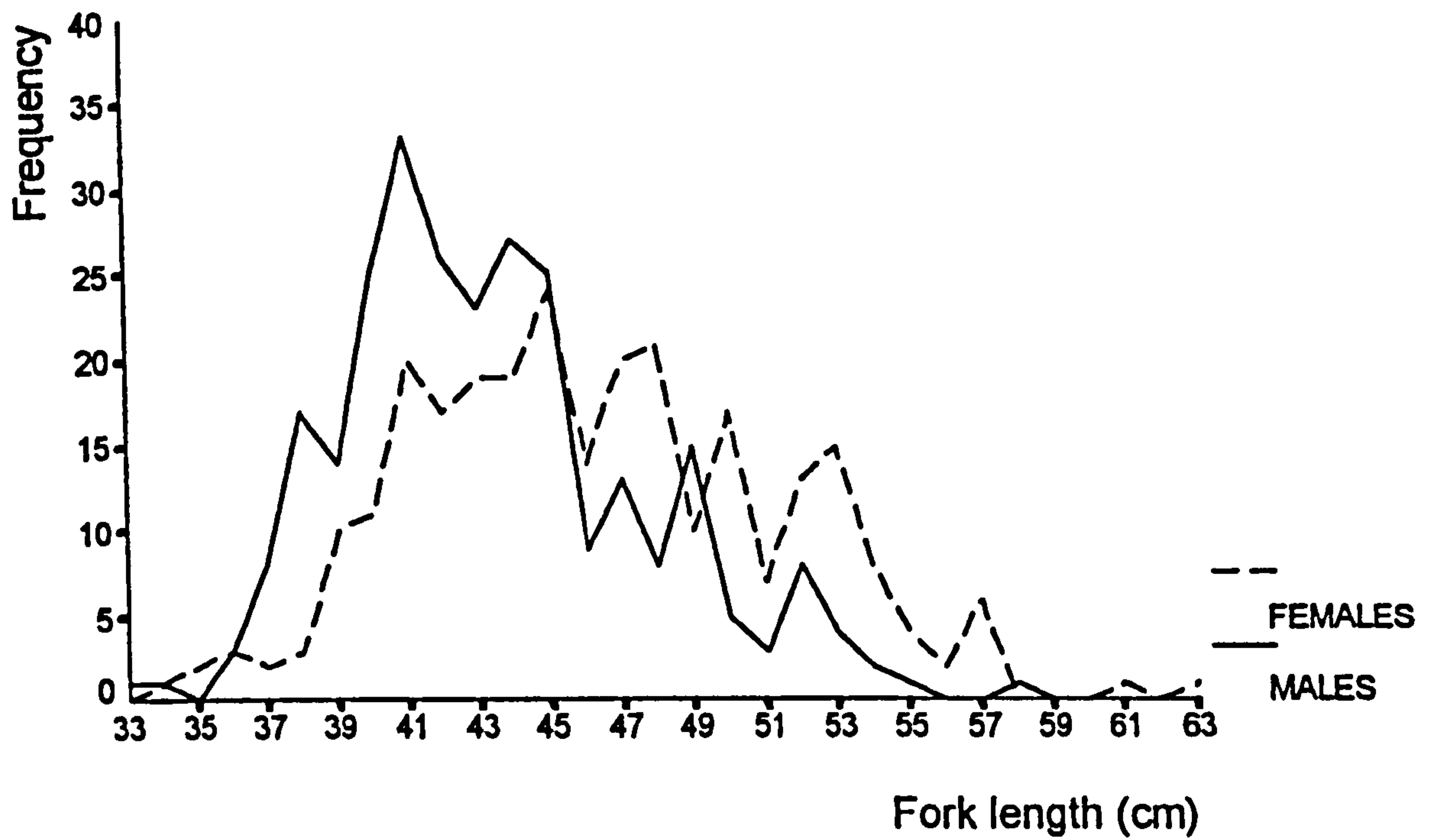


Figure 10: Relative changes in the frequency of *L. nebulosus* males and females with fish length.

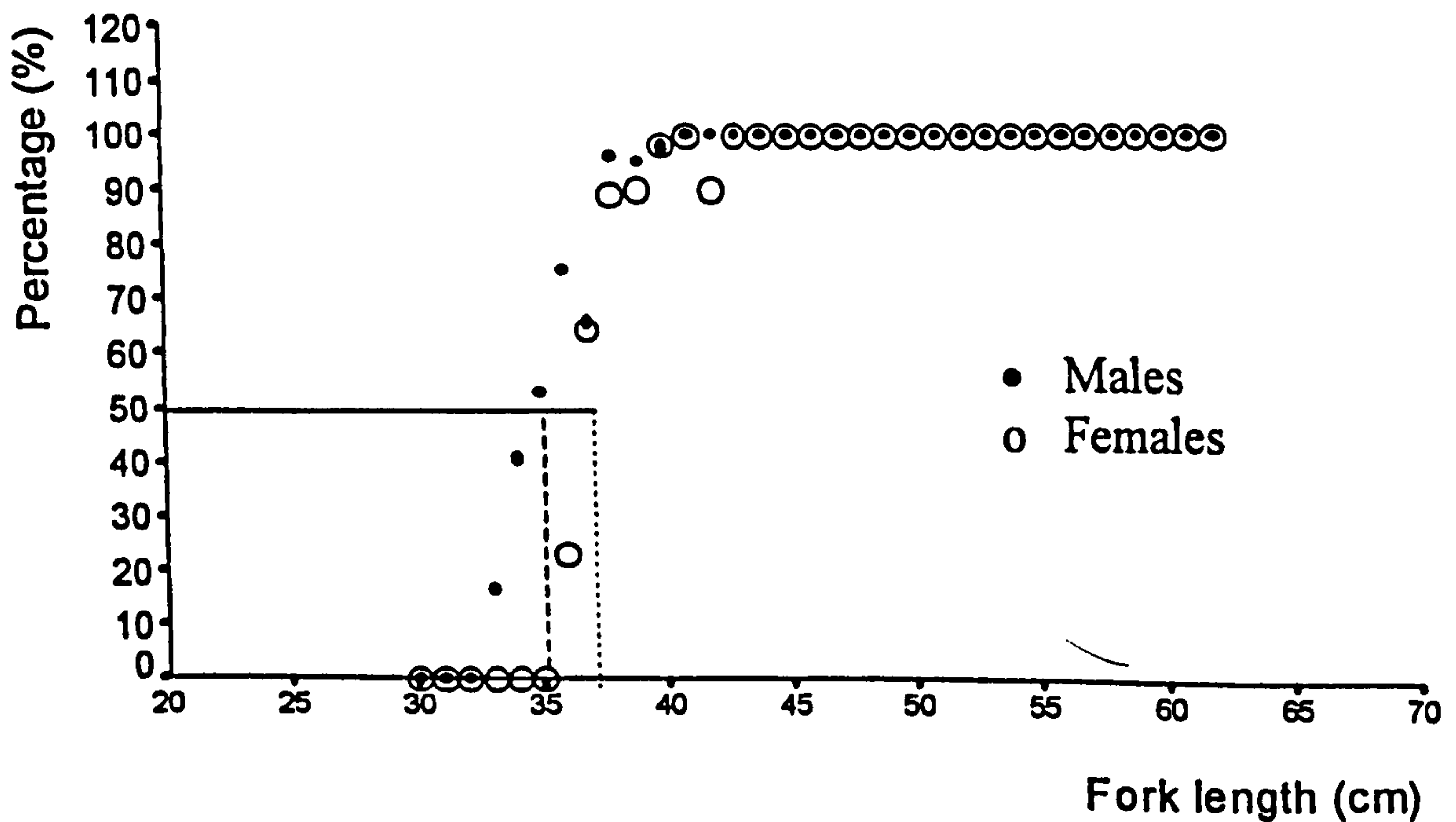


Figure 11: Percentage frequency of mature male and female of *L. nebulosus* in different length classes.

on which, the spawning period was separated into three phases: 1) early spawning period, which extended from the day -9 to day -4, 2) mid spawning period, which extended from the day -5 to -1, 3) and late spawning period, which extended from day zero to day + 7. The features and changes in gonads conditions over these three phases could be described as follows:

6.1. Ova diameter.

A wide range of ova sizes were observed in all specimens throughout the spawning period. However comparison of the daily ova diameter frequency distribution throughout the spawning period showed a distinctive dynamic, with all ova growing towards maturity and subsequent ovulation. The features of the daily ova frequency distribution during the three spawning phases were as follows:

A- Early spawning phase (figure 12a): during this stage the *L. nebulosus* ovaries contained ova whose diameter ranged between 0.06 and .49 mm, but, ova with diameters 0.21 and 0.43 mm, constituted 95.6 % of the measured ova. Ova larger than 0.45 mm were very rare and constituted less than 0.4 %.. No further growth was observed among ova at the most advanced stage. But growth was apparent in the smaller ova noticed, reflected in a reduction in the percentage frequency of ova smaller than 0.28 mm., and on a corresponding increase frequency of ova in the adjacent size class. The percentage of ova smaller than 0.28 mm were estimated to be 33.3, 19.4 and 10.3 % for -9, -8, -7 days respectively, whereas for the adjacent size (0.32 mm) the percentages were 13.3, 17.9 and 20 % for the same days respectively.

B- Mid spawning period (figure 12b): during this stage a further significant change occurred in the *L. nebulosus* ova frequency distribution. Further growth occurred among the large ova sizes. Ovaries contained ova that ranged in diameter

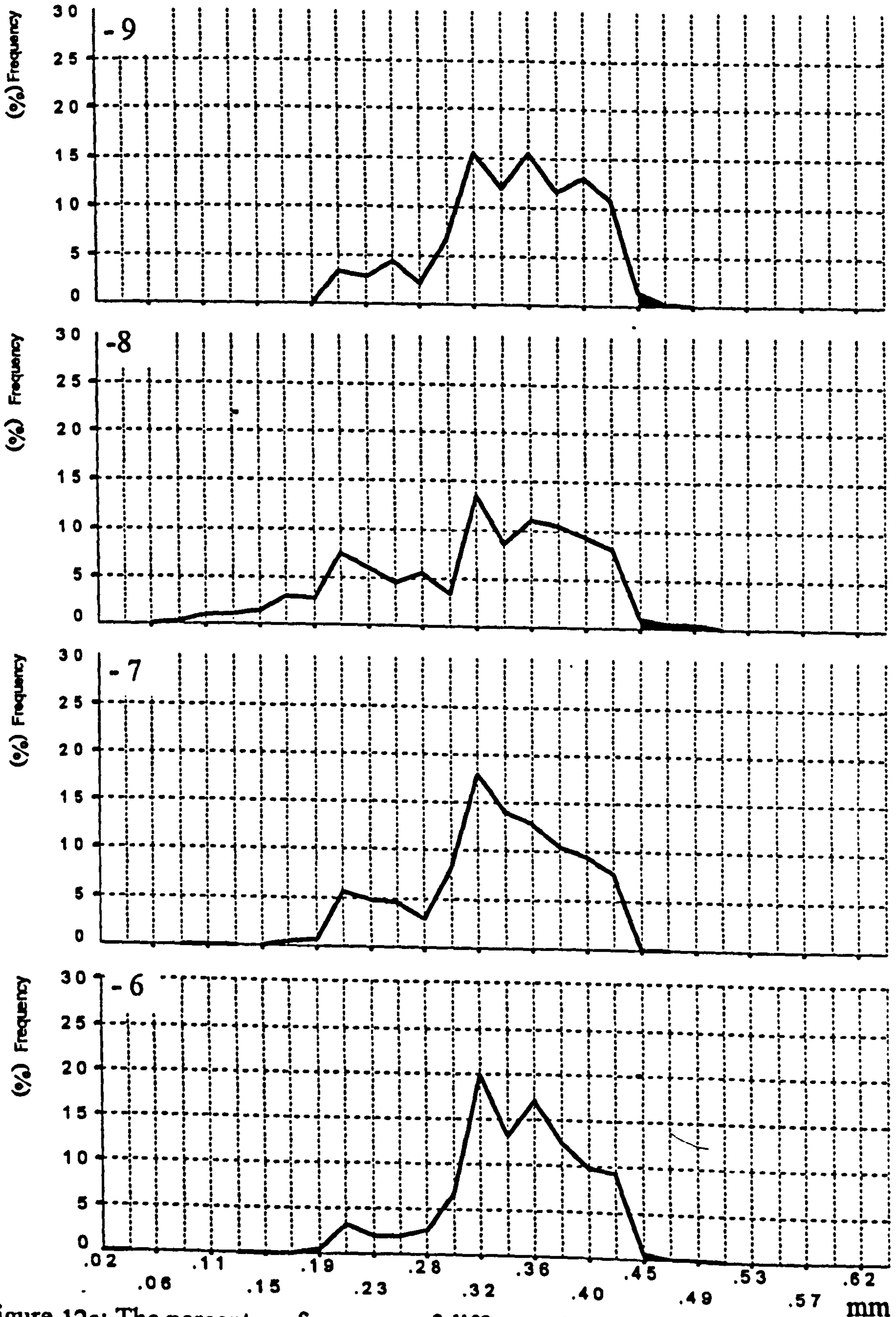


Figure 12a: The percentage frequency of different sizes of ova on different groups (-9 to -6) during the early spawning period.

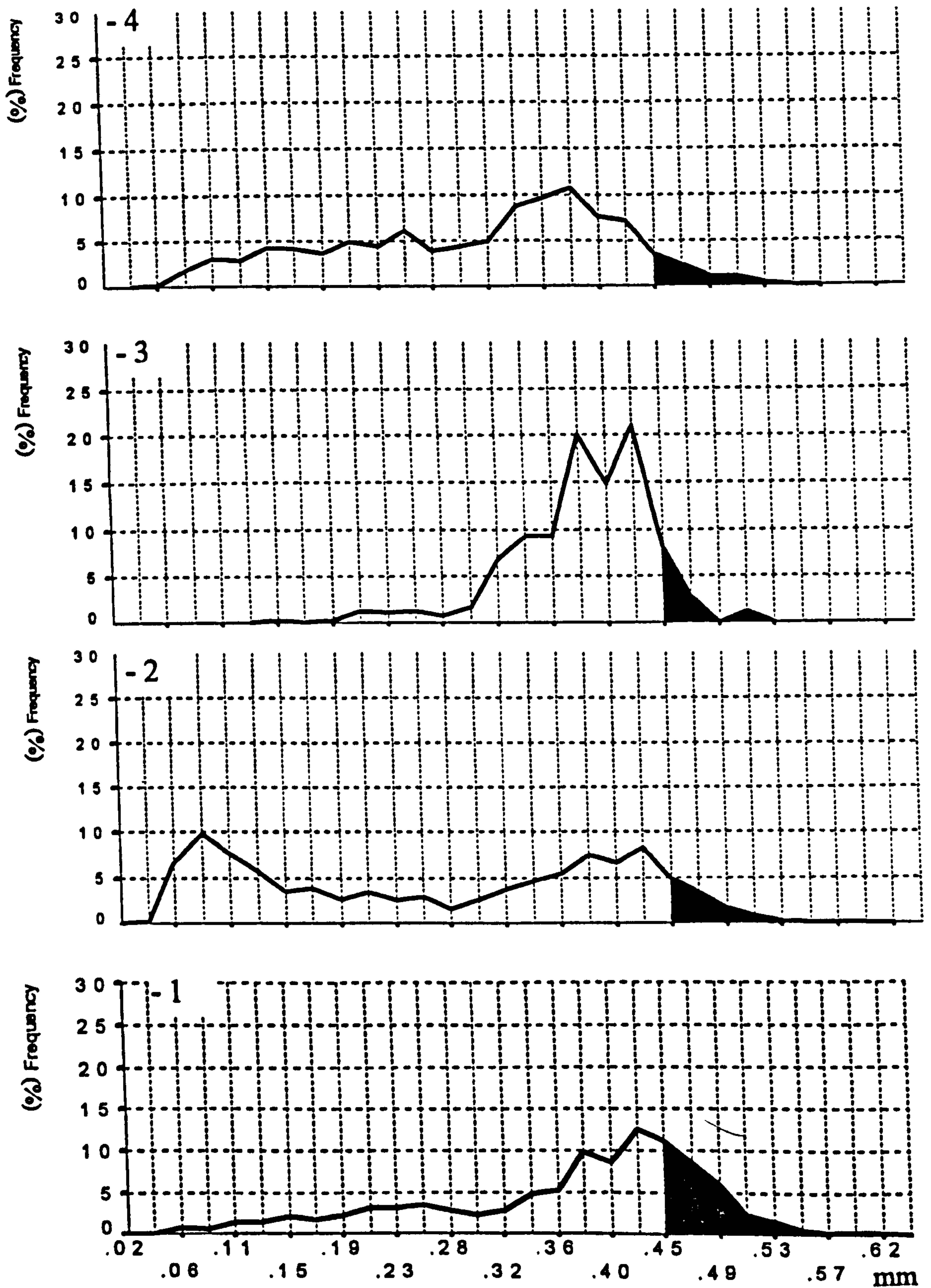


Figure 12b: The percentage frequency of different sizes of ova on different groups (-5 to -1) during the mid spawning period.

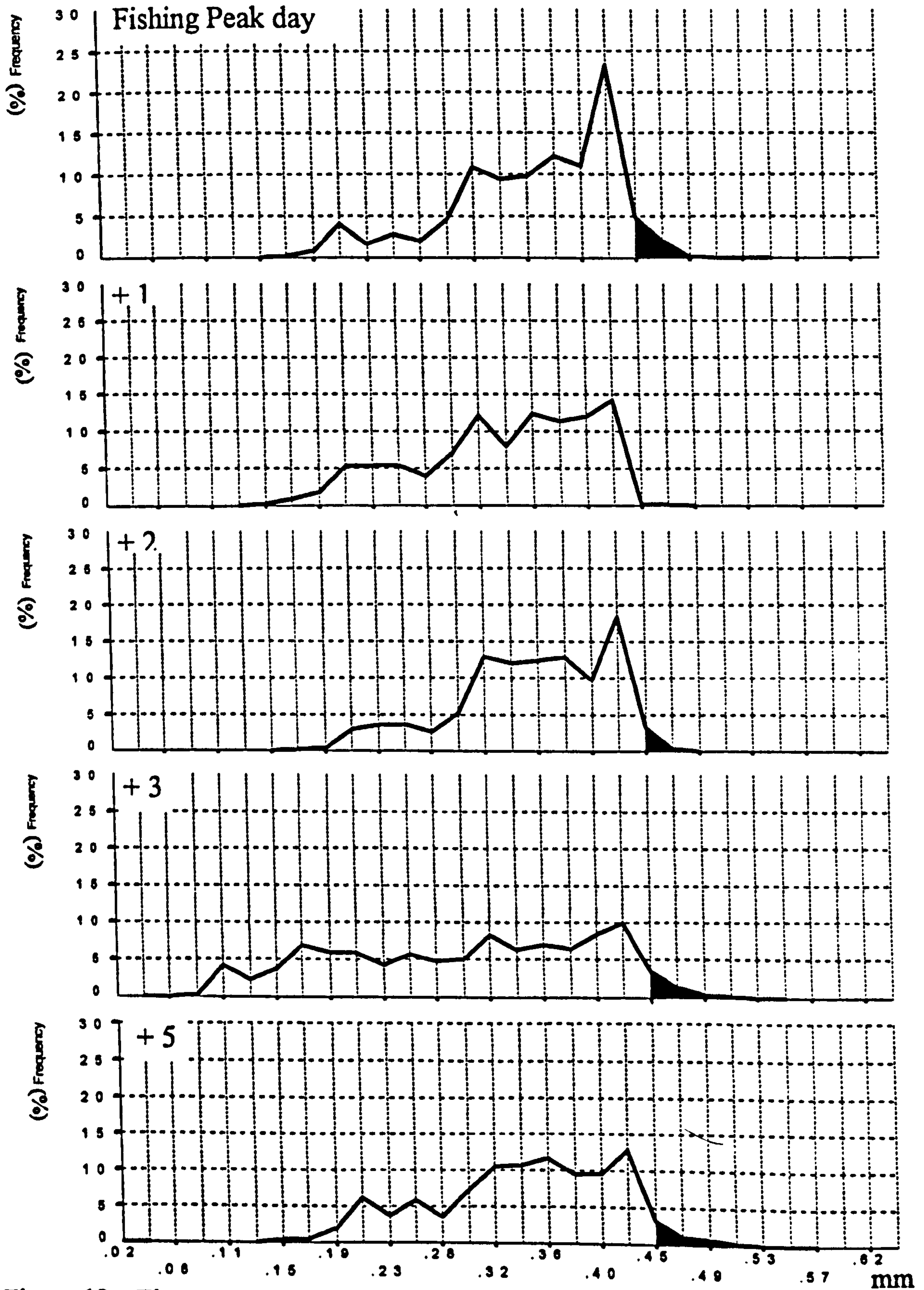


Figure 12c: The percentage frequency of different sizes of ova on different groups (peak fishing day to +5) during the late spawning period..

between 0.06 and 0.62 mm., with ova between 0.32 and 0.49 mm constituting 60.6 % of those measured. Ova greater than 0.45 mm in diameter were developed through this period, their percentage frequency being 8.3, 12.2, 11.0 and 31 % for days -4, -3, -2 and -1 respectively.

C- Late spawning season (figure 12c): at the beginning of this period, the day of peak in catch a sudden disappearance of almost all the ova that exceed 0.45 mm. in diameter was observed. Throughout the following days the percentage frequency of the large ova sizes (estimated at 7.2, .3, 3.5, 5.3 and 5.6 %.) remained low when compared with those observed earlier. No further accumulation of ova was observed.

6.2. Gonad histological structure

The histological study of the *L. nebulosus* gonads throughout the spawning period showed that the ovaries contained a wide range of oocyte stages, with all of these developing into the farther advanced stages. Other distinct differences in histological section character were observed between the three spawning phases.

A- Early spawning phase: at this phase the ovaries were maturing, dominated by oocytes in primary and secondary yolk globule stages, which were the most advanced oocyte form observed. No sign of post-ovulation condition was observed, and the tissue of all of the follicles was intact.

B- Mid spawning period: at this stage further maturation in the oocytes occurred, and the ovaries were dominated by oocytes at the tertiary yolk globule stage. Nevertheless, all forms of less developed oocyte were present. Again no sign of post-ovulation was observed, and the tissue of all of the follicles was entirely intact (figure 13a).

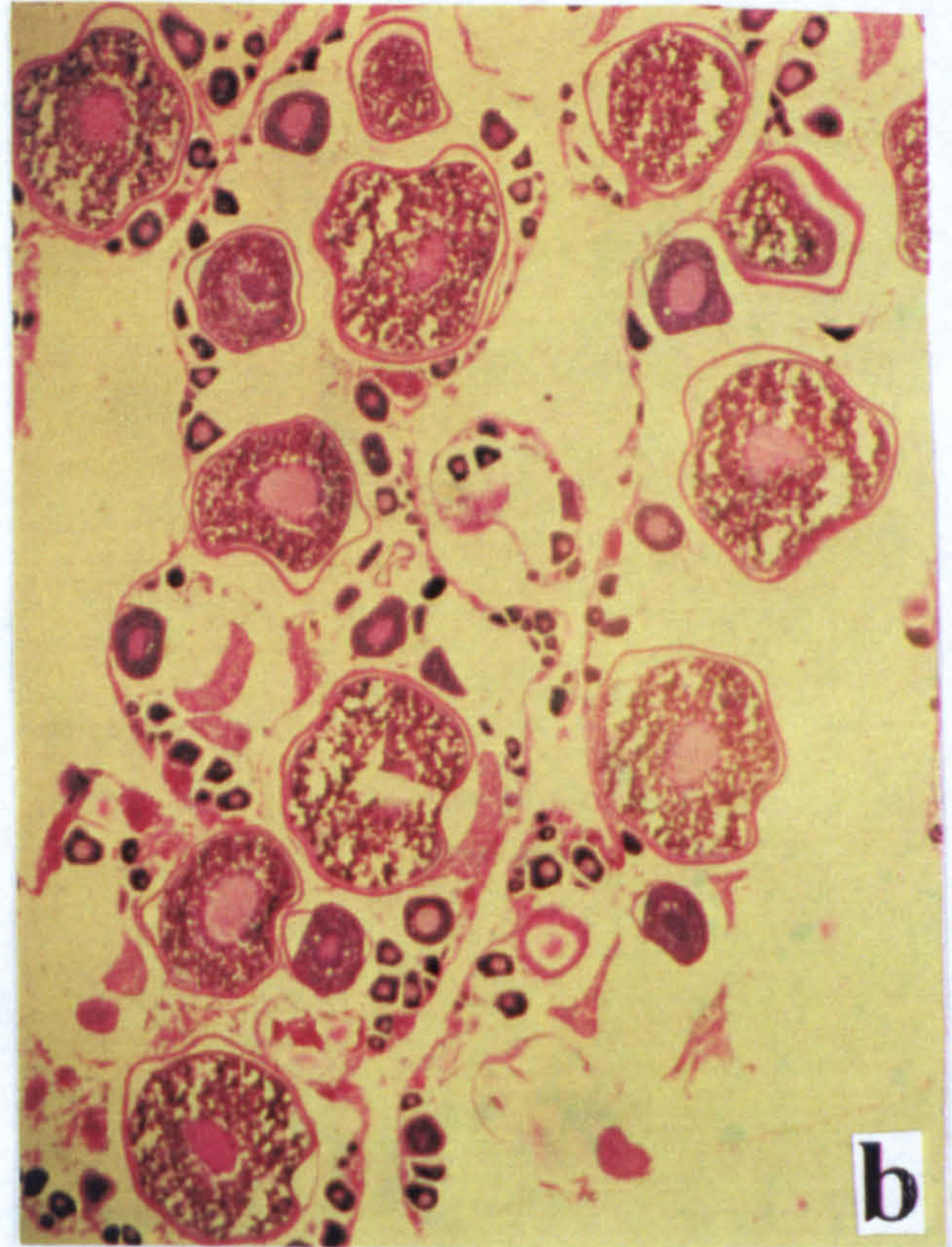
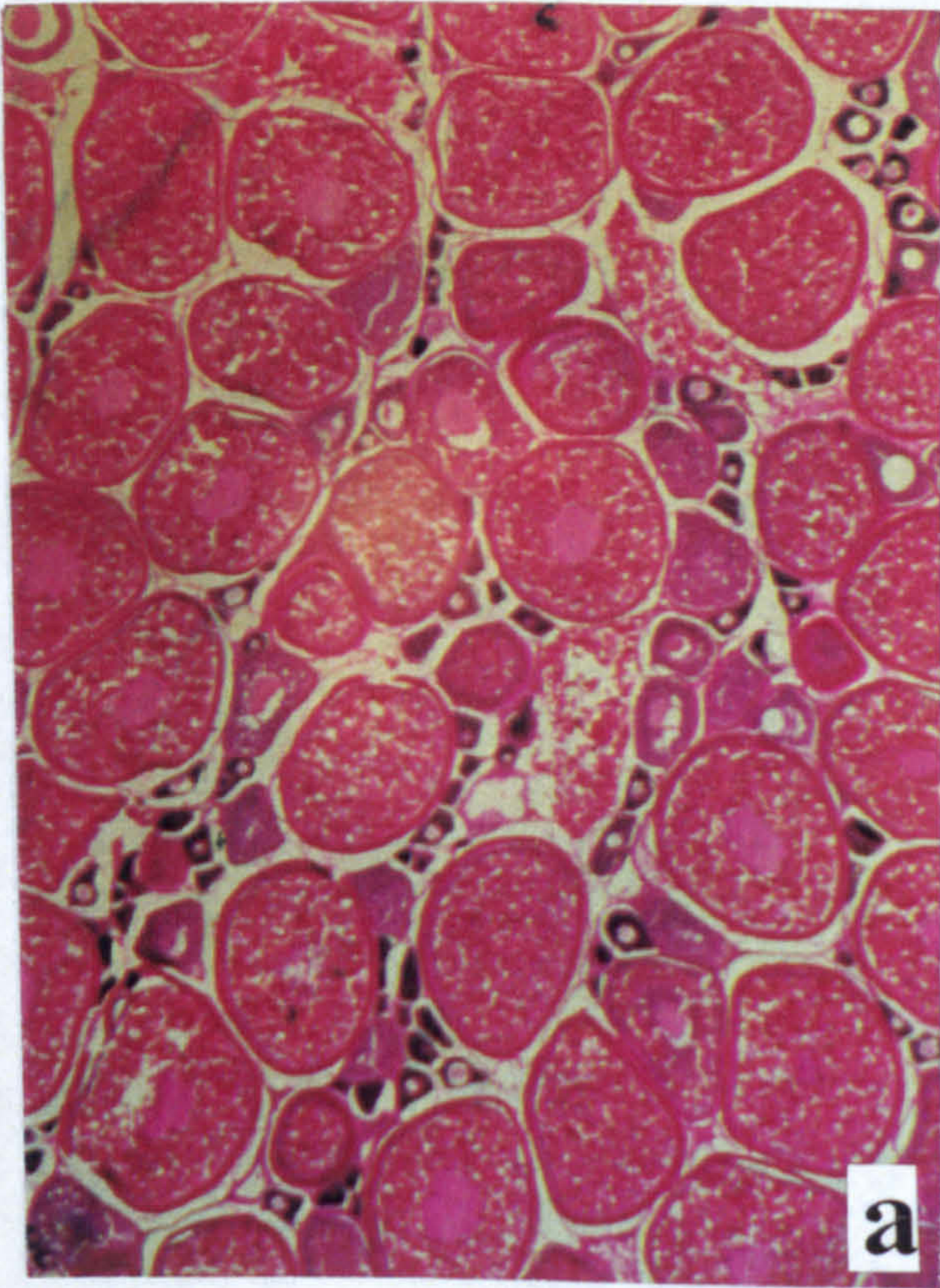


Figure 13. 13a. Ovary of *L. nebulosus* obtained during the early-mid spawning season showing asynchronous oocyte development, with no signs of post-follicle tissue. 13b. Post-ovulatory follicle tissue in spent female obtained during the late spawning season.

C- Late spawning season: at the beginning of this phase all of the advanced oocyte stages that dominated the ovaries in the earlier phases had entirely disappeared. At the same time the first appearance of post-ovulatory follicle tissues were observed, and the ovaries became dominated by oocytes the in secondary yolk globule stage, which are thus the most advanced form of oocyte present in this phase. Subsequently, a considerable reduction in the abundance of the yolked oocytes was observed in all sections, and at the same time simultaneously, a marked increase in the number of the post-ovulatory follicles tissues occurred (figure 13b).

6.3. Changes in gonad index

In total, 815 gonad weight records were used to assess the changes in the status of *L. nebulosus* breeding stock over the spawning period. A distinct change in the mean gonad weight and consequently gonad index was observed over the spawning period. Before the peak fishing day no marked change in the mean gonad index was observed, with mean gonad index fluctuating between 3.6 and 4.2. After the peak fishing day a substantial reduction in mean gonad index was observed, with gonad index declining gradually to reach a minimum value on day +8. By the end of the spawning period, the population mean gonad index declined significantly, and was estimated at 1.3. This value was equivalent to only 23 % of the mean gonad index before the peak fishing day. The changes in the *L. nebulosus* mean gonad index over the spawning period are shown in figure 14.

7. Changes in spawning potential

The proportional contribution of eggs by each female size class to the over all eggs production over the period from 1995 and 1998 is shown in table 1. In general, there was a reduction in quantity of eggs produced, the most productive year was

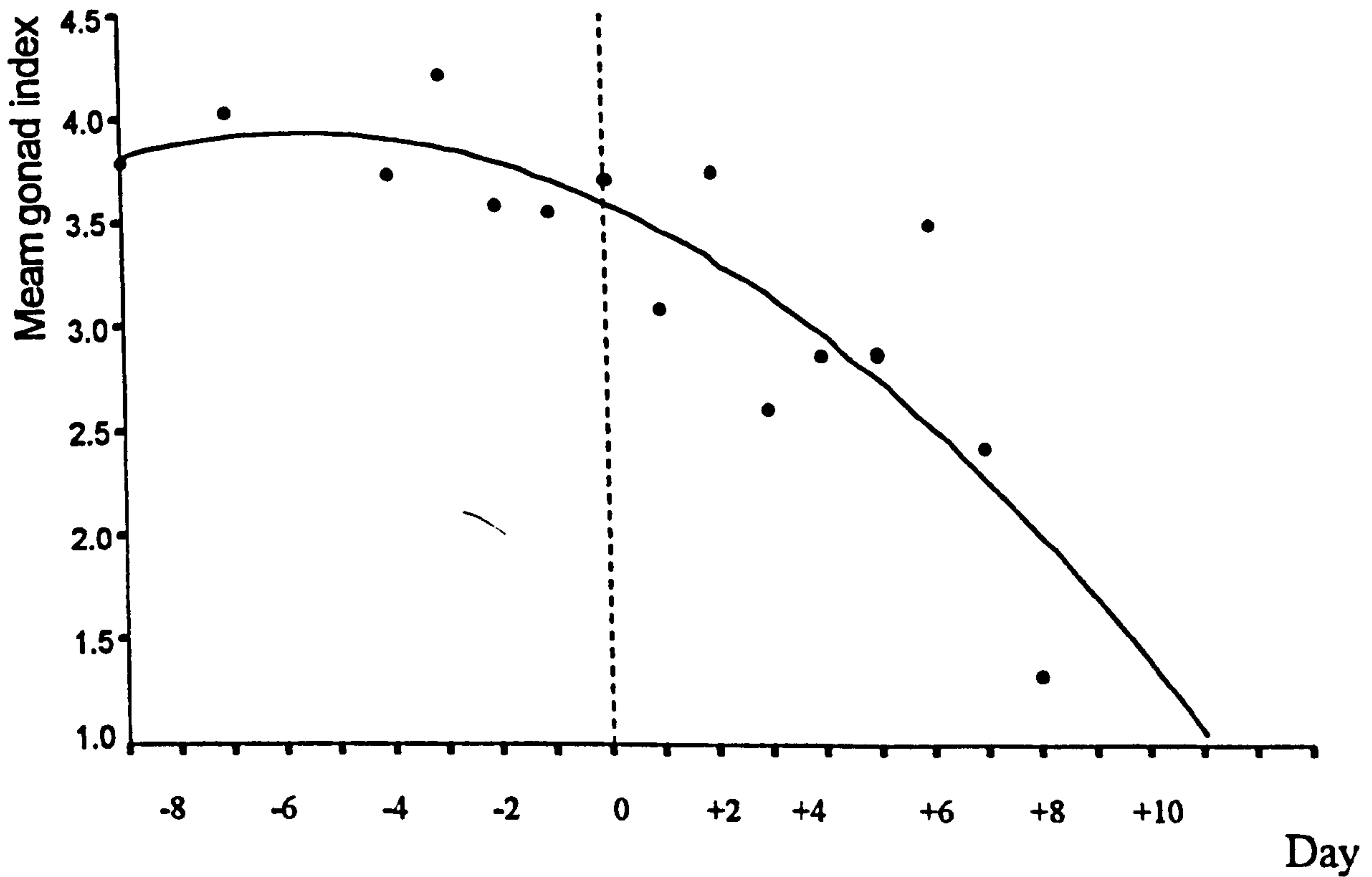


Figure 14: The changes in the *L. nebulosus* gonad index over the main spawning period in 1997. The dashed vertical line indicates the peak fishing day.

Table 1: The table shows the changes in proportional contribution of eggs by each female size class to the overall *L. nebulosus* spawning potential between 1995 and 1998.

Fork length (cm)	Back-calculated fecundity	Number of eggs produced by each female size class ()Percentage frequency of females in each size class			
		1995	1996	1997	1998
36	25271	21562 (.85)	8596 (.34)	35098 (1.39)	26142 (1.03)
37	109306	74610 (.07)	81794 (.75)	91088 (.83)	70358 (.64)
38	193341	29694 (.15)	286066 (1.48)	271886 (1.41)	253344 (1.31)
39	277377	315559 (1.14)	746904 (2.69)	1324281 (4.77)	1301864 (4.69)
40	361412	452279 (1.25)	1615154 (4.47)	1533770 (4.24)	939302 (2.60)
41	445447	1090025 (2.45)	2515682 (5.65)	3385213 (7.60)	2511739 (5.64)
42	529483	2857752 (5.40)	2705630 (5.11)	3343471 (6.31)	2935437 (5.54)
43	613518	3599544 (5.87)	3776106 (6.15)	4432991 (7.23)	5040451 (8.22)
44	697553	4228379 (6.06)	4213997 (6.04)	5002080 (7.17)	4437707 (6.36)
45	781589	4311612 (5.52)	8984524 (11.50)	6779084 (8.67)	6072299 (7.77)
46	865624	5394895 (6.23)	5734982 (6.63)	5122653 (5.92)	7873240 (9.10)
47	949659	7857351 (8.27)	6460266 (6.80)	6794699 (7.15)	7938634 (8.36)
48	1033694	8175152 (7.91)	8147345 (7.88)	8057173 (7.79)	9980498 (9.66)
49	1117730	4425141 (3.96)	4105946 (3.67)	4191486 (3.75)	4727868 (4.23)
50	1201765	10775988 (8.97)	8528295 (7.10)	7093752 (5.90)	6404390 (5.33)
51	1285800	6143756 (4.78)	5816716 (4.52)	3437730 (2.67)	2896746 (2.25)
52	1369836	7524857 (5.49)	5480230 (4.00)	6183286 (4.51)	3703880 (2.70)
53	1453871	6267811 (4.31)	4684869 (3.22)	7572244 (5.21)	5804929 (3.99)
54	1537906	8398123 (5.46)	3766301 (2.45)	4271962 (2.78)	4242500 (2.76)
55	1621942	5314211 (3.28)	2648068 (1.63)	2703236 (1.67)	2982881 (1.84)
56	1705977	5240202 (3.07)	8123699 (4.76)	1184706 (.69)	2353071 (1.38)

57	1790012	4276479 (2.39)	1826543 (1.02)	4350724 (2.43)	3291976 (1.84)
58	1874047	(0)	1784807 (.95)	(0)	1809425 (.97)
59	1958083	2806808 (1.43)	1398631 (.71)	(0)	945281 (.48)
60	2042118	975756 (.48)	486219 (.24)	(0)	985850 (.48)
61	2126153	3628248 (1.71)	(0)	(0)	488771 (.23)
62	2210189	2112126 (.96)	(0)	(0)	(0)
63	2294224	1566023 (.68)	780348 (.34)	(0)	(0)
64	2378259	2272739 (.96)	(0)	(0)	765417 (.32)
65	2462295	1176523 (.48)	(0)	(0)	(0)
66	2546330	(0)	(0)	(0)	409754 (.16)
67	2630365	628415 (.24)	(0)	(0)	423277 (.16)
68	2714400	(0)	(0)	(0)	(0)
69	2798436	(0)	(0)	(0)	(0)
70	2882471	688645 (.24)	(0)	(0)	(0)
Total		112563115	94707716	87162612	91617031

the 1995, and the lowest was the 1997. However, referring to the 1995 estimate, eggs productions are reduced by 16, 23, and 19 % in 1996, 1997, and 1998 respectively. In 1995 females larger than 50 cm in fork length formed 35 % of the over all females, producing 52.4 of the total eggs. While in 1998 these sizes constituted 19.6 % producing 33.9 % of the over all eggs.

In conclusion, the changes in the *L. nebulosus* gonad condition throughout the spawning period suggested that:

- The *L. nebulosus* breeding stock arrives at Jackfish Alley Reef at Ras Mohammed with their gonads at a pre-mature stage, so that the last stages of maturation take place at the spawning ground. The *L. nebulosus* develop their oocytes from secondary yolk globule stages to the pre-ovulation stage over a period of seven days; during this period developed oocytes accumulate in the ovaries, prior to a massive release on the third day after the full moon. The *L. nebulosus* spawn twice every year three days after full moon each during the period from late April to the early of June.
- The *L. nebulosus* feeding behaviour over the spawning period is probably reflected in the fishing pattern. In which case feeding may be driven by the need for the fish to obtain energy to support the rapid growth of their gonads, rather than being a result of starvation during or after the spawning event.
- The correlation between the breeding stock feeding habits and the spawning process suggested that the topographical and ecological characterisations of Jackfish Alley Reef could be a key factor in stimulating the *L. nebulosus* to choose this reef as a breeding ground. The study of *L. nebulosus* feeding habits (chapter 5) revealed that this species feeds mainly on coral reef

associated fauna. Jackfish Alley Reef is the widest coral garden in the South Sinai area, with dense cover, and so may be the best reef for providing sufficient food for large numbers of predatory fish species.

- All the *L. nebulosus* caught before the peak fishing day are removed from the spawning population and so have zero input to the spawning. These catches constituted 57 % of the *L. nebulosus* yearly catches. Also all of the fish caught after the peak fishing day are removed with a substantial percentage loss of their spawning potential.

DISCUSSION

Location and timing of spawning. That various factors influence fish to select specific locations as spawning grounds has been repeatedly hypothesised without any strong support from empirical investigation (Shapiro et al, 1988). A benefit resulting from the flow and destination of water moving over the site (current dynamics) is the factor most frequently proposed to be key to the selection of sites (Randall, 1961; Choat & Robertson, 1975; Colin 1985; Warner 1986). Specifically, it is argued that fish aggregate to spawn in areas where the current regime will ensure a wide dispersal of larvae (Barlow, 1981), by eggs being swept away from reefs and into off-shore water where predation by reef associated fauna is lower (Johannes, 1978), and where more planktonic food resources may be present (Doherty et al., 1985). However several research findings have argued against this hypothesis. Colin (1992) found no major movement of water masses around the spawning aggregation sites of Nassau grouper, either during or after the spawning period. Moyer & Yogo (1982) found that in Japanese waters many sites had similar current regimes to known spawning sites but were not used by fish for breeding. Further Colin et al. (1987) concluded that *E. striatus* aggregation sites along the Puerto Rico coast were not located at the most effective sites for achieving off-shore larval dispersal.

The *L. nebulosus* spawning aggregation studied here is focused on Jackfish Alley reef, very close to the most southern tip of the Sinai Peninsula. Quantitative information on current patterns at this site during the spawning period is not available so discussion of the extent to which current plays a key role in the choice of this site as a spawning ground can only be tentative. Nevertheless, based on personal observation of surface water movement during the study, it appears that the current regime at Jackfish Alley is very similar to that on neighbouring reef areas, with the direction and strength of current varying markedly through the day

in response to tidal movement. However changes in gonad condition suggest that *L. nebulosus* spawn in day 17th of the lunar cycle, which is not the best day in terms of strength of tidal current, but several days after a spring tide.

The onset of spawning has often been linked to a rise in surface sea water temperature. For example, Colin (1992) and Tucker et al. (1993) found that in Bermuda the Nassau grouper, *Epinephelus striatus*, aggregate to spawn between June and July, while in more southern latitudes they spawn from November to February. They found, however, that water temperatures were very similar, about 25 °C, in the two regions at the times when the fish began to spawn. In the Egyptian Red Sea it has been reported by local fishermen that the southern *L. nebulosus* aggregation at Ras Banas occurs one month before that at Ras Mohammed. In the northernmost part of the Red Sea proper, surface water temperature rises from mean values of 21.3 and 21.7 °C in February and March to 24.4 and 25.5 °C by May and June respectively, while at southern latitudes temperatures reach this level almost one month earlier (Edwards, 1987; Morcos, 1970). This suggests that in *L. nebulosus* also spawning occurs in response to an increase in temperature to a particular level. However, Ebisawa (1990), on measuring the correlation between gonad development and water temperature in *L. nebulosus*, found that spawning occurred at temperatures ranging between 21 and 27.5 °C. One possibility is that, rather than specific warmer temperatures being physiologically essential for spawning, a marked rise in temperature is used as a cue to co-ordinate reproductive behaviour.

Lunar patterns. In coral reef environments lunar-synchronised spawning has been considered especially characteristic of pelagic fish or those which migrate to spawn (Thresher, 1984; Colin & Clavijo, 1988). Colin (1992) found that in the Bahamas *E. striatus* spawning aggregations occur twice during two successive full

moon periods between November and February. This is a pattern similar to that observed at Ras Mohammed where *L. nebulosus* spawn twice every year between April and June, at the same time in relation to the lunar phases. By contrast Ebisawa (1990) found that in Japanese waters *L. nebulosus* spawn continuously between mid March and mid April, with no connection to lunar phases. However lunar periodicity in spawning has been reported for species in other families of reef fish including snappers (Grimes, 1987; Davis & West, 1993; Domeier & Colin, 1997), emperors (Johannes, 1978), and groupers (Samoilys & Squire, 1994; Colin, 1992; Shapiro et al., 1993b; Tucker et al., 1993 Colin et al., 1987; Domeier & Colin, 1997).

Johannes (1978a), as described above, proposed that fish synchronise their spawning with lunar phase in order to benefit from the strong current flows which occur at spring tide and flush larvae offshore, thereby reducing predation by reef associated fauna. However, as also mentioned, in the present study spawning was found to start on about day 17 of the lunar cycle and extend over the following 6 to 7 days, which is not the time of maximum tide that would achieve the best offshore dispersal. Instead two other processes were strongly correlated with the full moon: an increase in feeding rate and the last stage of gonad maturation. This observation is more consistent with Colin's (1987, 1988) suggestion that the timing of spawning during a specific lunar phase is only a tactic adopted to synchronise and co-ordinate the spawning process.

Feeding and spawning achievement. The distance travelled by *L. nebulosus* from resident reefs to the spawning site is not known, but based on underwater visual census (UVC) it appears likely fish gather from a relatively large area, probably exceeding one hundred kilometres in radius, since Galal (1999) estimated the population density of *L. nebulosus* along fished sections of the South Sinai coast at

no more than 1.5 fish per 2000 m². Long distance migration to spawning grounds is confirmed in other species. Carter (1989) recovered Nassau grouper individuals from up to 240 km from where they had previously been tagged during spawning aggregation. Spawners which migrate for long-distances will in particular require high amounts of energy to travel and develop gonads, energy which must come from either fat reserves or feeding.

Relatively little is known about the feeding habits of fish in spawning aggregations, whether fish actively feed at this time and to what extent any food consumption is important in supporting gonad growth. Rothschild (1986) suggested that the nutritional condition of spawners is the most important factor affecting reproductive output. MacDonald (1981) proposed that in general breeding fish sustain gonad development using fat reserves previously built up during periods of peak food availability. In support of this Ferreira (1995) observed an inverse relationship between fat-weight and gonad-weight in the Coral trout, *Plectropomus leopardus*, concluding that fat is probably consumed in the processing of gonad products. Conversely Fishelson et al. (1987) concluded that in surgeon fish gonad growth is not dependent only on fat reserves, since he measured a significant depletion in fat weight a long time before the spawning season. In the present study a strong correlation was observed between *L. nebulosus* feeding habits and gonad development during the late spawning period. Also it was noticed in studying specimens that fat structures around the gonads were very uncommon, suggesting that the fish utilise their fat reserves either during the early stages of gonad maturation or on migration from resident reef to the spawning ground. Thus the latest stages of gonad maturation may be largely dependent on food consumption on the spawning ground. Grimes, (1987) proposed that seasonal spawning tended to be correlated with food availability. Domeier & Colin (1997) attributed the limited spawning period of predatory fish to the lack of

sufficient food to support large numbers of fish at aggregation sites for a long period.

As its mentioned above, the correlation between the *L. nebulosus* feeding habits and spawning behaviour suggest that feeding may be important for completion of the spawning process. This feature might also be linked to the choice of Jackfish Alley as a spawning site. Its topography is unique among reefs in South Sinai, since while other nearby reefs are characterised by a very steep reef wall descending to considerable depth (>100 m), Jackfish Alley has a very wide reef terrace at a depth of 15 - 30 m. along the outer part of which is an elevated ridge with, as previously described, relatively high coral cover. These features could result in the site being the best area around the Ras Mohammed headland, in terms of surface area, for a large number of *L. nebulosus* to acquire sufficient food while also remaining in the vicinity of the point where strong currents divide between the Gulf of Aqaba and Gulf of Suez. Similar characteristics have been reported for some other traditional spawning aggregation sites. For example Aguilar-Perera & Aguilar-Perera (1996) reported that Nassau grouper traditionally spawn over a fore reef zone which has a patchy hard coral cover and extends seawards at a depth of 15 to 30 m for up to a 1000 meters, before dropping off in to deeper water. Similarly Colin (1992) found that along Long Island, Nassau grouper aggregate to spawn on reef shelf areas, ranging between 200 and 300 m in width, at depths of 18 to 30 m. Again, Shapiro et al. (1993b) and Colin et al. (1987) reported that the Red Hind, *E. guttatus*, spawn on a wide coral shelf, characterised by patchy hard coral cover, at a depth of between 20 and 30 m.

Spawning behaviour. Changes in gonad condition over the spawning season revealed that *L. nebulosus* spawn twice in each annual spawning season between mid-April and mid-June. The possibility that they might spawn at other times of

the year can not be excluded from the present study, since sampling and gonad histology only covered the Spring period. However, Sanders et al. (1984) found only one peak in gonad development, between April and June, in *L. nebulosus* sampled along the Egyptian Red Sea coast over whole year. He also concluded that they are a multi-spawner species, spawning over two very short periods of 6 to 8 days in two successive months. On the other hand Ebisawa (1990) found that *L. nebulosus* spawn regularly for short periods within a longer period, estimated at three months. However given that in the present study the spawning episodes could occur in April and May, or in May and June, depending on the timing of the lunar cycle, Ebisawa's conclusion may be an over-estimate. The duration of the spawning period is short compared to that observed in many other coral reef species, many of which in the Red Sea have an extended spawning season lasting from as early as February or March to as late as. By contrast even more restricted spawning has been reported for some other spawning aggregation species. Thus Tucker et al. (1993) and Aguilar-Perera & Aguilar-Perera (1996) found that *E. striatus* are sexually active for only three days before and after the full moon, with very little change from year to another. Similarly, Shapiro et al. (1993a) observed that in Puerto Rico the spawning duration of *E. guttatus* was restricted to only three days around the full moon.

Fecundity. Bagenal (1973) identified as a measure of the potential total fecundity the total number of yolked eggs in the ovary immediately before spawning. This measure can be applied if fish spawn only once a year, but for multi-spawner species, which release their eggs in pulses over the reproductive period, this measure could lead to an under-estimate of actual spawning potential. Hunter et al. (1985) suggested that the appearance in the ovary of different size groups of yolked oocytes is probably evidence of multiple or serial spawning. However in the present study, during the late spawning period, the partially spent female

gonads contained, alongside post-ovulatory follicles in various stages of vitellogenesis, oocytes in various developmental stages. Furthermore, changes in ova diameter frequency and frequency of oocyte growth-phases over the spawning period suggest that transformation in oocytes from a primitive growth stage to ovulation can occur over a relatively short period, estimated at as little as 10 to 12 days. These observations suggest that unyolked oocytes mature continually throughout the spawning season. Thus *L. nebulosus*, besides being multi-spawners, have an indeterminate fecundity, meaning fecundity can not be determined by a simple count of yolked eggs in the ovary. Instead this study suggests that it would be more accurate to estimate potential fecundity by counting all the oocytes in the ovary regardless their developmental stage. However, counts suggest that *L. nebulosus* is highly fecund, with larger fish having a much higher fecundity than smaller ones.

Histology. Histological study of the gonads demonstrated clearly that gametogenesis in *L. nebulosus* is similar to that typical among teleosts, with all of the oocyte developing-stages described by Wallace & Selman (1981) occurring during the process of maturation. Fish arrive at the spawning ground with gonads dominated by oocytes at the tertiary yolk globule stage, generally considered the most advanced growth phase. However, Liley & Stacey (1983) stated that some oocytes at the tertiary yolk globule stage may have developed and persevere within the ovary for a variable period of time prior to final maturation and subsequent ovulation. In the present study, growth from the tertiary yolk globule to the maturation stage occurred over only 4-5 days. In fact fully ripe oocytes were only infrequently seen, indicative of the speed of ripening, which Clarke (1987) found to occur over only a few hours prior to ovulation. Probably for this reason, associated with a relatively long sampling interval, Ebisawa (1990) failed completely to observe any oocytes at this late stage.

Sex ratio and sex determination. In the present study the *L. nebulosus* sex-ratio indicated a slightly higher proportion of males in the spawning population. However, there were slightly more females among the exploited portion of the population (> 45 cm), and correspondingly more males among the smaller size classes (45 cm). Such an effect could be the result of faster growth among females than among males. Grimes (1987) on the other hand suggested that such differences in population sex ratio and sex ratio at size are caused by differential mortality rates between sexes. In fact intensive fishing can lead to large shifts in population sex ratio. Thus Coleman et al. (1996) found that in a *Mycteroperca microlepis* population the proportion of males declined from 17 to 1 % over 20 years as result of intensive fishing. Similar effects have been reported for *Epinephelus guttatus* (Thompson & Munro, 1983) and *E. striatus* (Carter, 1989). This may occur either if males tend to be larger at age, or, in particular, where spawning aggregations are exploited, if individual males are present in the spawning aggregations for slightly longer or from an earlier age than females. The shift in *L. nebulosus* sex ratio with size in the present study seems most likely to be a consequence of fishing caused in this way.

Another possible explanation for the change in sex ratio with age would be that some fish change sex with age. Protogynous and protandrous hermaphroditism are common among reef fish. According to Ebisawa (1990) *L. nebulosus* exhibits juvenile hermaphroditism, with sex being determined at a size of 32 cm fork length. In the present study, however, there was no indication of bisexuality in the spawning population, the sexes being completely separated. Whether or not some juveniles in the Red Sea exhibit hermaphroditism can not be determined from the present study since relatively few specimens smaller than 35 cm in fork length were investigated.

Another possibility is that in the present *L. nebulosus* population sex change may occur among adults, after one spawning season is fully over and before the commencement of gonad maturation for the next. Smith (1965) and Chan et al. (1975) suggested that in protogynous fish, sex change normally occurs well outside the breeding season in order to prevent self-fertilisation. Also this would presumably be the easiest time for sex reversal to be initiated, at the time when gametogenesis is renewed. Munro & Williams (1985) suggested that selective removal of either sex in an exploited population may stimulate mechanisms controlling sex reversal. Thus Ferreira (1995) found that in *P. leopardus* sex reversal was more common among heavily exploited than among lightly exploited populations. Shapiro (1987) and Samoilyis & Squire (1994) have suggested that the social interaction among sexes that occurs within spawning aggregations may be an important opportunity for females to assess their future reproductive value, determining whether an individual stays as a female or reverses sex and in order to reproduce as a male in the following year. In the present study many of the fish caught from the breeding aggregation appeared to be unproductive individuals. This might have been individuals that were incidentally present in the same area. But an alternative explanation is that it pays these individuals to attend the spawning aggregation in order to assess the relative population balance of the two sexes.

Fishing interference with reproduction. Munro (1983) argued that, contrary to earlier dogma, fishing may, by decreasing the output from spawning, decrease population size, and Rothschild (1986) concluded that egg production during the spawning season can be strongly correlated with subsequent recruitment. This effect can be marked where spawning aggregations are exploited since fishing then removes the largest, most productive size classes (Bohnsack, 1990) and may dramatically alter the population sex ratio (Coleman et al., 1996). This study

suggests a further way in which fishing of spawning aggregation may decrease population size: histological examination demonstrated that the majority of the fish are caught before they have released any eggs, while the remainder are caught only partially spawned. This observation must heighten concern that exploitation of the spawning aggregations could result in failure of recruitment, collapse of the stock, and loss of the fishery for this species over a wide area.

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CHAPTER FOUR

**AGE, GROWTH, AND MORTALITY
OF SHOUR, *LETHRINUS NEBULOSUS*
FROM
RAS MOHAMMED, NORTHERN RED
SEA, EGYPT.**

ABSTRACT

Age and growth of *Lethrinus nebulosus* from the Ras Mohammed breeding stock and from a nearby control reef (Al-Konysa) were investigated. Age determination was based on interpretation of otoliths, scales, and length frequency data. Rings on otolith sections were readable in most samples examined, and determined to be formed annually. Age data indicate that *L. nebulosus* is a long-lived, slow-growing species; the oldest fish was aged 19 years and measured 65 cm in fork length. Back-calculated mean lengths-at-age were estimated to be 14, 24, 30, 35, 39, 42, 45, 48, and 50 cm fork length for ages 1 to 9 respectively. Shour are recruited to the spawning stock and thus to the fishery at an age of four, but the spawning population was dominated by fish aged 6-8 years. The length-weight relationship was best described by a power regression equation with a and b values of 0.023 and 2.92 respectively. Mean condition factor (K) was estimated at 1.78 but was found to change slightly with body size. Growth in weight was highest during the first four years, slowing thereafter. The growth parameters of von Bertalanffy's growth equation, obtained using several different methods, were asymptotic length (L_{∞}) = 62 - 82 cm, growth coefficient (K) = 0.14 - 0.22, and t-zero (L_0) = - (0.5 - 0.8). Total and fishing mortalities both increased markedly between 1995 and 1998, with exploitation ratio estimated to be 0.47 by 1998.

INTRODUCTION

The most valuable fishery information that can be obtained from catch specimens are age and growth parameters. This information is the basis of many well-established fish stock assessment methods. In addition, such information is helpful understanding the biology and life history of an exploited fish population (Bagenal, 1974). Three main techniques have been widely used in fish age determination: length frequency analysis, tag-recapture methods and counting of annual rings in fish hard parts (Jones 1976, Ricker 1979). Using a combination of these three methods to determine age and growth increases the accuracy of estimates, and consequently, allows for a better interpretation of a stock's population dynamics, especially among tropical fish species (Pauly & Morgan 1987).

There has been much interest in using length-frequency based methods to assess a stock's population dynamics especially among tropical fish species. Bhattacharya (1967) established a statistical method for separating a single length frequency data set in to age classes by determining likely growth modes. More recently Pauly (1987) developed another technique for obtaining age and growth parameters based on relating growth modes in sets of length-frequency measurements sampled at intervals. This method was subsequently computerised (ELEFAN software) and has become one of the most widely used methods for ageing and obtaining the growth parameters of tropical fish species.

Until the late sixties attempts to age coral reef fish by examination of their hard parts had not achieved the success achieved with temperate species (Panella 1980, Longhurst & Pauly, 1987). This failure occurred because most tropical fish species do not produce annual rings, a phenomenon attributed to the fact these fish do not experience marked variation in water temperature between seasons and so

generally grow continuously through the year (Pannella 1980, Brothers 1987). Formation of annuli rings in fish hard structures had been attributed to either seasonal variation in ambient temperature or physiological changes during the reproductive cycle. Beckman & Wilson (1995) demonstrated that, in temperate fish species, deposition of opaque zones in otoliths is controlled by seasonal changes in ambient temperature rather than by reproductive cycles. Recently, similar conclusions have been reached for many reef fish species in different tropical areas: Lutjanidae (Johnson 1983; Mason & Manooch, 1985; and Morales-Nin & Ralston 1990), Scaridae (Lou, 1992), Serranidae (Ferreira & Russ, 1992; Hood & Schlieder, 1992), Holocentridae (Dee & Radtke, 1989), Sparidae (Smale & Punt, 1991; Both & Buxton, 1997), Pomacentridae, (Fowler, 1990), and Lethrinidae, (Morales-Nin 1988).

The Shour, *L. nebulosus* (Forsskal, 1775) is one of the most valuable species (in terms of total catch) in the family Lethrinidae. It is distributed throughout the Indo-Pacific, being recorded in the Red Sea, Persian Gulf, East Africa, southern Japan and Australia. The juvenile stages inhabit either seagrass beds or mangrove stands before moving to coral reef areas (Fishbase, 1997). *L. nebulosus* feeds on echinoderms, molluscs and crustaceans. Because of its carnivorous feeding habits, it is very vulnerable to handline fishing (Fishbase, 1997).

Despite the ecological and economical importance of *L. nebulosus* only a few studies have examined their biology and population dynamics. Morales-Nin (1988) studied the age and growth of *L. nebulosus* in New Caledonia using otoliths, Ezzat et al. (1992) investigated age and growth of fish in Arabian Gulf waters using fish scales, and Ebisawa (1990) studied the reproductive behaviour of *L. nebulosus* in Japan.

In the Egyptian Red Sea, large *L. nebulosus* spawning aggregations occur during May and June every year at locations well-known to local fishermen. These have been heavily targeted during the last ten years. Accordingly, information on the age and growth of the breeding stock has become essential in order to assess the effects of exploitation on their stock size and population dynamics. Thus age and growth parameters of *L. nebulosus* from the Ras Mohammed breeding stock were determined using population length-frequency analysis and measurements of otolith and scales. Subsequently total, natural and fishing mortalities and so exploitation ratios were estimated using a number of different mathematical models.

METHODS

Sampling

A total of 719 *L. nebulosus* fish specimens were used in the estimation of age and growth parameters. These specimens were obtained from two sources in South Sinai during the period May 1995 to May 1997. The first source was the Ras Mohammed *L. nebulosus* spawning stock, where specimens were collected during the 1995 to 1997 fishing seasons (N = 450). These specimens represented the adult size classes, which ranged in fork length between 28 and 65 cm. Since no smaller individuals were present or caught at Ras Mohammed, a second source of specimens was used. This was the Al-Konyasa fishing ground, which is the nearest reef associated fishing ground to the Ras Mohammed National Park. It is located in the Suez Gulf (27°56' N and 33°53' E) 30 km north of Ras Mohammed. Samples from El-Konyasa were collected seasonally between May 1996 and May 1997. These specimens represented the immature *L. nebulosus* size classes, ranging in fork length between 10 and 30 cm (N = 269). The Ras Mohammed specimens were caught using handlines from depths between 5 and 40 meters. The Al-Konyasa specimens were caught using a combination of handlines and trammel nets at depths between 1 and 15 meters.

Age determination

Specimens were first examined in fresh condition within a maximum of two hours after removal from the reef. Each was weighed and measured to the nearest gram and 0.5 cm of fork length. All mature specimens were also sexed.

a- Using otoliths

Otoliths (sagittae) were removed by carefully cracking the ventral side of the fish skull using a sharp pair of pliers, and picking out the otolith using pointed tweezers. Otoliths were washed in fresh water, dried at 60 °C for 24 hours,

weighed to the nearest 0.0001 gram and stored in labelled plastic bags. A thin transverse section passing through the otolith core was examined. This was achieved by first grinding the otolith anterior apex to the nuclei horizontal plane using a series of increasingly fine grade carborundum sand papers (800, 1000 and 1200). Then the ground otolith was embedded in a drop of polyester resin on a microscope slide with the ground side facing the glass surface. Then after 15 hours hardening the posterior apex was also ground to the nuclei plane. The section was checked regularly during grinding using a light microscope until best resolution had been obtained. All grinding was undertaken in wet conditions using a controlled speed rotating grinding disk.

When otolith sections were studied using a compound microscope they showed very clear growth rings. The contrast between opaque and hyaline zones increased when a drop of clarifying medium (Clove oil) was placed over the otolith section. For each section the number of continuous annual rings (opaque bands) were counted. The counts were independently repeated after three months. When the estimated age differed by one year only, the section was studied carefully again. Sections for which estimates showed two years or more difference were discarded. For a subsample of sections (N= 100) the distances between the centre of the otolith nuclei (nucleus) and the distal edges of each ring were measured using an eyepiece micrometer. All measures were taken along the line between the otolith nuclei and the upper side of the otolith sulcal wall. The relationship between *L. nebulosus* fork length and otolith radius was thus obtained. The fish fork lengths at the end of each year were back-calculated based on Bagenal & Tesch's (1978) formula:

$$L_t = R_t / R (L - a) + a$$

Where R_t and R are the annulus and total otolith radius respectively,

L_t and L are the back-calculated length at the time of annulus formation and the measured fish length respectively, and

a is the correction factor (intercept obtained from the regression equation of fish fork length on otolith radius relationship).

Use of *L. nebulosus* otoliths for age determination was validated by estimating the seasonal marginal increments for each size class. This was done by measuring the distances between the last annulus and the upper margin of the otolith section. The seasonal marginal increment was estimated as the percentage of new growth compared to the distance between the last two annuli. Also the frequency distribution of nucleus-to-ring distances was analysed.

B- Scales

From each fish specimen approximately 20 scales were removed from the pectoral areas. These scales were washed in fresh water, then placed in 7% potassium hydroxide solution for one hour to remove soft tissues. Scales were then washed in fresh water again and dried. From each fish specimen six well-developed scales were chosen and pressed between two microscope slides, the slide ends being sealed using transparent cellotape. The scales were studied using a transmitted light microscope. The growth rings were counted, and the distances between scale nucleus and each ring measured. The relationship between scale radius and fish fork length was obtained. Fork lengths at the end of each year were back calculated as described above.

C- Using length frequency

Four sets of *L. nebulosus* length measurement obtained during the 1995, 1996, 1997 and 1998 fishing seasons were converted to age structures. This was done

using the Bhattacharya (1967) analysis routine in the FAO-ICLARM Stock Assessment Tools (FISAT) package (Gayanilo & Pauly, 1993) by which means the *L. nebulosus* length frequency measures were decomposed to normally distributed age groups or cohorts. Decomposing was initiated at the left-side of the measured population, and progressed towards the large size classes as far as possible. Adjacent age classes were split when the difference in their respective age class-size means was more than double the mean of the standard deviations for each of these two groups (Hasselblad 1966, Clark 1981). Fish in the samples used ranged in fork length between 28 and 68 cm. Samples of the smaller fish were not used in a Bhattacharya analysis since the length available had not been randomly obtained.

Growth parameters

The *L. nebulosus* von Bertalanffy growth parameters (L_{∞} , K and L_0) were estimated using both length-frequency measurement and length-at-age results. The yearly length frequency measurement as well as all measurement combined together were used as input data in Powell-Wetherall routine in the FiSAT software package (Gayanilo & Pauly, 1993). Using the least squares regression analysis method, length-at-age results were used as input data in the von Bertalanffy growth function model in the FiSAT software package. Growth parameters were estimated by applying the length-at-age data to the von Bertalanffy (1934), Gulland-Holt (1959), and Ford-Walford (1946) models.

a- Length frequency based method

Powell-Wetherall method

This method was established by Powell (1979), developed by Wetherall (1986), and later computerised by Gayanilo & Pauly, (1993). Powell (1979) and Wetherall (1986) measured a positive linear relationship between the mean lengths and the cut-off lengths of catch sub-samples (cut-off length is length not smaller than the

smallest length and fully represented in the catch samples). The asymptotic length and the ratio of the coefficients of the total mortality (Z) and growth (K) can be obtained from this linear relationship using the following formulas:

$$L_{\infty} = a / (1-b)$$

and

$$Z/K = b/(1-b)$$

where a and b are the intercept and the slope of the straight line respectively, and estimated using the following formulas:

$$a = L_{\infty} / [1+(Z/K)]$$

and

$$b = (Z/K) / [1+(Z/K)]$$

b- Length-at-age based method

The length- at-age data obtained from otolith reading were fitted to three different plot models to estimate the *L. nebulosus* growth parameters.

von Bertalanffy plot, this method was introduced by von Bertalanffy (1938) to estimate the coefficients of the growth (K), and theoretical length at age zero (t_0). While it requires an estimate of asymptotic length (L_{∞}) as input parameter. the von Bertalanffy plot using the following formula were used

$$-\ln(1-L(t)/L_{\infty}) = K * L_0 + K * t$$

Where L(t) is fish length at time t.

L_{∞} is maximum observed length

The Ford-Walford plot, following a series of algebraic manipulations Walford (1946) transformed the original von Bertalanffy growth equation to the following formula:

$$L(t+\Delta t) = a + b L(t)$$

where $a = L_{\infty} (1-b)$

and $b = \exp(-k \Delta t)$

While the growth parameters are obtained from:

$$K = -1/\Delta t \ln b$$

and $L_{\infty} = a/1-b$

Gulland and Holt plot, this method was introduced by Gulland & Holt (1959) to estimate the growth parameters using growth increments data, depending on the fact that growth rate decrease linearly with length reaching zero at L_{∞} . The Gulland and Holt plot is based on the following equation:

$$\Delta L/\Delta t = a + b L(t)$$

where $K = -b$ and $L_{\infty} = -a/b$

The weight- length relationship

A total of 1226 fish samples were used to obtain a weight-length relationship for *L. nebulosus*. These samples represented a wide range of fish sizes and weights, with fork lengths ranging between 10 and 65 cm., and total weights between 19 and 5032 grams. The measurements were applied to a power regression analysis to estimate values of the parameters a and b in the well-established weight-length relationship:

$$W = aL^b \quad (\text{Beckman, 1948}).$$

The constants were obtained for the sexes combined as well as for each sex separately. Also, the relationship was estimated between gutted weight and fish fork length. Weight and length measures were logarithm transformed and the constants of the straight-line relationship estimated.

The condition factors

The degree of well-being of *L. nebulosus* was investigated using the length-weight information. by calculating Fulton's condition factor (**K**):

$$K = 100 W/L^3 \quad (\text{Bagenal \& Tesch , 1978}).$$

Changes in condition factor with body length were thus obtained. The condition of *L. nebulosus* was also investigated by calculating the relative coefficient of condition (K_n):

$$K_n = W / W'$$

Where W is the observed weight.

W' is the weight estimated using the weight-length relationship.

Mortalities

Estimation of mortality is essential for fish stock assessment. Total mortality (**Z**) is the sum of fishing (**F**) and natural (**M**) mortalities ($Z = M + F$).

Total mortality

Three different methods were used to estimate the total mortality coefficient (**Z**) of the *L. nebulosus* population: a) the length converted catch curve (Pauly, 1984 a; b and Sparre, 1990), b) the mean length method (Beverton & Holt, 1956), and c) the maximum age model (Hoenig, 1982). In each case the length-frequency data and growth parameters were input to the mortality estimate routine in the FAO-ICLARM Stock Assessment Tools (FISAT) package (Gayaniilo & Pauly, 1993).

A- Length converted catch curve.

This method was established by Pauly (1983) and is based on converting fish length frequency measures to age structure using the von Bertalanffy growth

parameters. Conversion of length measures to age structure is based on the following equation:

$$\ln (N_i / \Delta t_i) = a + b t_i$$

Where N is the number of fish in length class i .

Δt_i is the time needed for the fish to go through length class i .

t_i is the age corresponding to the mid length of class i .

b is an estimate of total mortality coefficient.

The yearly length-frequency data sets of *L. nebulosus* as well as the pooled data were converted to age-catch data using the total mortality estimate routine in the FAO-ICLARM Stock Assessment Tools (FISAT) package (Gayaniilo & Pauly, 1993). The yearly total mortality coefficients were then obtained by fitting a regression line to the right hand descending limb of each curve. As described by Pauly (1983), the highest and lowest age class points can not be included in the analysis because the highest point is usually not fully recruited to the fishery, while the age of the fish represented by the lowest point is uncertain because they are very close to L_∞ .

B- Total mortality from mean length.

The total mortality of *L. nebulosus* was estimated by applying the mean length of the length-frequency measurement to two models: Beverton & Holt (1956) and Ault & Ehrhardt (1991). Beverton & Holt (1956) established a relationship between total mortality coefficient and the mean length of the exploited portion of a fish stock as follows:

$$Z = K (L_\infty - L) / (L_\infty - L')$$

Where K and L_{∞} are the fish growth parameters.

L is the mean length of the catch greater than of L' .

L' is the cut -off length.

Ault & Ehrhardt (1991) similarly established a model for estimating total mortality depending on the fish growth parameters, mean length of exploited portion and maximum length. The model is:

$$(L_{\infty} - L_{\max} / L_{\infty} - L')^{2/k} = Z (L' - L) + K (L_{\infty} - L) / Z (L_{\max} - L) + K (L)$$

Where K and L_{∞} are the growth parameters.

L is the mean length in the catch above of L' .

L' is the cut -off length.

L and L' estimates were obtained from length-frequency data for each year independently and for all data pooled.

Natural mortality.

Two methods were used to estimate natural mortality: Pauly's multiple regression model (1980) and Rikhter & Efanov's (1976). Based on a review of detailed studies on different species, Pauly (1980) derived a general relationship between fish natural mortality, the von Bertalanffy growth parameters and ambient habitat mean water temperature:

$$\ln M = -0.0152 - 0.279 \ln L_{\infty} + 0.6543 \ln K + 0.463 \ln T$$

Where M is the natural mortality coefficient,

L_{∞} and K are the von Bertalanffy growth parameters, and

T is the mean annual surface water temperature in which the stock lives.

Based on Morcos, (1970) the mean surface water temperature for the study area was taken to be 24.4 C°.

Based on Morcos, (1970) the mean surface water temperature for the study area was taken to be 24.4 C°.

Rikhter & Efanov also developed a model to estimate fish natural mortality (M) based on the relationship between natural mortality and age at first sexual maturity:

$$M = 1.521 / (T_{\text{mass}}^{0.72}) - 0.155$$

Where M is the natural mortality coefficient, and

T_m is the age at massive maturity.

Based on the study of *L. nebulosus* reproductive biology (chapter three), age at first maturity applied to Rikhter & Efanov's model was taken as four years.

Fishing mortality (F)

Fishing mortality provides a value for the level of depletion in a fish stock that results from fishing activities. Yearly *L. nebulosus* fishing mortality coefficient was estimated indirectly by subtracting the natural mortality coefficient from the estimated total mortality coefficient.

Exploitation ratio (E)

The exploitation ratio is the ratio between fishing mortality coefficient (F) and total mortality coefficient (Z), which is equal to the fraction of the stock taken by fishing activities over time. Gulland (1971) suggested that for sustainability of an exploited fish stock fishing, mortality should be no more than equal to natural mortality. This corresponds to an exploitation ratio ($E = F / Z$) of 0.5. Annual and overall exploitation ratios of the *L. nebulosus* stock were calculated.

Relative Yield per Recruit and relative Biomass per Recruit

The present status and sustainability of the *L. nebulosus* spawning stock under the current level of exploitation were assessed. The *L. nebulosus* asymptotic length (L_{∞}), coefficients of growth (K), natural mortality (M) and length at first capture (L_c) were used as input data to the relative Y'/R and B'/R analysis model routine in the FAO-ICLARM Stock Assessment Tools (FISAT). This routine is developed by Pauly (1984) based on Beverton & Holt, 1966) model, and computed based on the following model:

$$Y'/R = EU^{M/K} [1-3U/(1+m) + 3U^2/(1+2m)-U^3/(1+3m)]$$

where $U=1-(L_c/L_{\infty})$

$$m = (1-E)/(M/K) = (K/Z)$$

$$E = F/Z$$

while the relative biomass per recruit is estimated from the following relationship:

$$B'/R = (Y'/R)/F$$

RESULTS

Ageing of fish

Otolith Analysis.

Otoliths were examined from a total of 719 *L. nebulosus* specimens, ranging in fork length from 10 to 65 cm. The *L. nebulosus* otolith is elongate in shape and white in colour. It is concave towards the ventral side, with a pointed anterior apex and semi-rounded posterior apex. It has a well-developed depression, the sulcal, that runs from the anterior apex to almost the posterior apex. The sulcal is narrow at its posterior end, but gets wider toward its anterior apex. The *L. nebulosus* whole otolith showed clear annual rings when examined by light microscope with dark background. The first five rings were easily counted, but moving towards the outer margin the rings became very close to each other and so unreadable.

The *L. nebulosus* otolith weight ranged between 0.03 and 0.42 gram, and otolith radius (distance between the otolith nucleus and the dorsal edge) between 0.50 and 2.23 mm. The relationships between *L. nebulosus* fork length and otolith weight and otolith radius are shown in figures 1 and 2. The relationships were highly significant and best described by linear regressions analysis represented by the following equations:

$$\text{FL} = 14.764 + 136.19 (\text{OW}) \quad (\text{Rsq} = 0.90, \text{P} < 0.001)$$

Where **FL** is fish fork length, and

OW is fish otolith weight.

and:

$$\text{FL} = -5.8637 + 31.0159 (\text{OR}) \quad (\text{Rsq} = 0.91 \text{ P} < 0.001)$$

Where **FL** is the fish fork length

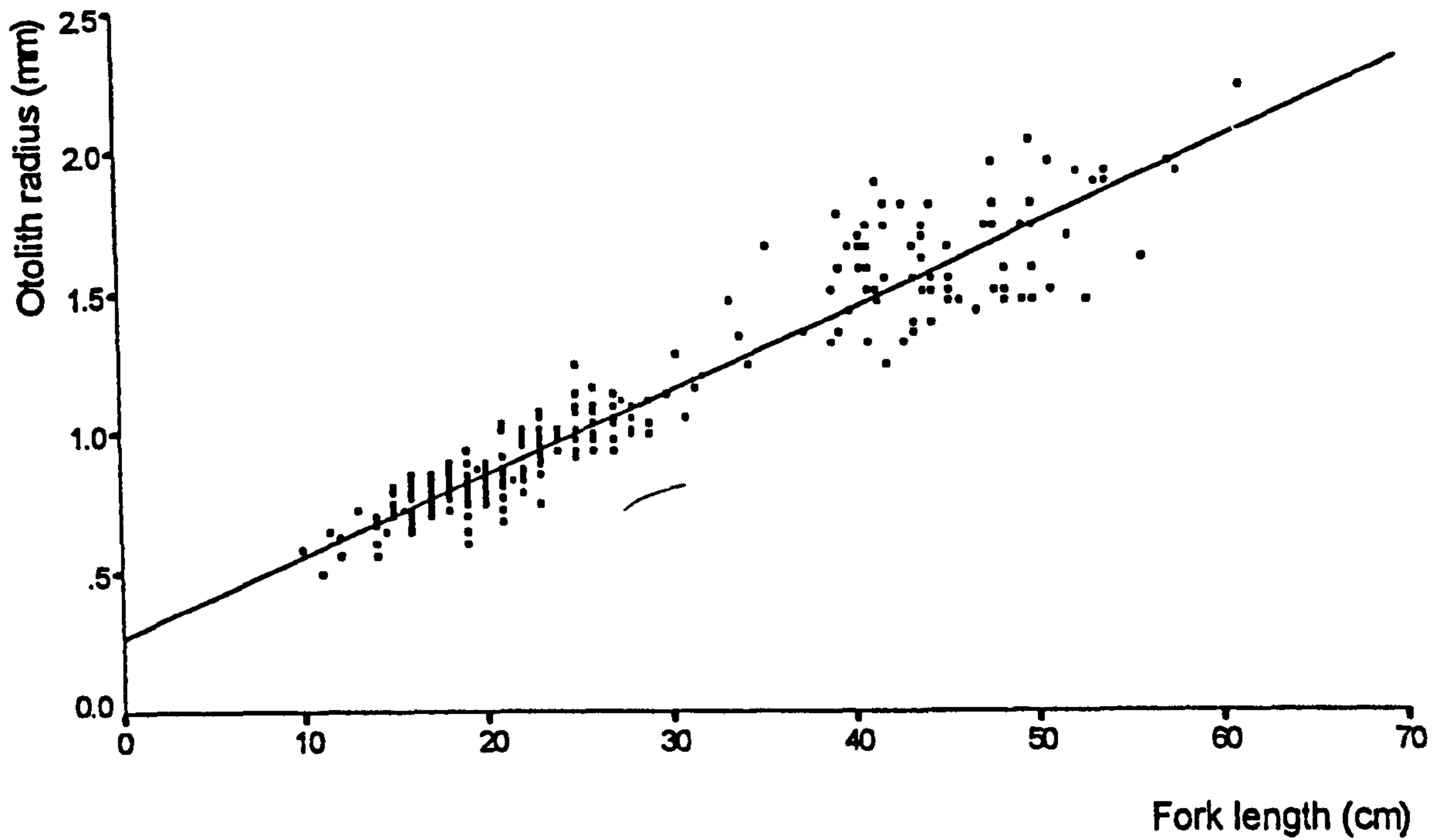


Figure 1: Relationship between *L. nebulosus* fork length and otolith radius.

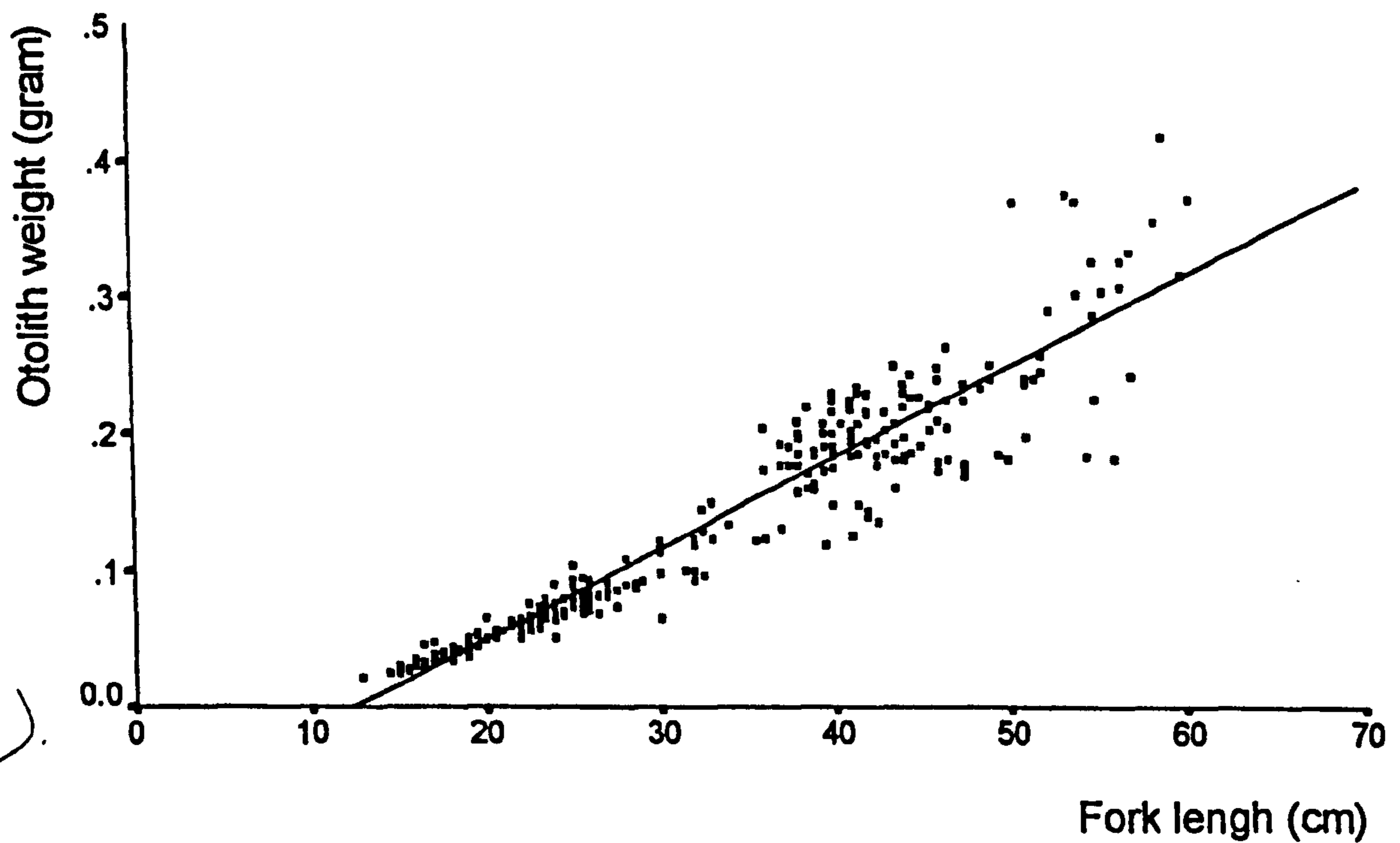


Figure 2: Relationship between *L. nebulosus* fork length and otolith weight.

OR is the fish otolith radius.

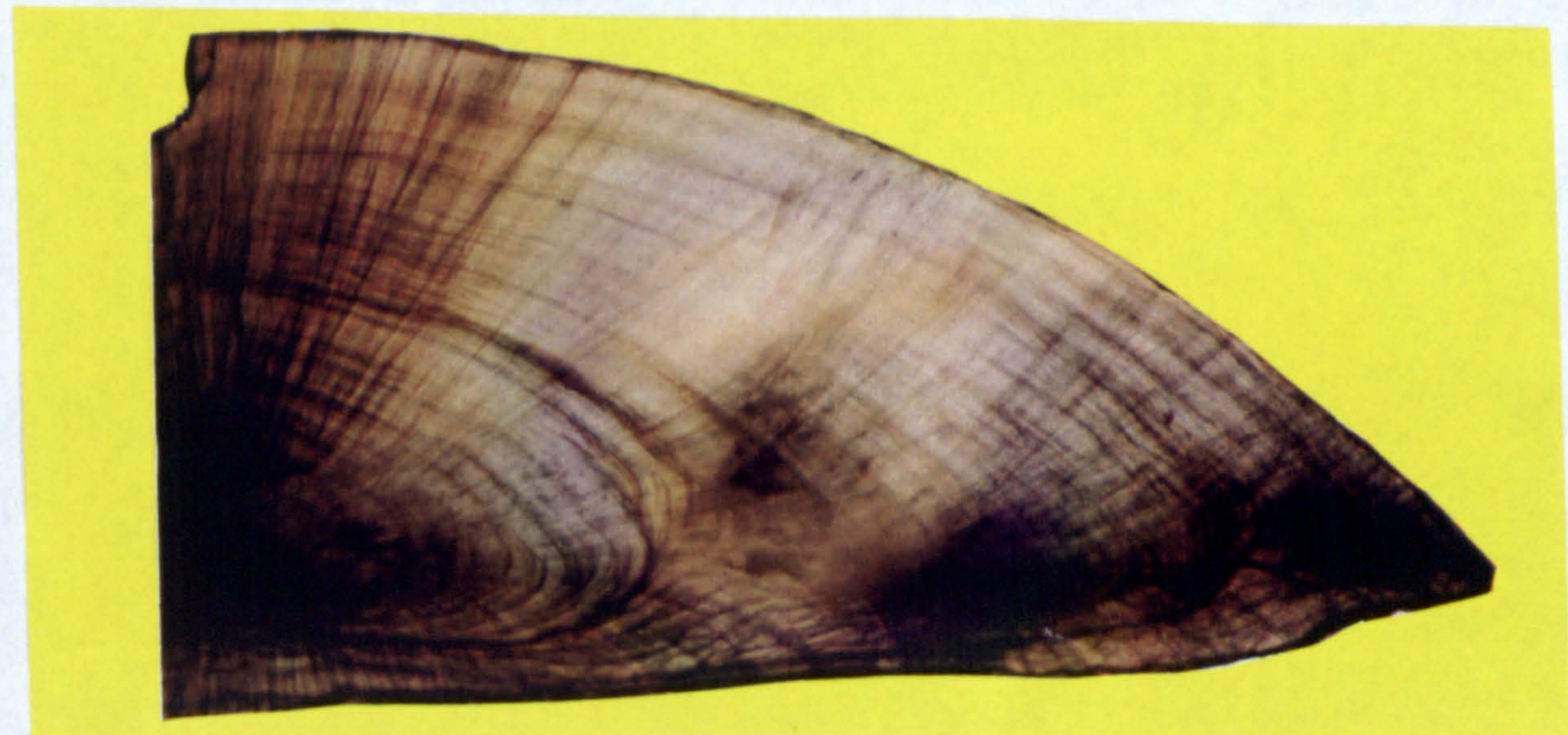
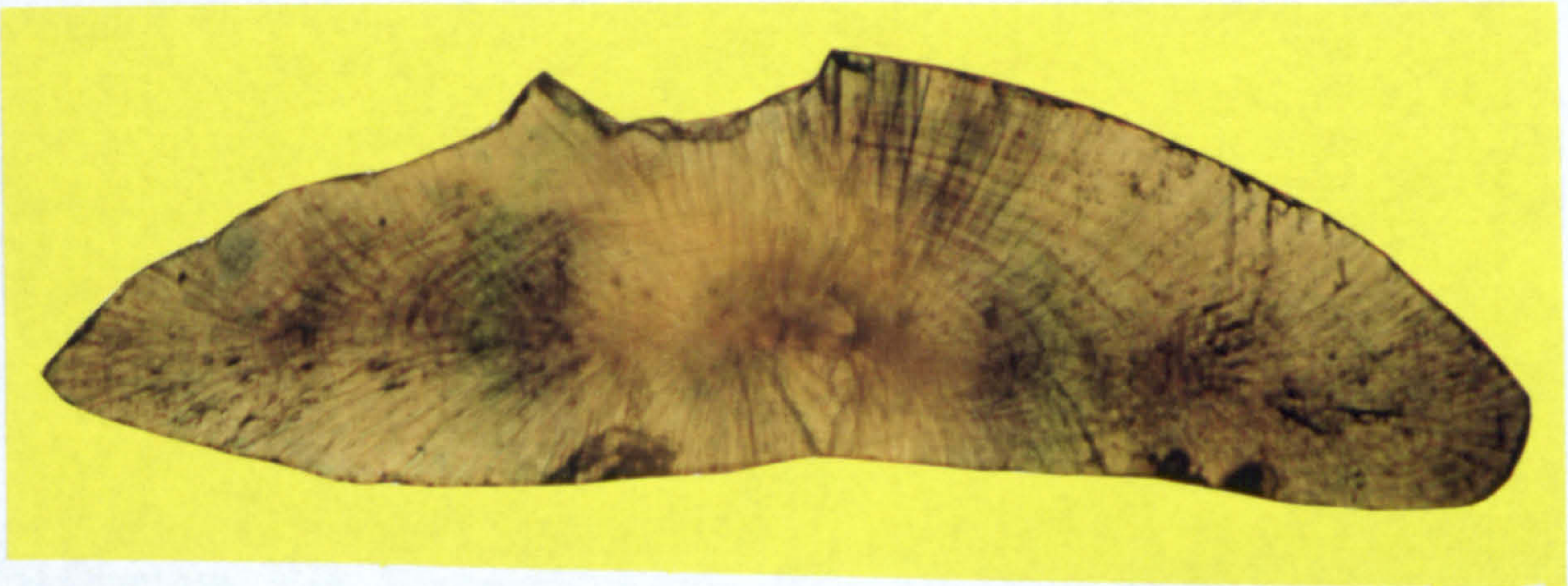
Variation in otolith weight and radius were greater among large size classes (>50 cm) than among smaller sizes.

The otolith sections showed clear growth ring formations, varying in number between 0 and 19. Opaque zones were thin, continuous around the entire sections and separated by wider hyaline bands (see figure 3). Fish smaller than 13 cm (N = 9) in fork length did not shown any sign of opaque zone formation. Samples with more than eleven rings were infrequent, and constituted less than 0.9 % of the total studied samples; therefore, these were excluded from the growth curve estimate. The most frequent number of rings was six, which the number present in 178 specimens. The relationship between fork length and number of counted rings (age) is shown in figure 4.

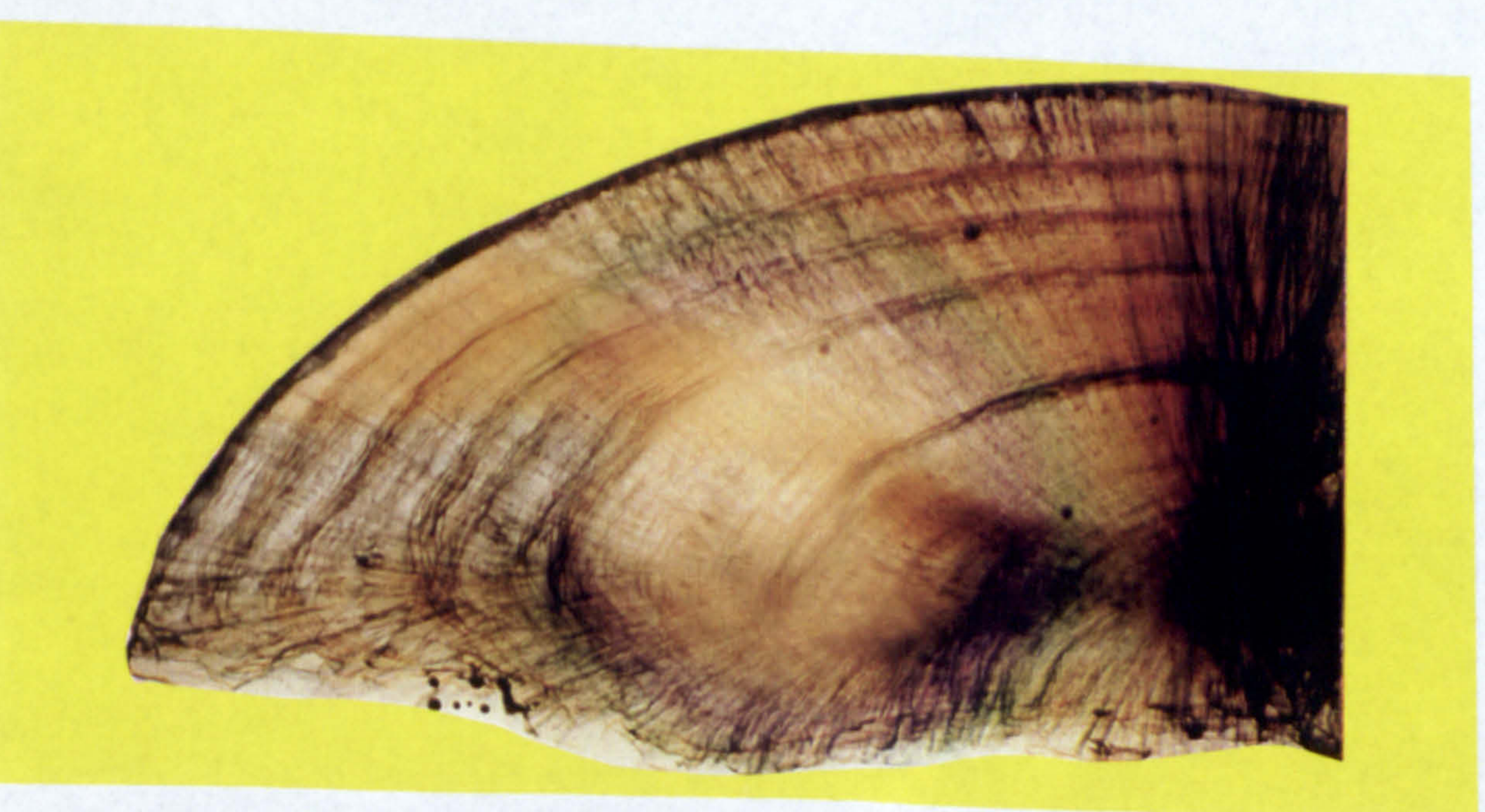
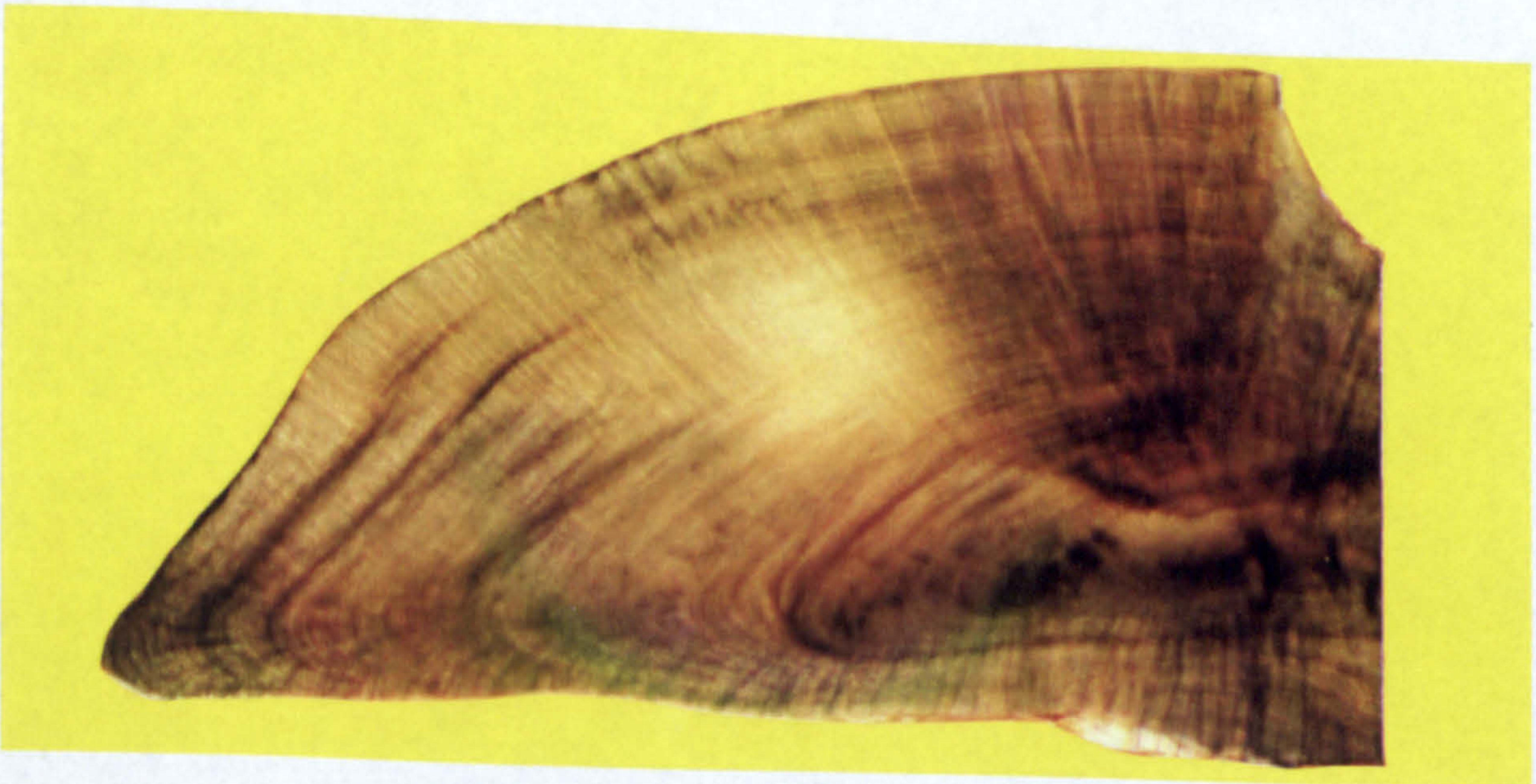
The *L. nebulosus* length-at-age estimates obtained from direct otolith reading and back-calculated length at time of annulus formation are summarised in table 1, and graphed in figure 5. The mean fork length at the time of each annulus formation was back-calculated. Generally, *L. nebulosus* growth rate appears relatively fast during the first four years, and declines gradually thereafter. Yearly observed growth-increment rates were 13.3, 6.5, 6.6 and 11.3 cm for ages 1, 2, 3 and 4 years respectively. For ages 5 and 6 growth increments were 3.8 and 2.4 cm respectively. The back-calculated length at age varied slightly from the observed measures, especially in the smaller sizes. These differences could result from the fact that the smaller size classes (immature) were obtained from a different reef area, while the larger sizes were (breeding stock) were obtained from the spawning population at Ras Mohammed and likely to be gathered from a very wide area, over which mean growth rate of young fish could have been different. The

Figure 3: Otolith cross-sections from *L. nebulosus* viewed in transmitted light.

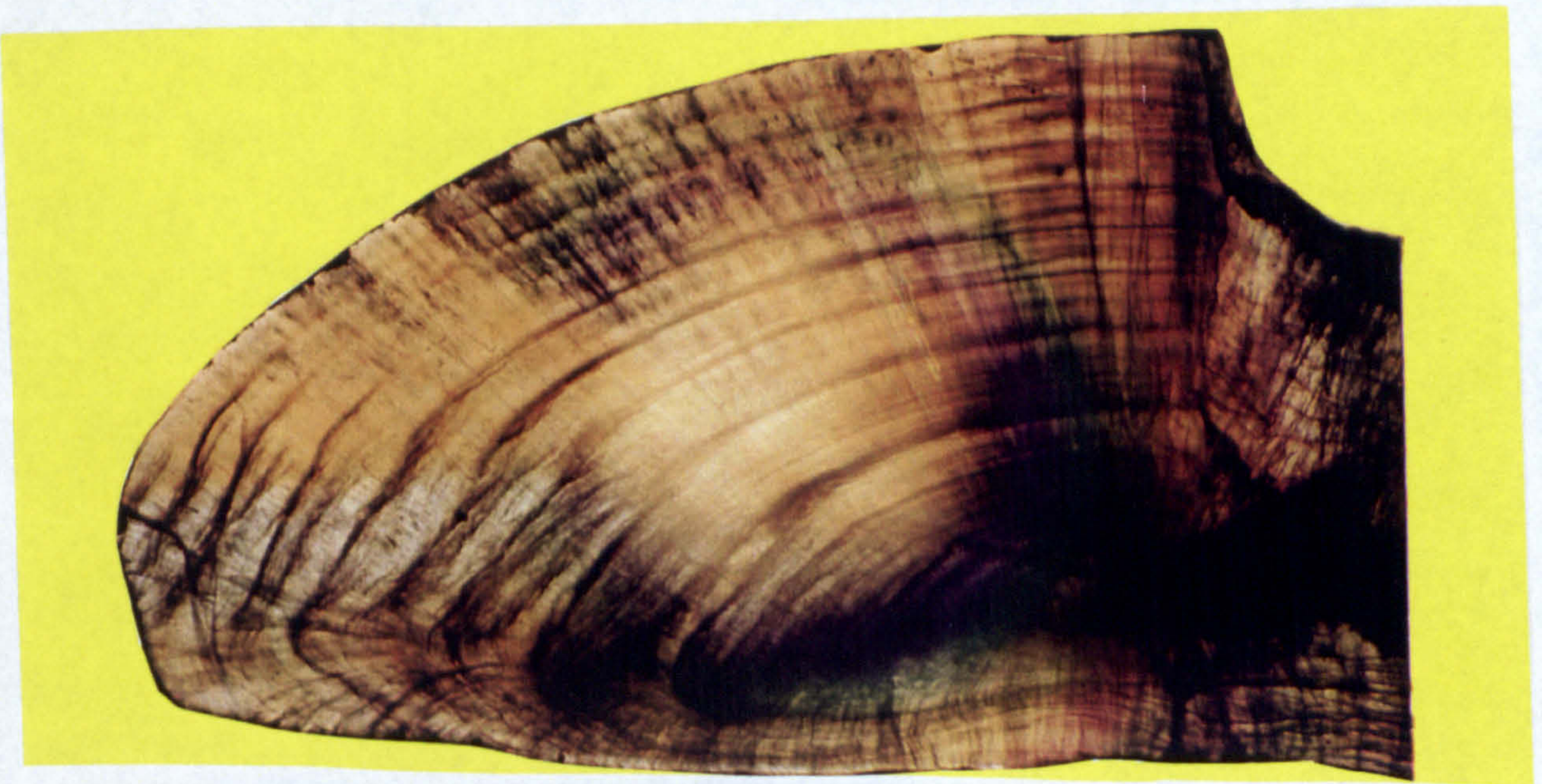
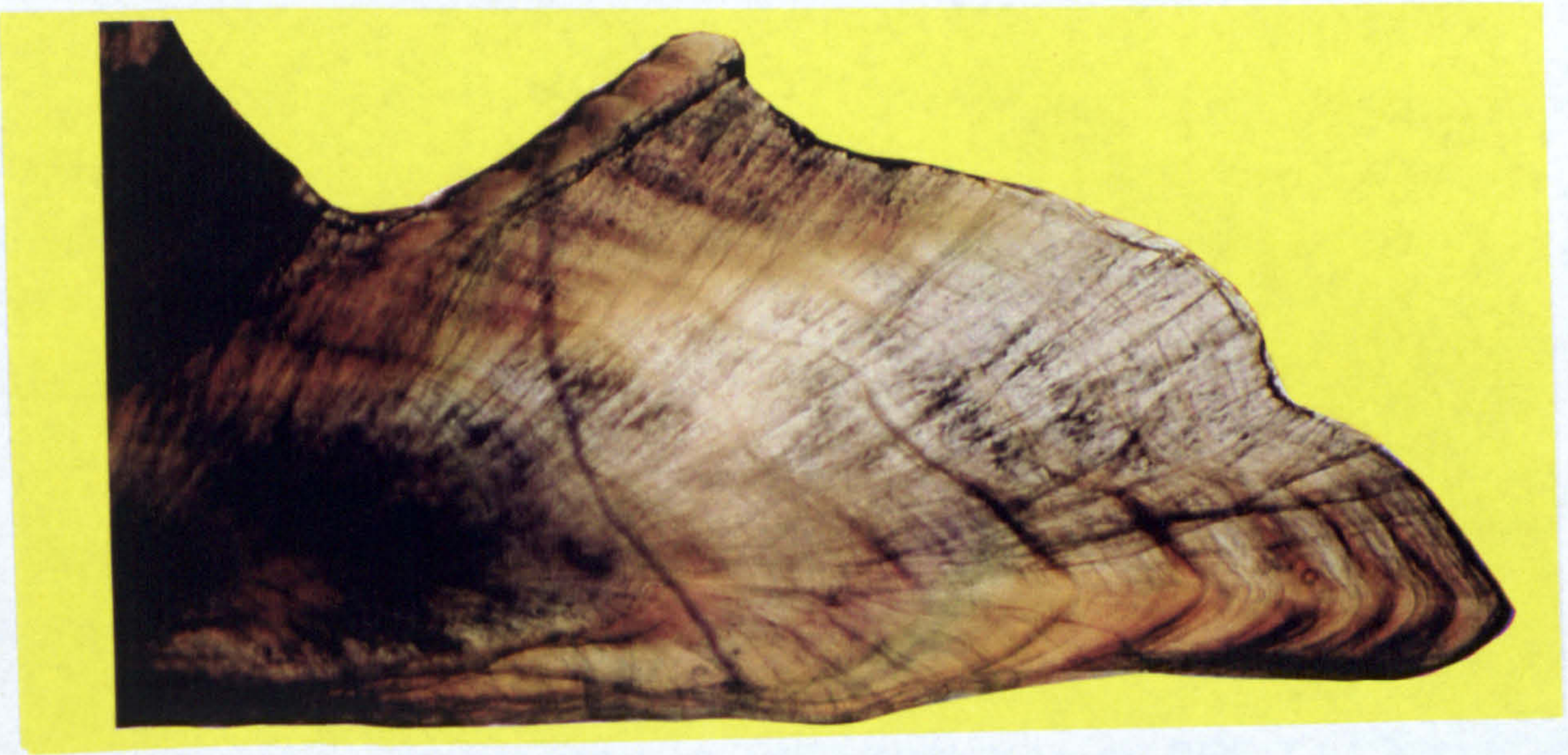
Sections are arranged in ascending order from -1 to +9 years.



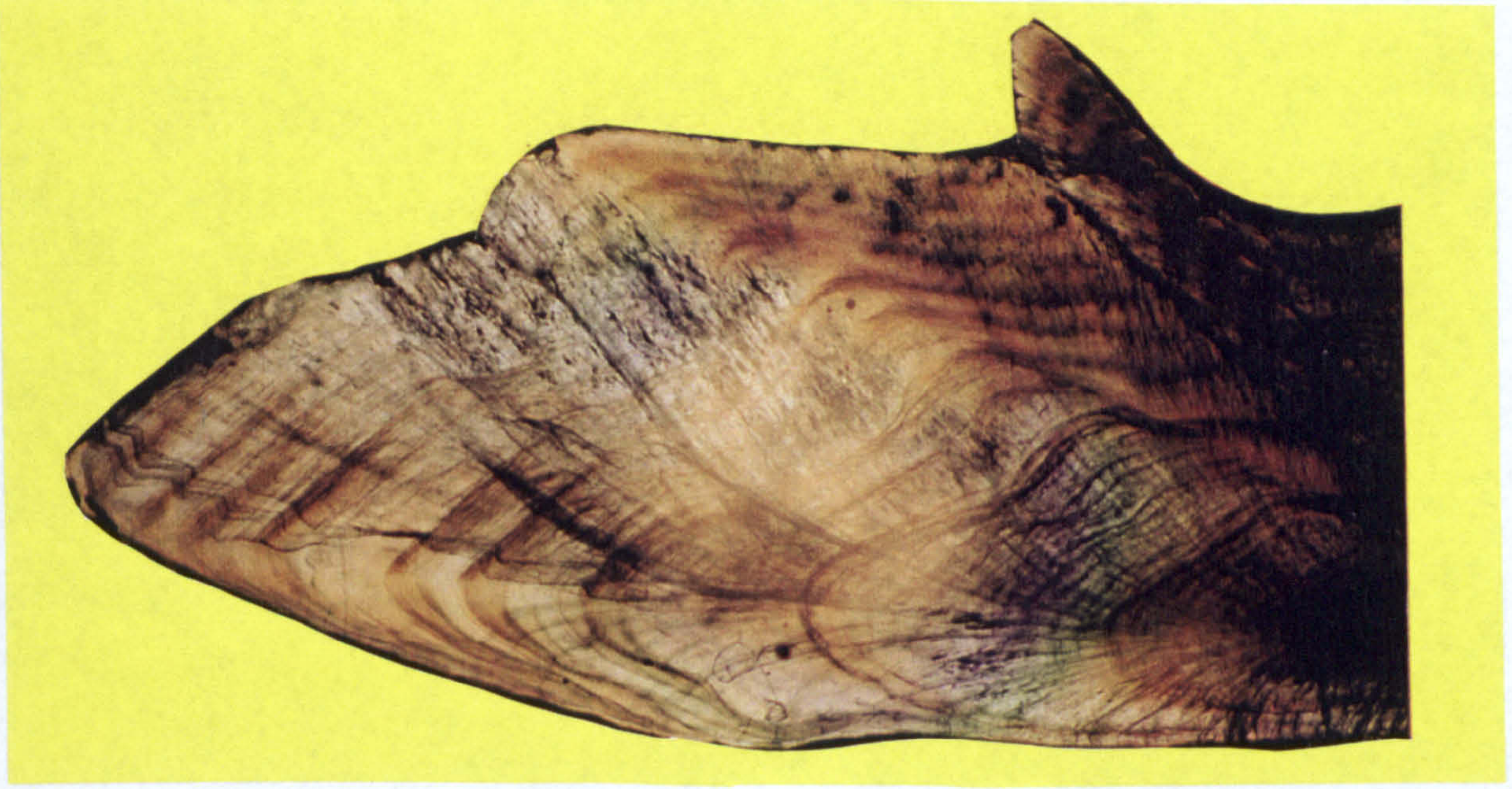
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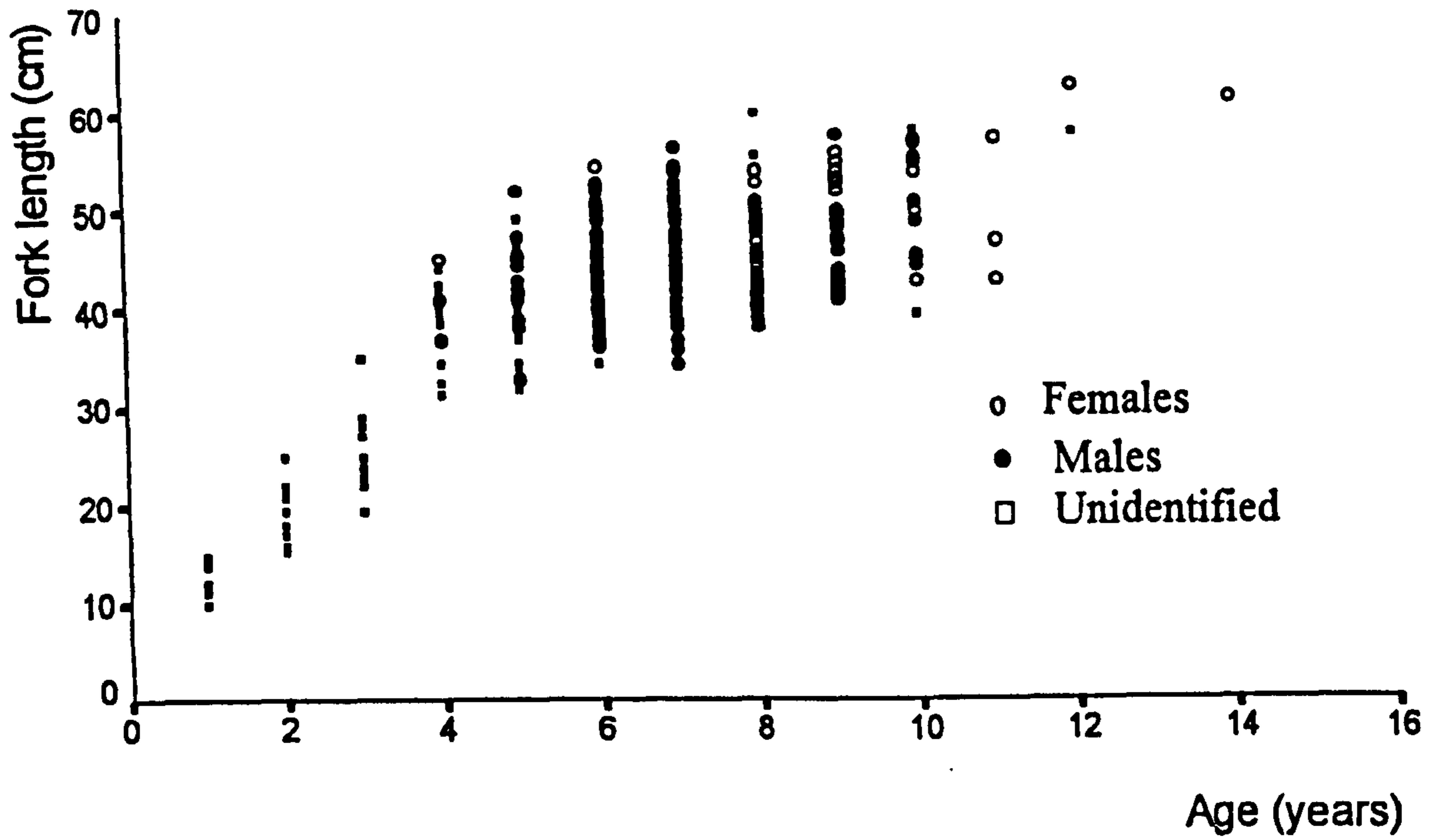


Figure 4: Relationship between *L. nebulosus* fork length and age, data based on otolith reading.

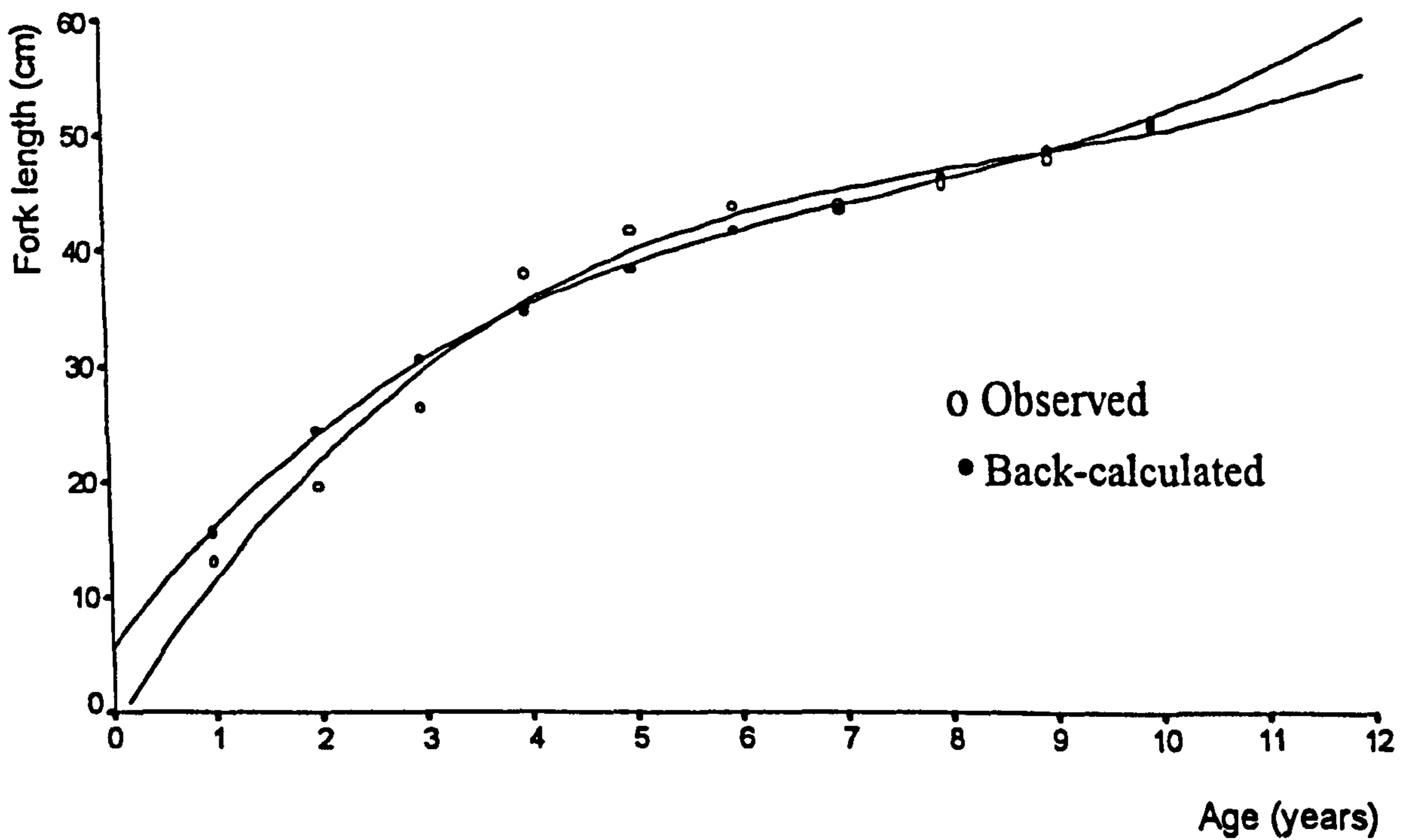


Figure 5: Relationship between *L. nebulosus* observed and back-calculated fork length and age, estimate based on otoliths reading.

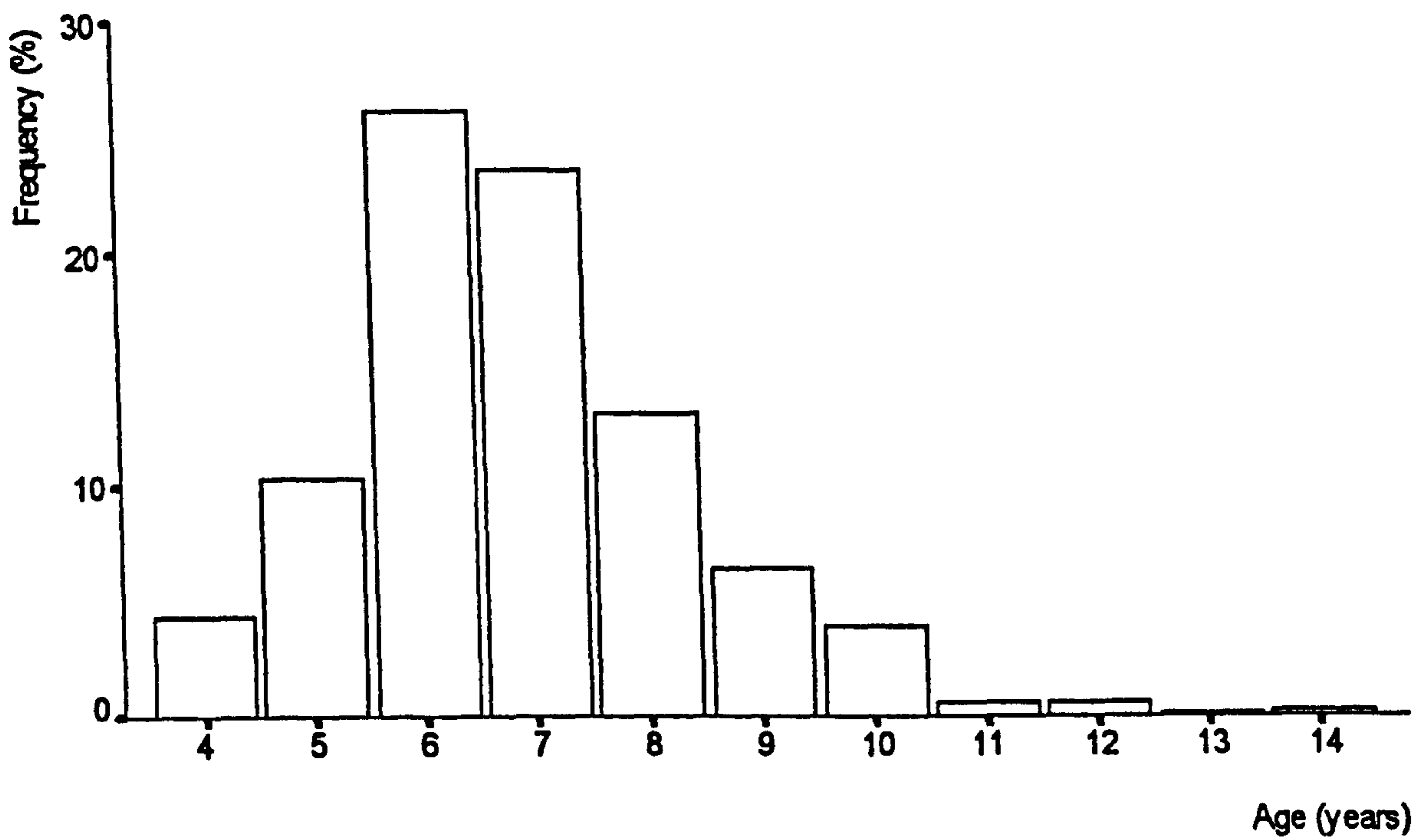


Figure 6: *L. nebulosus* breeding stock age structure, based on age otolith reading (specimens were randomly obtained during the 1997 season).

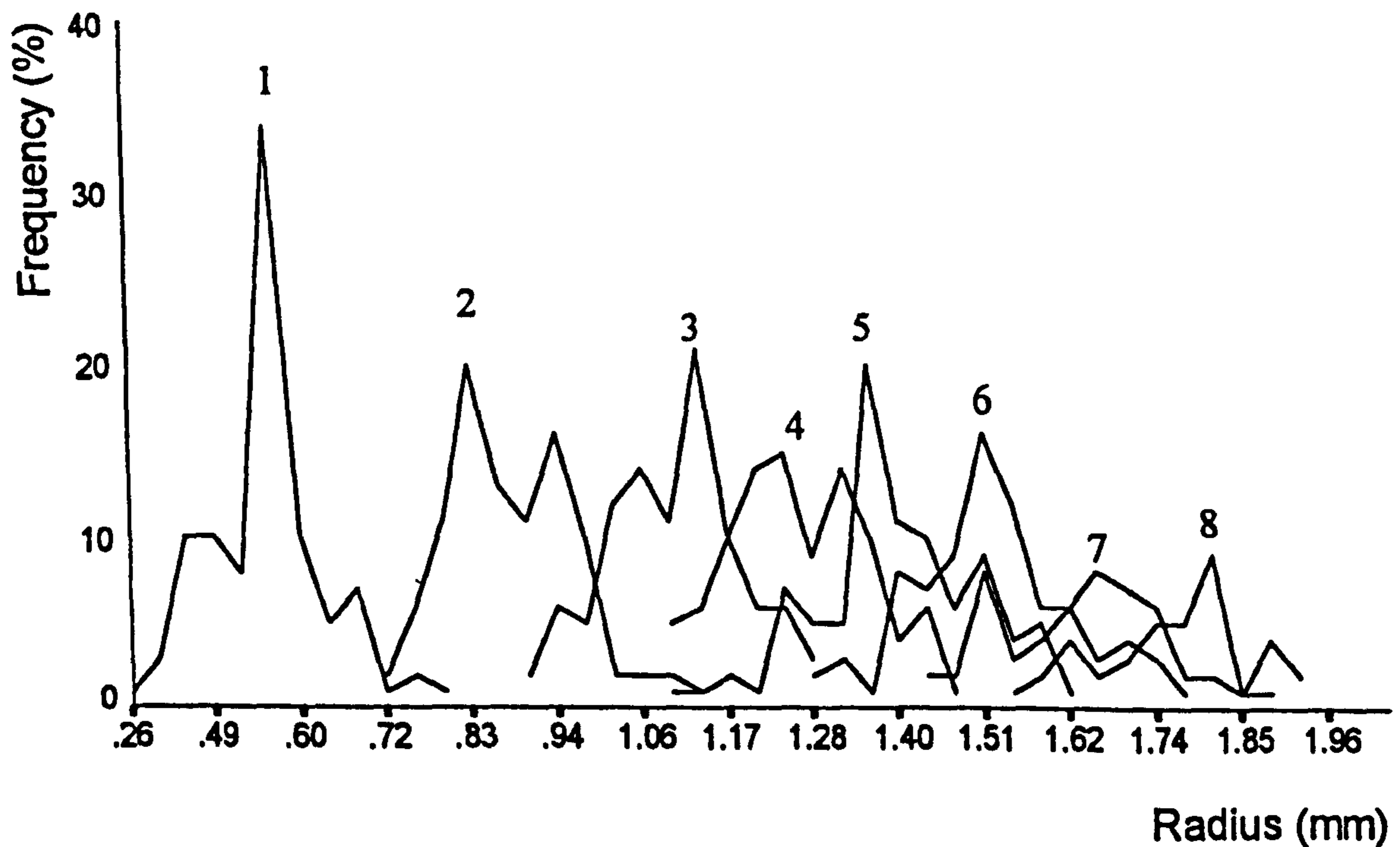


Figure 7: Frequency distribution of nucleus-to-ring distances of the first eight rings.

Table 1: Table to show the mean observed and back-calculated lengths-at-age (cm) of *L. nebulosus*, based on otolith reading.

Age (years)	Observed fork length (\pm S.D)	Number of samples used.	Back-calculated fork length (\pm S.D)	Number of samples used.
1	13.3 (1.7)	13	14.0 (2.5)	94
2	19.8 (3.0)	36	23.5 (2.7)	96
3	26.4 (5.5)	22	29.8 (3.3)	96
4	37.5 (5.1)	20	34.9 (3.6)	95
5	41.3 (5.0)	70	38.6 (3.8)	89
6	43.7 (4.6)	178	42.3 (4.1)	80
7	44.0 (4.7)	160	45.2 (4.2)	52
8	45.5 (4.8)	90	48.1 (4.8)	39
9	50.1(5.7)	27	50.1 (5.5)	16
10	50.3 (5.7)	5	54.3 (4.8)	4
11	60.5 (2.5)	3	57.7 (4.4)	1
12	57.0 (-)	1	58.2 (-)	1
13	60.3 (1.8)	2	(-)	(-)

increment rates from the back-calculated length at age for the first six years were 14.0, 9.5, 6.3, 5.1, 3.7, and 2.4 respectively. The *L. nebulosus* age structure for 1997 the based on otolith reading of randomly sampled fish is shown in figure 6.

The frequency distributions of the distances between otolith nuclei and each ring in studied specimens are shown for the first eight rings in figure 7. Each ring showed a distinctive size mode, and modes were clearly separated from each other. No significant overlap was observed between the first five rings. The validity of using otoliths in ageing *L. nebulosus* was supported, the presence of annual rings in immature fish (sizes <35 cm) suggesting that these rings are not produced during spawning periods, the regularity of the annuli-nucleus distances, and the very strong positive correlation of otolith radius and fish length.

Scales Analysis

The *L. nebulosus* scale is ctenoid in type, semi-circular in shape and strongly embedded in the skin. The scales showed clear successive growth ring formation (hyaline zones) around the focus of the scale. Scale radius was strongly correlated with fish length ($R_{sq} = .907$), this relationship was best described by a linear regression represented by the following equation:

$$FL = -7.2958 + 70.0851 (SR)$$

where **FL** is the fish fork length

SR is the fish scale radius.

The relationship between fork length and scale radius is shown in figure 8.

The number of annual rings (age) varied between 2 and 10. Marginal rings in scales with more than 7 rings were close to each other and indistinct. Observed fork length at age, using scales to estimate age, were 19, 23, 30, 40, 42, 45, 50 cm

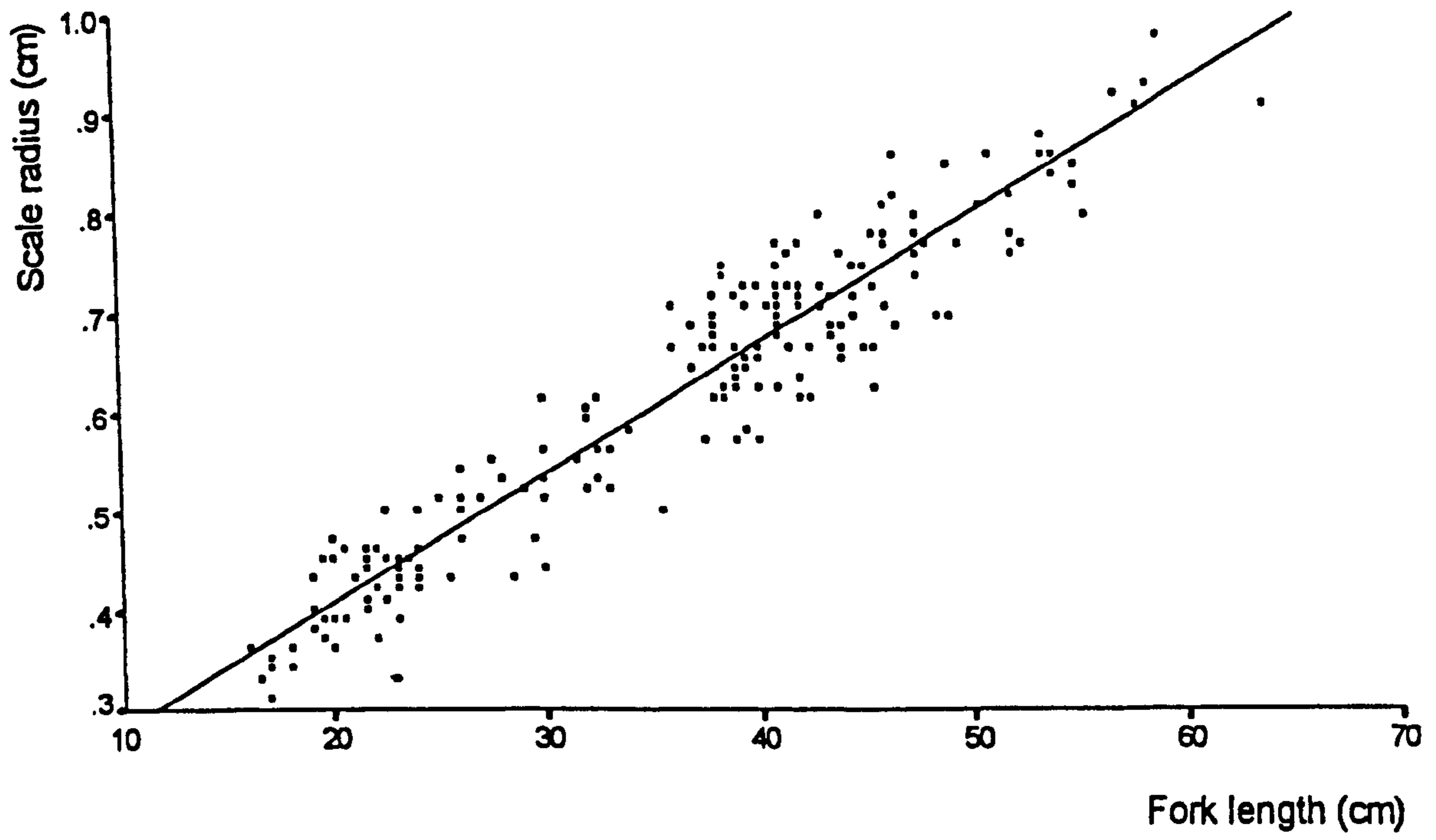


Figure 8: Relationship between *L. nebulosus* fork length and scale radius.

for ages two to seven respectively. Length at age was also back-calculated, giving estimates of fork lengths 12, 20, 29, 35, 39, 44, 49 cm for ages from one to seven respectively.

Size Frequency Analysis

The *L. nebulosus* population age structure was also estimated from their length frequency measurement using Bhattacharya's method. The length-frequency data were separated into normally distributed length classes. The number of length cohorts (age) that was represented by adequate number of samples ($N > 5$) varied between six and eight cohorts. When all the measures were combined together the mean length of coherence were 34.9, 38.8, 41.5, 45.2, 49.6, 56.6, 59.8 and 63.8, which represented ages 4 to 11 respectively. The smallest mean length for a single cohort (30.5 cm) was recorded in 1998, and had a modal size of 30.5 cm but with few individuals ($N=3$). The subsequent cohort was represented by an adequate sample with a modal size of 35 cm, which appeared to be typical of new recruits to the spawning stock. The largest mean length was 62.5 cm, recorded in the 1995 population. The mean length, population size (N), standard deviation (S.D) and separation indexes (S.I) of each length cohort are shown in table 2. The population structure by length of *L. nebulosus* for each year (1995-1998), and for all years combined together with the separated length (age) modes is shown in figure 9.

Growth parameters (L_{∞} , K and L_0)

A- Using ageing data

The von Bertalanffy growth parameters of *L. nebulosus* (L_{∞} , K and L_0) obtained using the different methods are shown in table 3. Estimates of L_{∞} ranged between 62.1 and 73.7 cm obtained using the Gulland & Holt and Ford-Walford plots

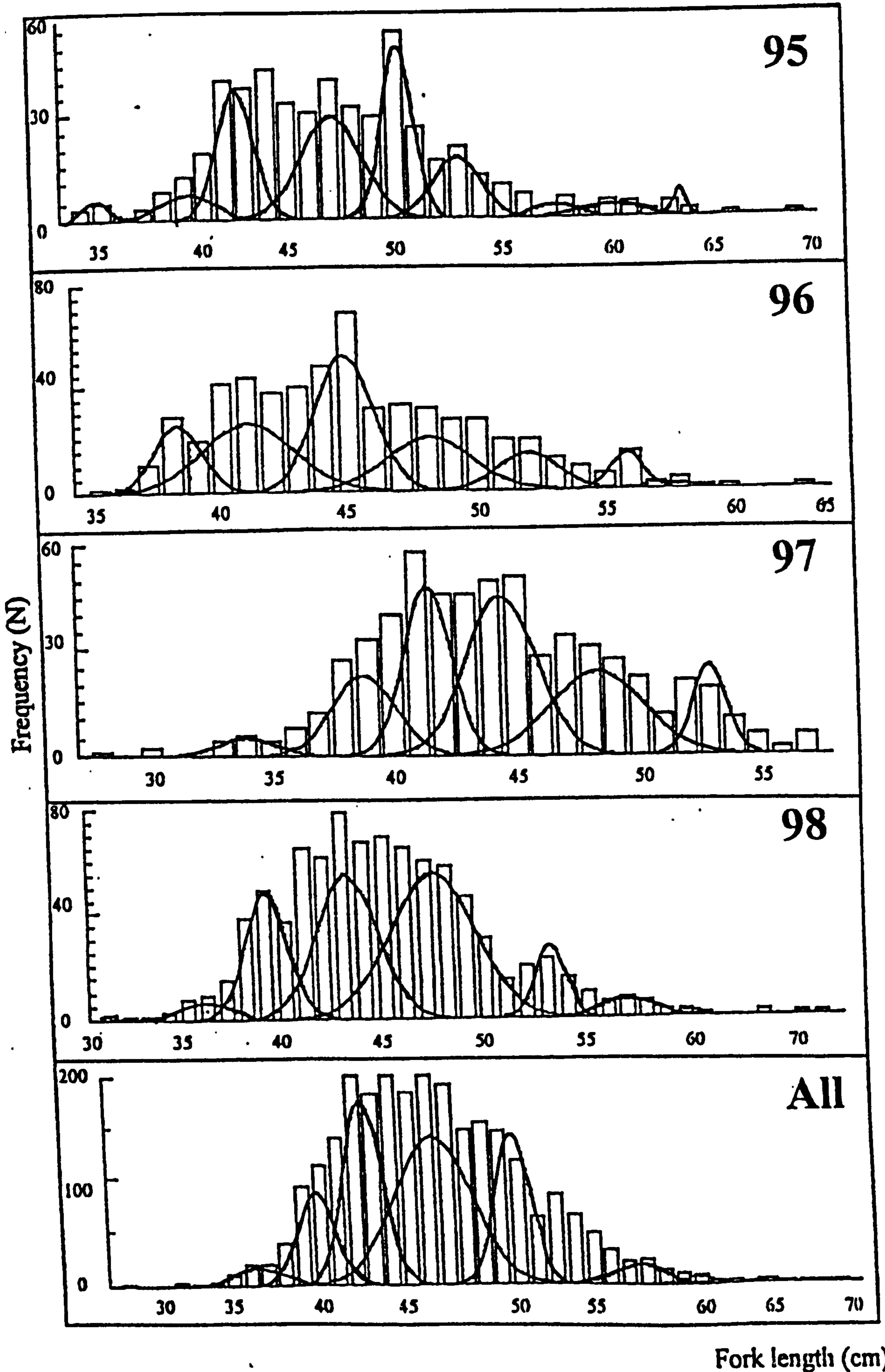


Figure 9: *L. nebulosus* length frequency data decomposed to age structure, using the Bhattacharya's method, for each year from 1995 to 1998 separately and for all years combined together.

Table 2: Mean fork length at age as identified by Bhattacharya's routine using the FiSAT software package.

1995 (N = 507)

Group No.	Mean length	±S.D	N	S.I
1	34.74	0.687	9	-
2	39.20	1.309	23	4.463
3	42.68	1.445	157	2.531
4	46.35	1.022	84	2.971
5	49.10	.755	97	3.095
6	51.92	1.066	46	3.102
7	56.50	0.954	8	4.533
8	59.15	1.398	11	2.259
9	62.46	0.257	5	4.003

1996 (N = 605)

Group No.	Mean length	±S.D	N	S.I
1	38.21	0.970	61	-
2	41.04	1.839	119	2.015
3	44.79	1.120	147	2.539
4	48.11	1.658	83	2.389
5	51.97	1.181	41	2.716
6	55.88	0.633	22	4.319

1997 (N= 581)

Group No.	Mean length	±S.D	N	S.I
1	34.00	1.110	14	4.057
2	38.82	1.267	72	2.328
3	41.39	0.940	113	2.533
4	44.39	1.424	161	2.368
5	48.31	1.894	112	2.368
6	52.98	0.708	45	3.582

1998 (N = 869)

Group No.	Mean length	±S.D	N	S.I
1	30.50	1.201	3	-
2	35.82	1.261	21	4.319
3	39.07	1.066	130	2.798
4	43.13	1.503	206	3.157
5	47.38	2.096	289	2.364
6	53.12	0.725	49	4.066
7	57.03	1.425	23	3.640
8	60.28	0.491	3	3.384

All measures (N =

Group No.	Mean length	±S.D	N	S.I
1	30.50	0.849	5	-
2	34.93	0.469	51	6.712
3	38.81	1.225	241	4.587
4	41.48	0.991	427	2.407
5	45.23	2.079	727	2.444
6	39.62	0.950	336	2.988
7	56.58	1.360	59	6.026
8	59.81	0.822	15	2.959
9	63.77	0.815	6	4.838

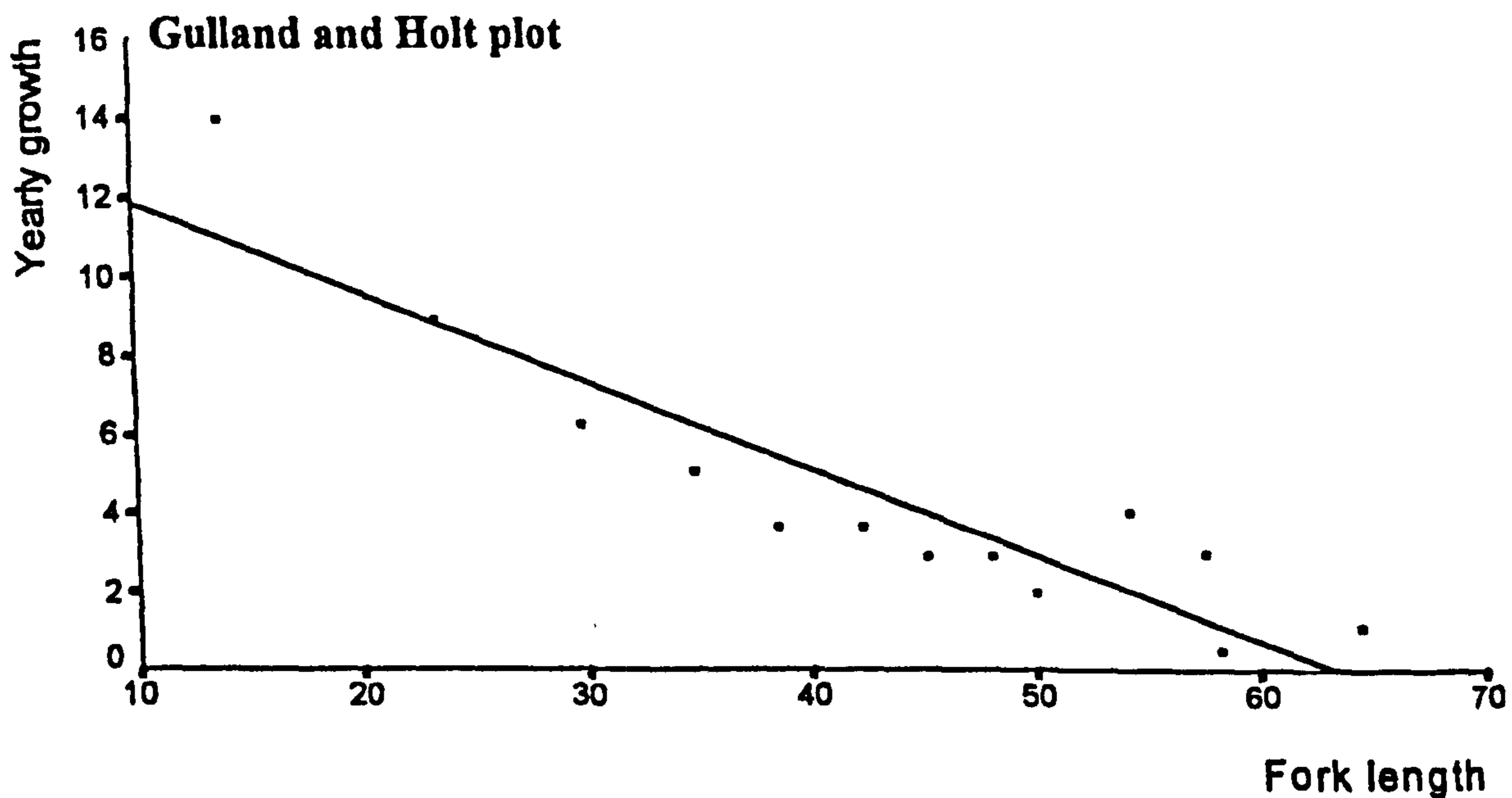
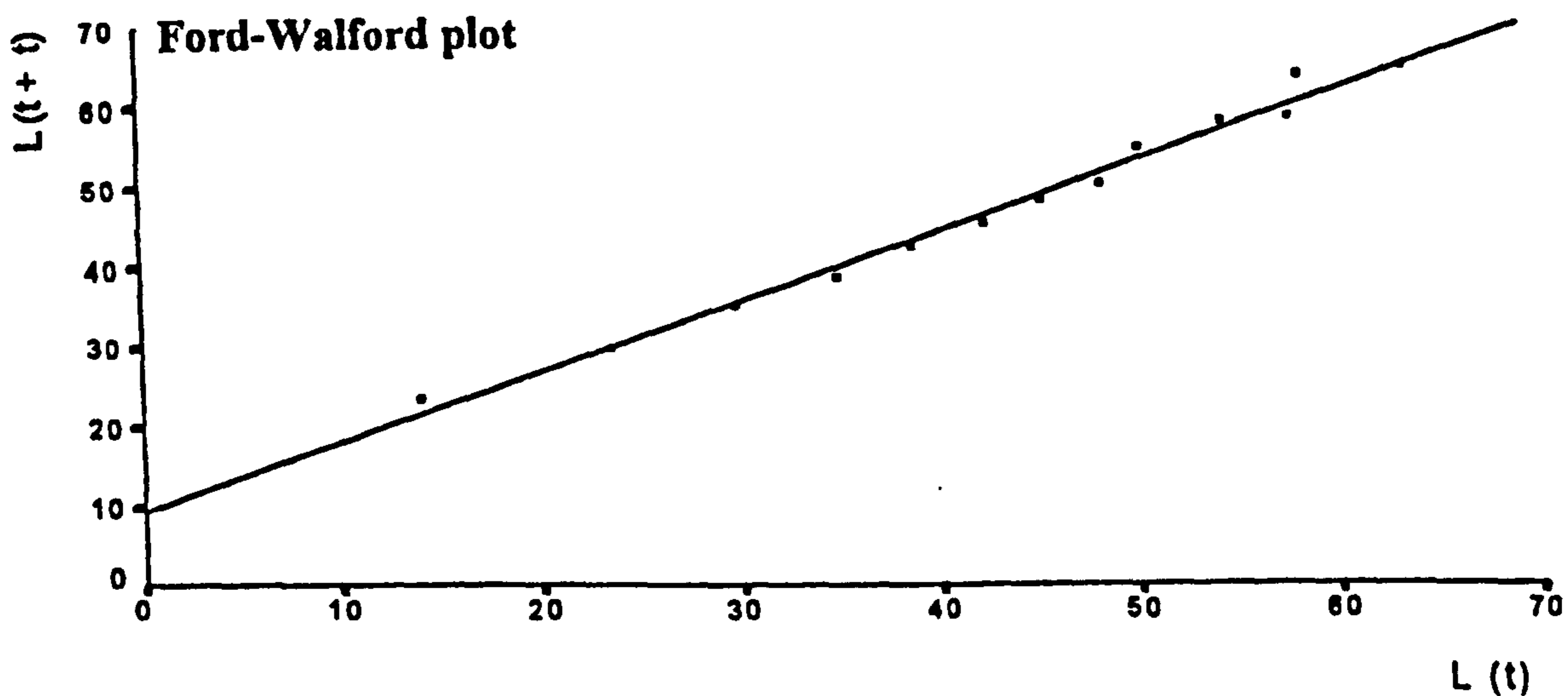
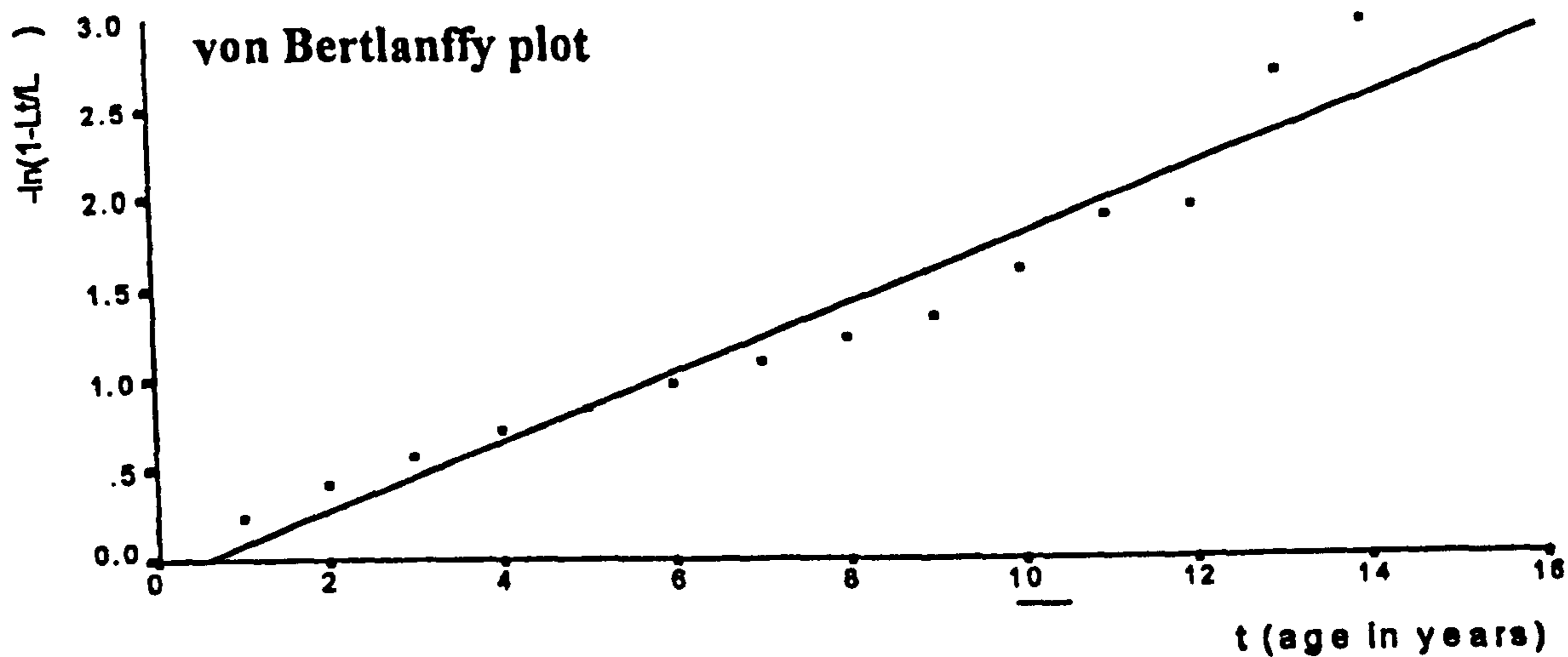


Figure 10: Graphs to show the plots of the three age-based methods used to estimate the von Bertalanffy growth parameters of *L. nebulosus*.

Table 3 : Estimated growth parameters for *L. nebulosus*(L_{∞} , K and L_0) based on length-at-age data using Gulland and Holt, Ford-walford, von Bertalanffy plots and the Least squares method.

Method	Equation	L_{∞} cm	K years	L_0	Rsq
Gulland and Holt	$\Delta L/\Delta t = a + b L(t)$ where $K = -b$ and $L_{\infty} = -a/b$	62.1	0.22	-	0.82
Ford-walford	$L(t+\Delta t) = a + b L(t)$ where $K = -1/\Delta t \ln b$ and $L_{\infty} = a/1-b$	73.7	0.14	-	0.98
von Bertalanffy plots.	$-\ln(1-L(t)/L_{\infty}) = -K * L_0 + K * t$	68	0.19	0.5	0.93
Least squares (FISAT)	$L(t) = L_{\infty}\{1 - \exp[-K(t-t_0)]\}$	69.7	0.14	-0.8	0.99

Table 4: Estimated *L. nebulosus* growth parameters (L_{∞} , Z/K) based on length frequency measures using the Wetherall method. Length-frequency measures were obtained during the period between 1995 and 1998.

Year	L_{∞}	Z/K	Rsq	N
1995	82.2	6.258	.766	507
1996	64.7	3.486	.974	605
1997	58.7	2.242	.993	581
1998	67.7	4.411	.966	869
All measures	76.2	6.170	.961	2562

Length Frequency Data

The *L. nebulosus* length-frequency measures obtained from Ras Mohammed between 1995 and 1998 were used as input data in the FiSAT software package (Gayanilo & Pauly, 1993). Both L_{∞} and Z/K were estimated using the Wetherall routine, for each year's data set separately and the combined data. The cut-off length was 50.5, 48.5, 42.5 and 45.5 cm for 1995, 1996, 1997 and 1998 respectively (Fig 11). Estimated L_{∞} , Z/K and correlation coefficient for each year and across the whole period are shown in table 4.

Growth in weight

The *L. nebulosus* total weight at the end of each year was estimated directly from age determined specimens. The growth in weight of *L. nebulosus* increases steadily during the first four years, drops significantly for age 5, 6, 7 and 8, before it increases again thereafter. Annual weight increment was 42, 102, 339, 636, 339, 124, 11, 95, 268, 223 and 340 grams for ages one to eleven years respectively. The relationships between both the observed and the back-calculated mean total weights and fish age are shown in fig 12.

Weight-length relationship

Increase in weight of *L. nebulosus* with body length is isometric, with fish total weight being almost a cubic function of fish fork length. The relationship between the *L. nebulosus* total weight (grams) and fork length (centimetres) is best described by a power function regression. For the sexes together (figure 113a), and for each sex separately, the equations are:

For both sexes $W = 0.0239 L^{2.9214}$ $R_{sq} = 0.97$

For males $W = 0.0302 L^{2.8547}$ $R_{sq} = 0.99$

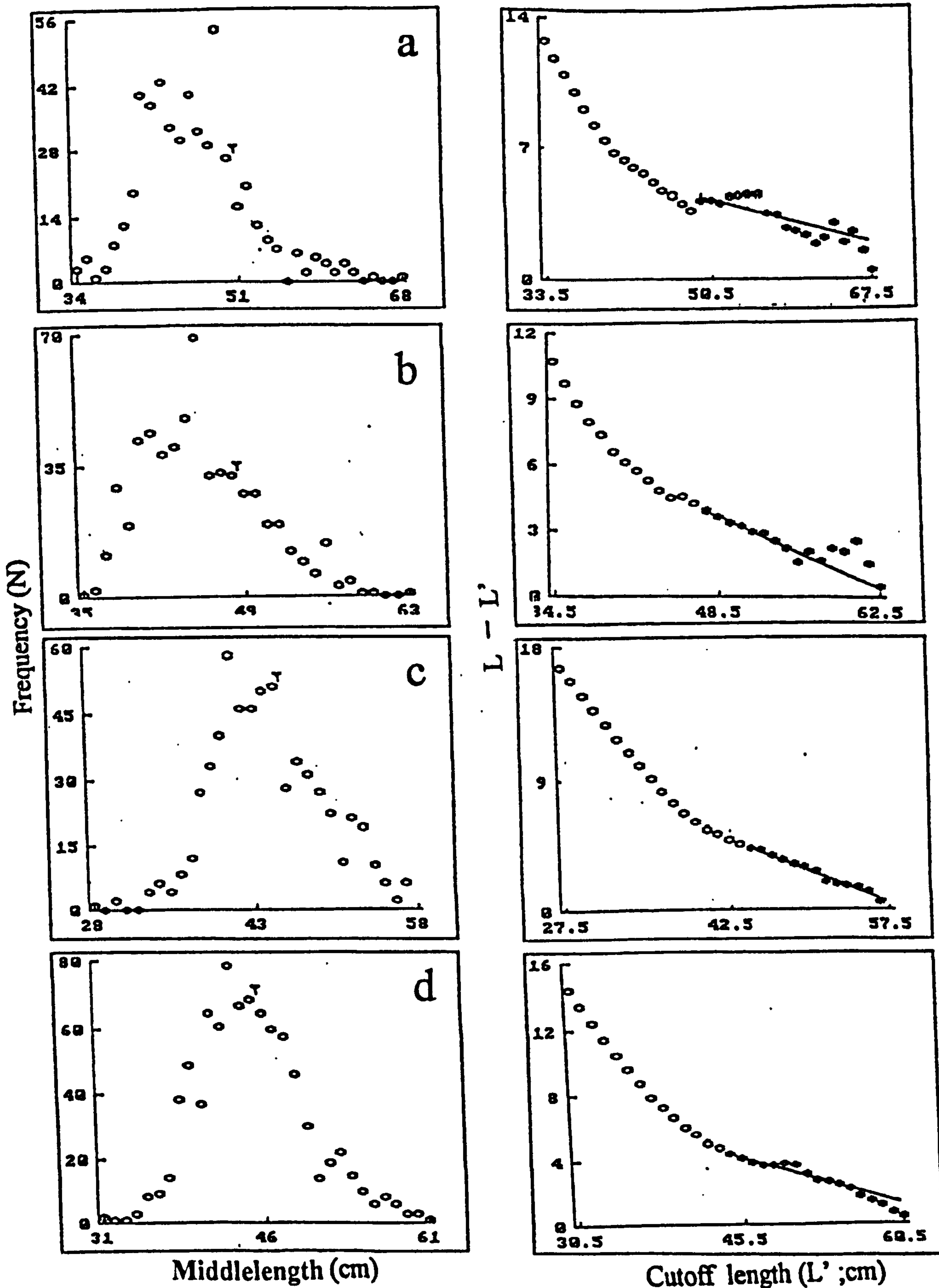


Figure 11: Regression lines obtained by the Wetherall method used to estimate the *L. nebulosus* growth parameters, using the length frequency data for each year from 1995 to 1998 separately.

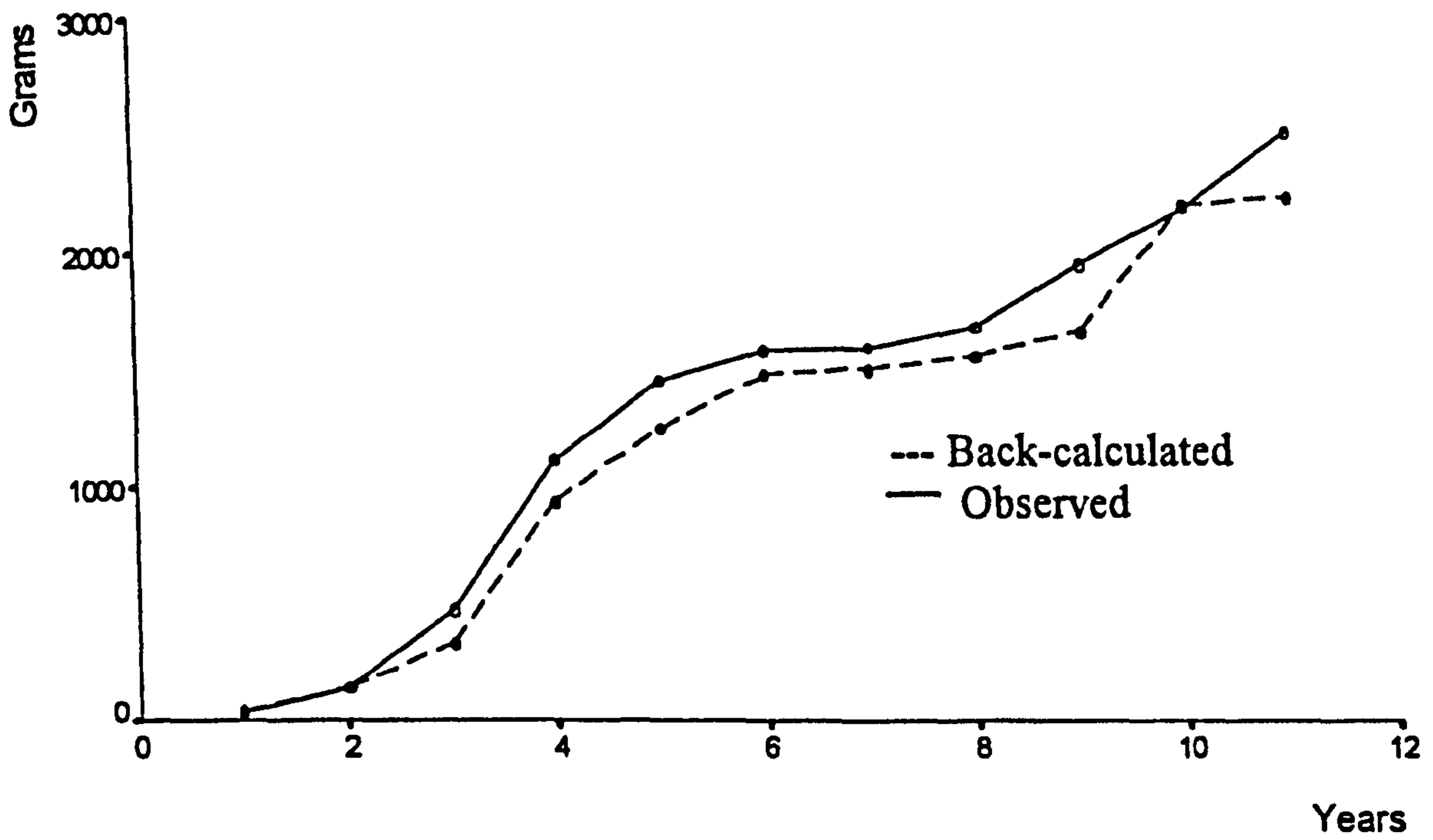


Figure 12: Relationship between the observed and back-calculated body weight in relation to age of *L. nebulosus*.

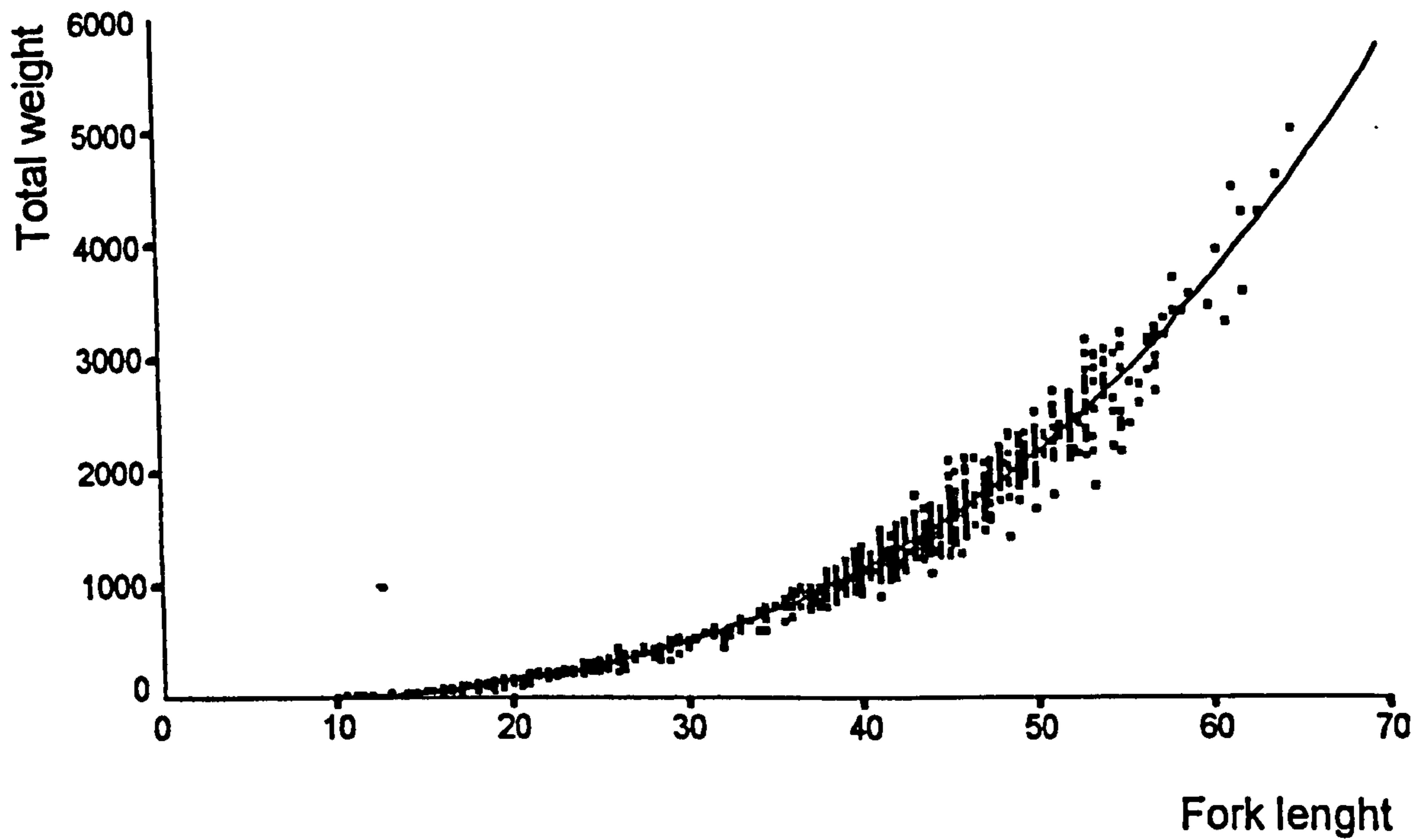


Figure 13a: Relationship between total weight and fork length for *L. nebulosus* from Ras Mohammed.

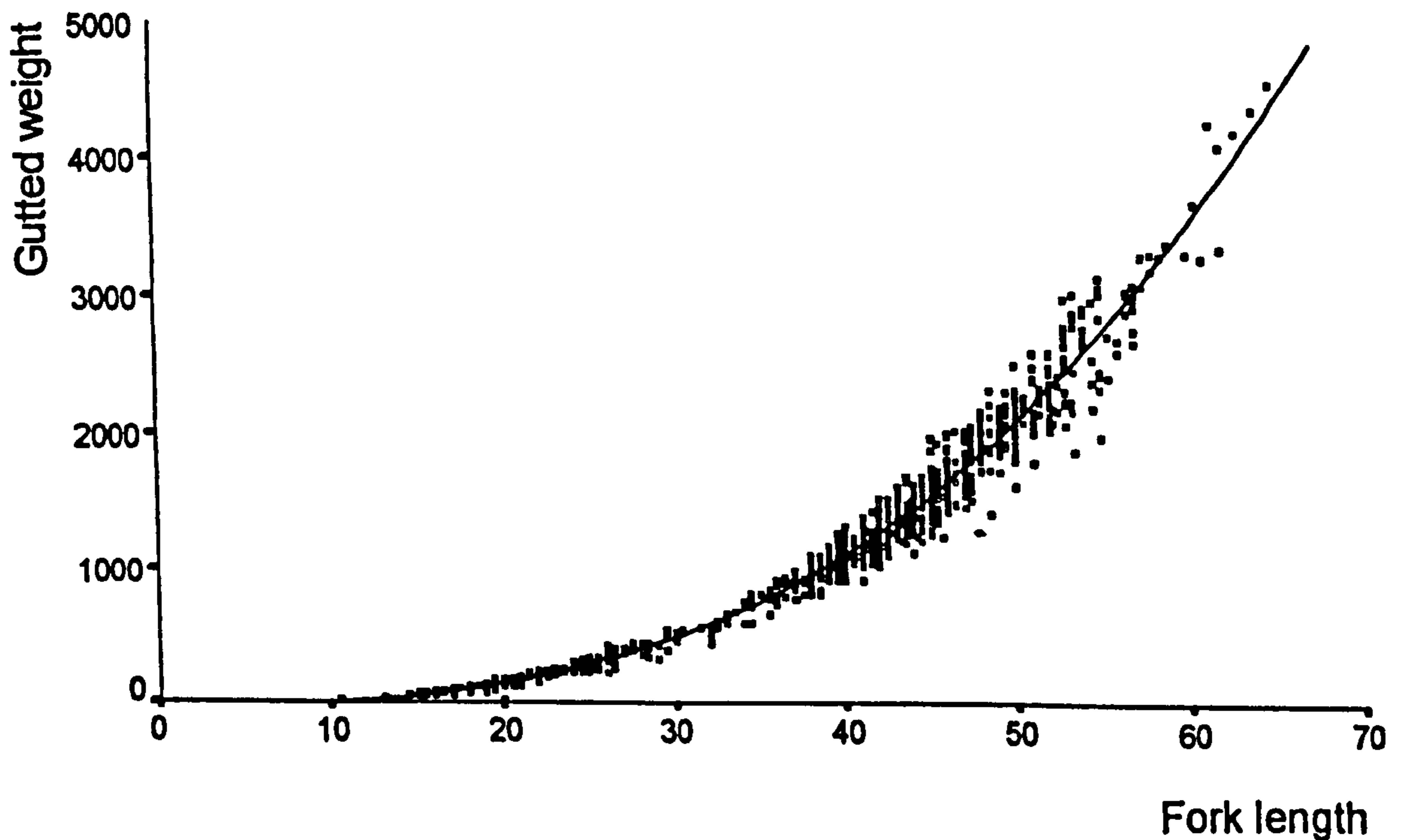


Figure 13b: Relationship between gutted weight and fork length for the *L. nebulosus* from Ras Mohammed.

For females $W = 0.0288 L^{2.8687}$ (Rsq = 0.99, P < 0.001)

For males, total length ranged between 33 and 62 cm (mean 43.6 cm) and the total weight between 702 and 3590 grams (mean 1501 grams). For females, total length ranged between 34 and 65 cm (mean 46.6 cm.), and total weight between 769 and 5032 grams (mean 1874 grams). Guttred weight-length relationships were also determined (figure 13b); for both sexes combined together, the equation is:

$$\text{Guttred weight} = .0272L^{2.8773} \quad (\text{Rsq} = 0.97, P < 0.001)$$

The *L. nebulosus* weight-length relationship converted to a straight line equation when log-transformed, giving:

$$\text{Log } W = -1.6129 + 2.9159 \log L \quad (\text{Rsq} = 0.99, P < 0.001)$$

Condition factor (K)

L. nebulosus condition factor and relative coefficient of condition (k_n) both varied with body length. Condition factor was highest among small fishes, then declined gradually with increase in size, ranged between 1.52 and 1.94 with an average of 1.78. There was no significant difference in mean condition factor for females (1.725) and males (1.703). The relative coefficient of condition (k_n) ranged between 0.85 and 1.05 with a mean of 0.96. Relative coefficient of condition (k_n) was also high for smaller fish classes than for bigger sizes. The relationship between *L. nebulosus* fork length and both of condition factors and relative coefficient of condition is presented in table 5, and graphed in figure 14.

Mortalities

A- Total mortality (Z)

L. nebulosus total mortality (Z) was estimated independently for each fishing season and across all seasons combined together. The *L. nebulosus* total mortality

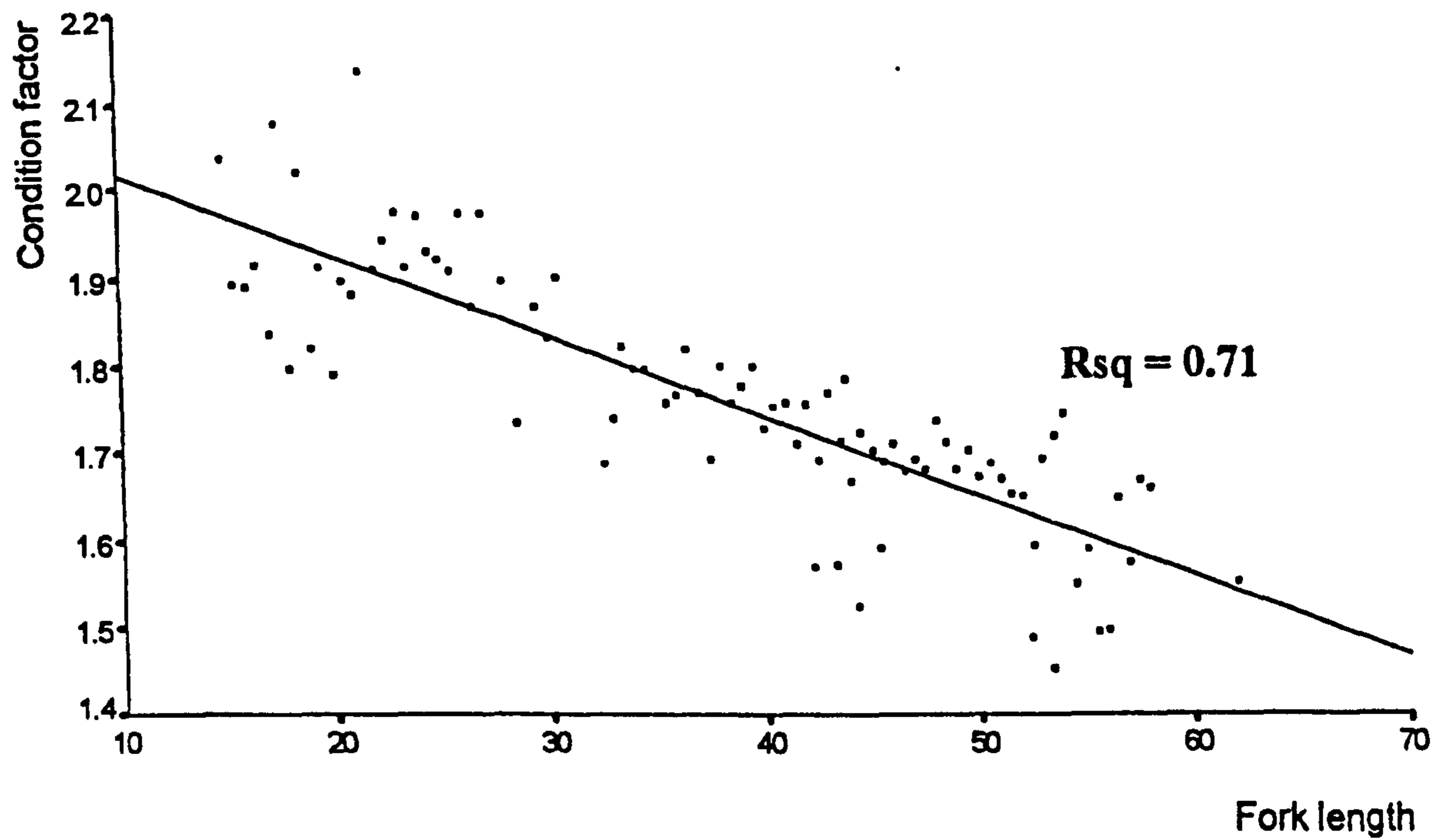


Figure 14 : Plot of Fulton's condition factor (K) against fork length for *L. nebulosus* from Ras Mohammed.

Table 5: The table shows the mean total, gutted, estimated weight and condition factor in relation to body length for *L. nebulosus* from Ras Mohammed.

F.length (cm)	Mean total weight (gm)	No.	Mean gutted weight (gm)	No.	Estimated total weight	Condition factor (Kc)	No.	Kn
10	*	0	19 (-)	1	20	1.9 (-)	1	*
11	22 (-)	1	23 (2)	3	26	1.75 (0.11)	3	0.85
12	*	0	31 (5)	3	34	1.77 (0.30)	3	*
13	41 (-)	1	42 (1)	2	43	1.91 (0.06)	2	0.95
14	*	0	51 (3)	5	53	1.87 (0.12)	5	*
15	67 (6)	5	65 (6)	7	65	1.94 (0.18)	7	1.03
16	75 (9)	26	75 (8)	30	79	1.84 (0.20)	30	0.95
17	88 (11)	29	88 (11)	30	95	1.79 (0.23)	30	0.93
18	106 (20)	14	106 (19)	16	111	1.81 (0.32)	16	0.96
19	125 (22)	17	125 (21)	18	130	1.82 (0.31)	18	0.97
20	143 (36)	20	143 (33)	24	151	1.79 (0.41)	24	0.94
21	168 (26)	9	174 (24)	15	174	1.88 (0.26)	15	0.97
22	207 (20)	20	205 (18)	30	199	1.93 (0.17)	30	1.03
23	233 (21)	24	233 (20)	28	227	1.92 (0.16)	28	1.03
24	266 (23)	20	265 (23)	23	257	1.92 (0.17)	23	1.04
25	294 (36)	16	294 (34)	19	290	1.88 (0.21)	19	1.02
26	332 (44)	25	332 (44)	25	325	1.89 (0.25)	25	1.02
27	360 (53)	10	359 (49)	12	363	1.82 (0.25)	12	0.99
28	423 (33)	6	423 (28)	8	404	1.93 (0.13)	8	1.05
29	395 (53)	5	418 (65)	7	447	1.72 (0.27)	7	0.88
30	489 (49)	8	489 (49)	8	394	1.81 (0.18)	8	0.99
31	540 (12)	2	565 (30)	4	544	1.90 (0.10)	4	0.99
32	524 (45)	5	552 (60)	7	596	1.68 (0.18)	7	0.88
33	606 (39)	7	611 (48)	7	653	1.70 (0.13)	7	0.93
34	698 (63)	5	700 (63)	5	712	1.78 (0.16)	5	0.98
35	753 (83)	6	761 (84)	6	775	1.77 (0.20)	6	0.97
36	820 (71)	14	836 (78)	14	841	1.79 (0.17)	14	0.97
37	895 (57)	17	913 (60)	17	911	1.80 (0.12)	17	0.98
38	966 (85)	35	1000 (86)	35	985	1.82 (0.16)	35	0.98
39	1035 (75)	48	1063 (79)	48	1063	1.79 (0.13)	48	0.97
40	1106 (93)	63	1140 (97)	63	1145	1.78 (0.15)	63	0.97
41	1201 (89)	81	1246 (98)	82	1230	1.81 (0.14)	82	0.98
42	1274 (110)	75	1316 (111)	75	1320	1.78 (0.15)	75	0.96
43	1364 (125)	60	1413 (60)	60	1414	1.78 (0.17)	60	0.96
44	1416 (104)	70	1464 (111)	70	1512	1.72 (0.13)	70	0.94
45	1534 (137)	73	1591 (147)	73	1615	1.75 (0.16)	73	0.95
46	1625 (158)	65	1690 (177)	65	1739	1.74 (0.18)	65	0.93
47	1746 (142)	37	1809 (153)	37	1833	1.74 (0.15)	37	0.95
48	1866 (149)	46	1942 (163)	46	1969	1.76 (0.15)	46	0.95
49	1968 (176)	32	2055 (198)	32	2071	1.75 (0.17)	32	0.95
50	2083 (168)	36	2162 (167)	37	2197	1.73 (0.13)	37	0.95

51	2204 (195)	17	2306 (219)	17	2328	1.74 (0.17)	17	0.95
52	2311 (153)	29	2417 (155)	30	2463	1.72 (0.11)	30	0.94
53	2456 (241)	22	2558 (275)	23	2604	1.72 (0.18)	23	0.94
54	2650 (295)	18	2760 (324)	18	2751	1.75 (0.21)	18	0.96
55	2601 (383)	12	2723 (382)	12	2902	1.64 (0.23)	12	0.9
56	2595 (137)	4	2670 (173)	4	3059	1.52 (0.10)	4	0.85
57	2933 (143)	10	3082 (173)	10	3221	1.66 (0.09)	10	0.91
58	3206 (110)	4	3435 (209)	4	3389	1.76 (0.11)	4	0.95
59	3320 (64)	2	3502 (95)	2	3563	1.70 (0.05)	2	0.93
60	3305 (-)	1	3471 (-)	1	3742	1.61 (-)	1	0.88
61	3452 (279)	2	3643 (455)	2	3927	1.61 (0.20)	2	0.88
62	3880 (484)	3	4136 (486)	3	4118	1.74 (0.20)	3	0.94
63	4177 (-)	1	4293 (-)	1	4315	1.72 (-)	1	0.97
64	4351 (-)	1	4620 (-)	1	4518	1.76 (-)	1	0.96
65	4545 (-)	1	5032 (-)	1	4728	1.83 (-)	1	0.94

coefficient estimated using the length-converted catch method was slightly higher than that obtained using mean length based methods. In general total mortality appeared to increase with time, the lowest total mortality being recorded in the 1995 fishing season, followed by higher values thereafter. The regression coefficients in the length-converted catch-based method were estimated to be 0.95, 0.96, 0.91, 0.98 and 0.99 for 1995, 1996, 1997, 1998 and for all years combined respectively (Figure 15). The total mortality coefficients estimated for each data set using the length-converted-catch method, Beverton & Holt model, and Ault & Ehrhardt model, are shown in table 6. By each of the three methods total mortality was estimated to be lowest in 1995 and highest in 1998.

Table 6: Yearly estimated total mortality coefficient using the Length converted catch method, Beverton & Holt model and Ault & Ehrhardt model.

Method Year	Length converted catch	Beverton & Holt model	Ault & Ehrhardt model
1995	0.56	0.525	0.515
1996	0.85	0.614	0.604
1997	0.83	0.677	0.667
1998	0.88	0.691	0.681
All	0.77	0.675	0.665

Natural mortality

L. nebulosus natural mortality, using Pauly's multiple regression model (1980), was estimated at 0.38. This was based on growth parameters are $L_{\infty} = 73$ cm and $K = 0.14$. Using Rikhter & Efanov's model (1976) *L. nebulosus* natural mortality coefficient was estimated at 0.41 when age at first maturity was applied as 4 years.

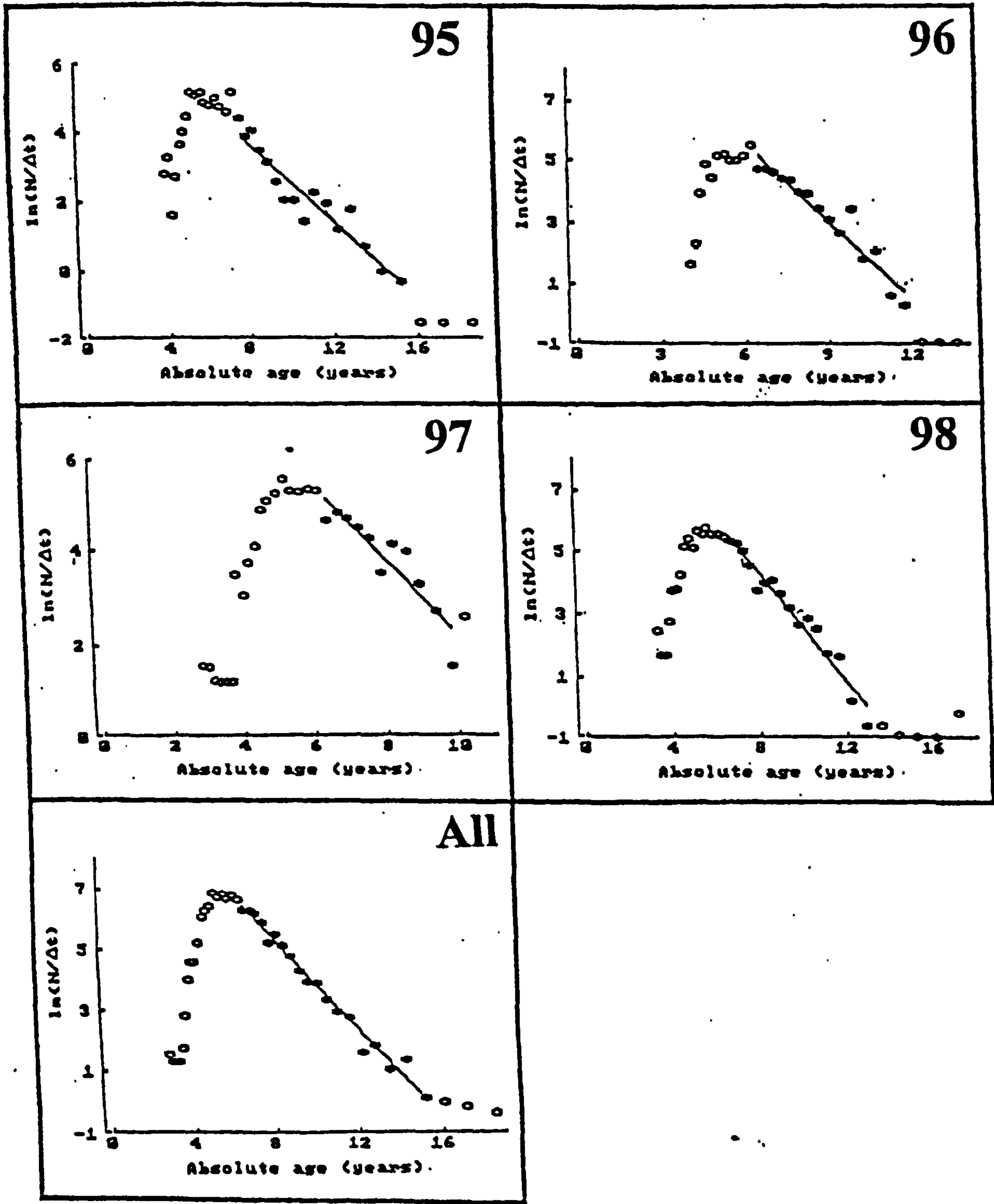


Figure 15: Graphs show the catch converted age plots (Pauly, 1983) used to estimate *L. nebulosus* total mortality for each year from 1995 to 1998 separately and for all years combined together.

C- Fishing mortality

Fishing mortality of *L. nebulosus*, estimated indirectly by subtracting the expected natural mortality from the total mortality, and using the mean of the total mortalities obtained using different methods, thus was estimated to be 0.138, 0.294, 0.330 and 0.345 for the 1995, 1996, 1997 and 1998 respectively. For all four data sets combined fishing mortality was estimated to be 0.308.

Exploitation ratio(E)

Using the above estimates of total and fishing mortalities the exploitation ratio (E) was estimated to be 0.259, 0.427, 0.455 and 0.466 for 1995, 1996, 1997 and 1998 respectively.

Relative Yield per Recruit and relative Biomass per Recruit

The relative yield per recruit and relative biomass per recruit of *L. nebulosus* in relation to exploitation rate (E) were influenced by the values of parameters used as input data to the model, especially the length at first capture (L_c). Based on the *L. nebulosus* catch record from the Ras Mohammed breeding stock, two length at first capture values were used: 35 and 40 cm. In addition, since the *L. nebulosus* populations are exploited continuously throughout the year their resident habitats, two additional length at first values were used: 12 and 15 cm. With each of these values, other parameters were entered as follows: asymptotic length (L_∞) = 80 cm, coefficients of growth (K) = 0.14 and natural mortality (M) = 0.4.

Using $L_c = 40$ cm, the model produced unidentifiable maximum sustainable yield (MSY), while the relative biomass per recruit plot shows that at under the current level of exploitation ($E = .47$) the *L. nebulosus* breeding stock may be reduced to 38 % of the original unexploited biomass (fig. 16a). For $L_c = 35$ cm, the plot suggested that the stock can sustain extra pressure ($E_{max} = 0.82$) than the current pressure before reaching the maximum sustainable yield (fig. 16b). Using smaller

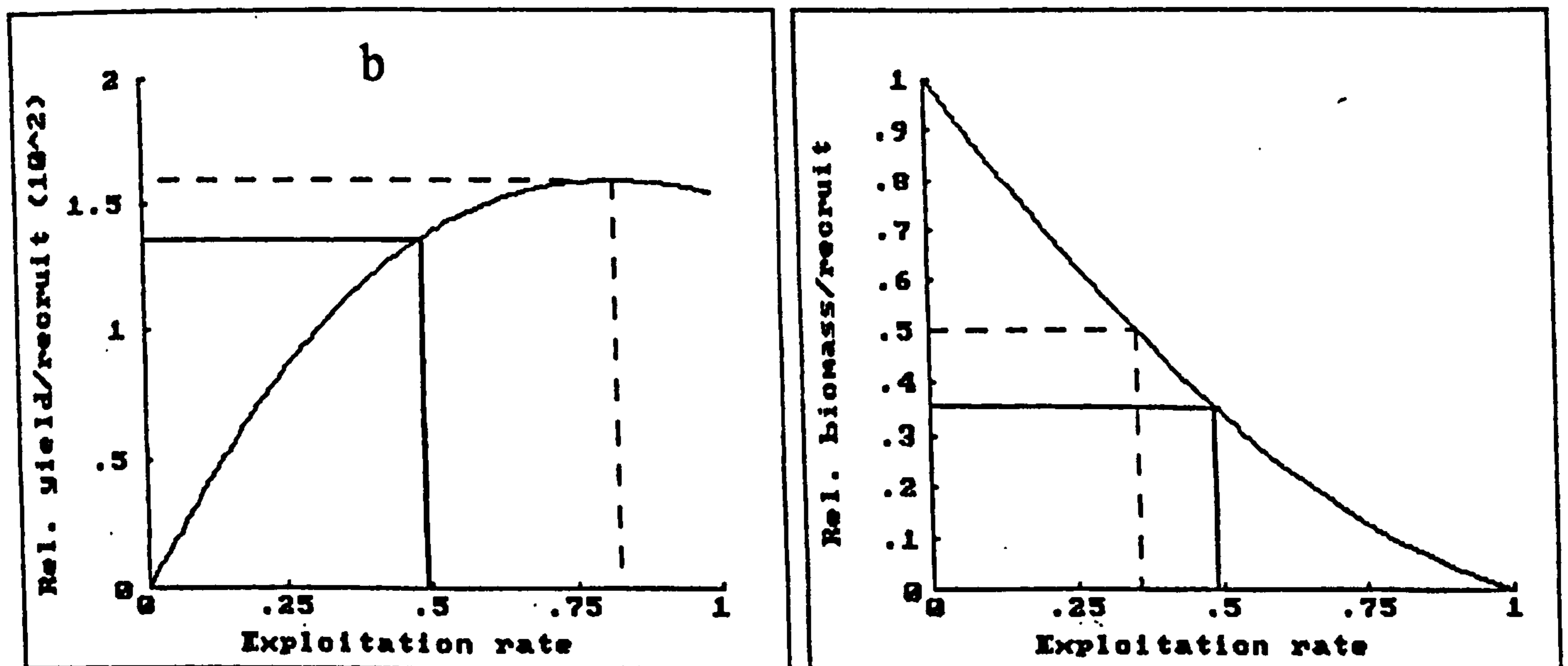
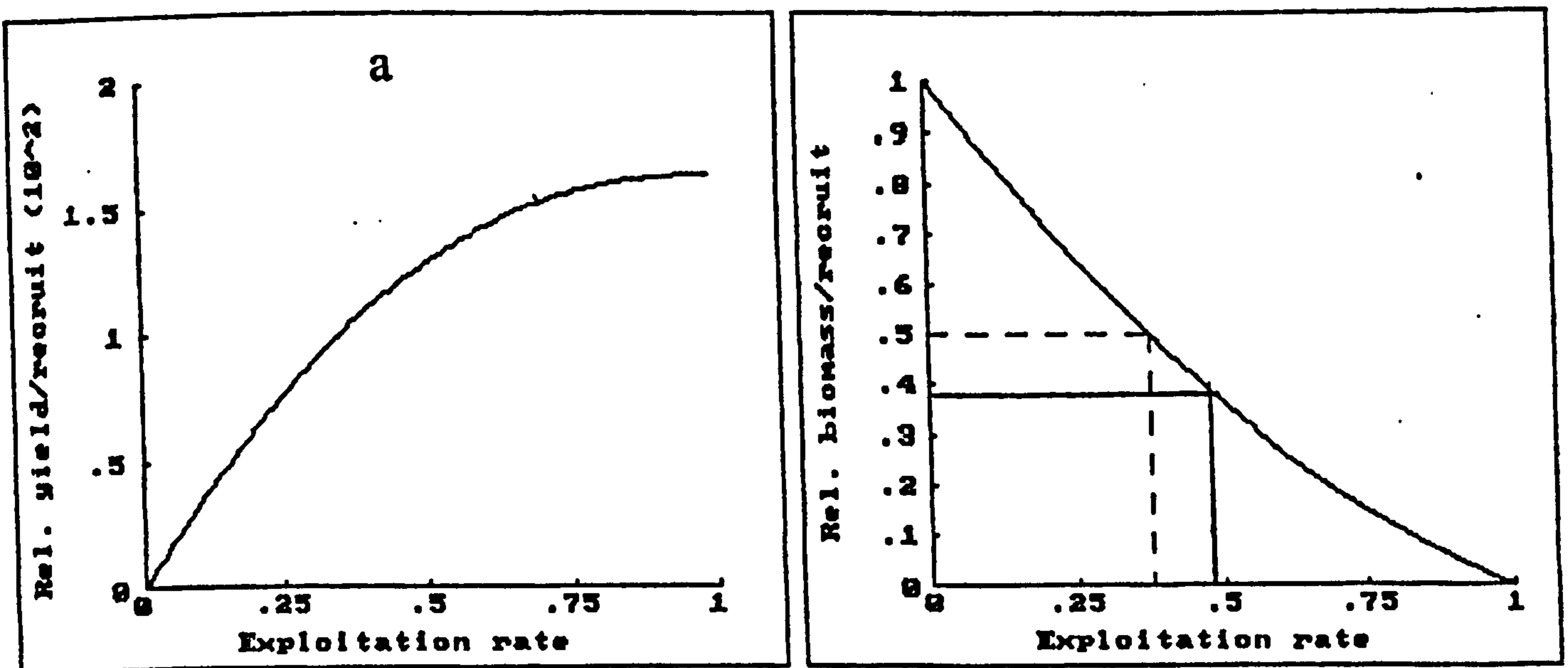


Figure 16: Relative yield per recruit and relative biomass per recruit for the exploited *L. nebulosus* stock at a) $L_c = 40$, b) $L_c = 35$. The dashed lines represent the exploitation rate at maximum sustainable yield, while solid lines the represent Y'/R and B'/R at the present level of exploitation.

Lc values (12, 15 cm), plots suggested that the current level of exploitation exceeded the sustainable level, and E_{max} are .41 and .45 respectively. For these Lc values the relative biomass per recruit models suggested that the stock reduced to 20 and 22 % of the original population size (fig. 17c and 17b).

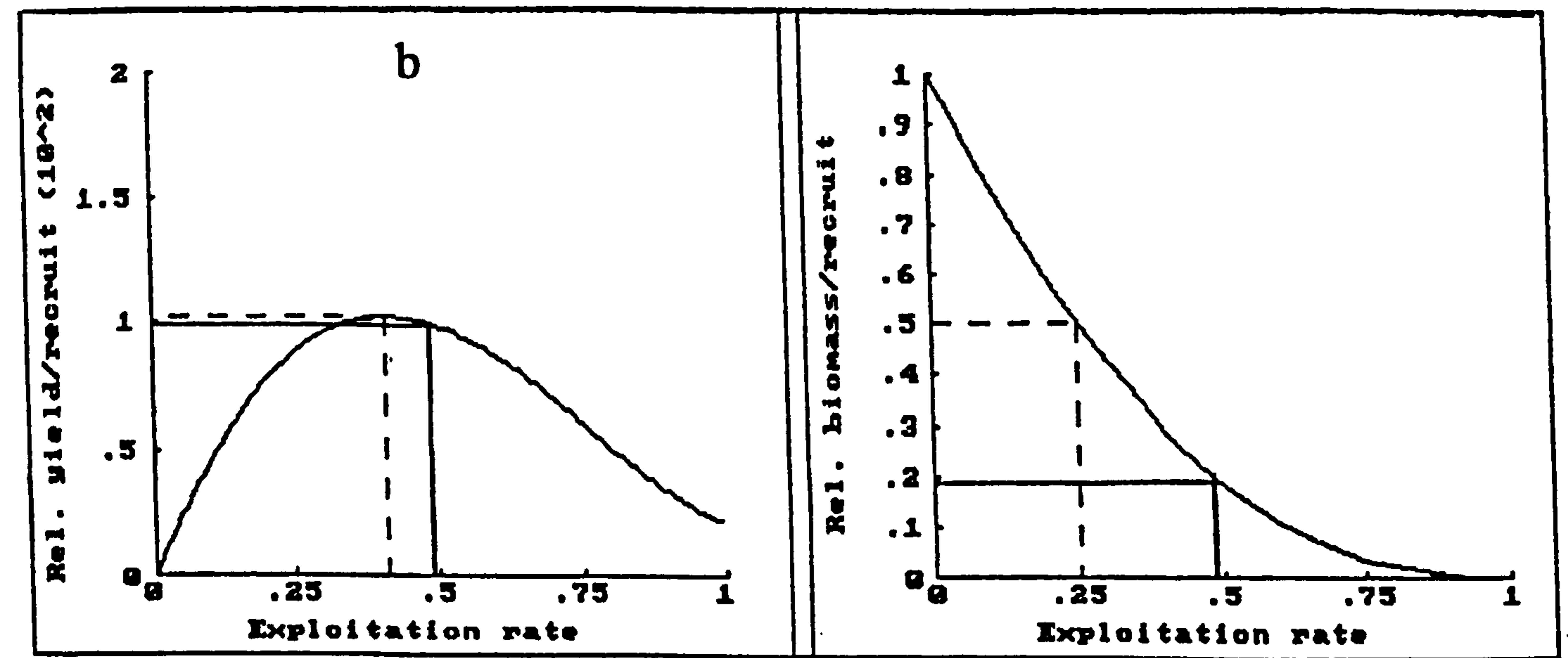
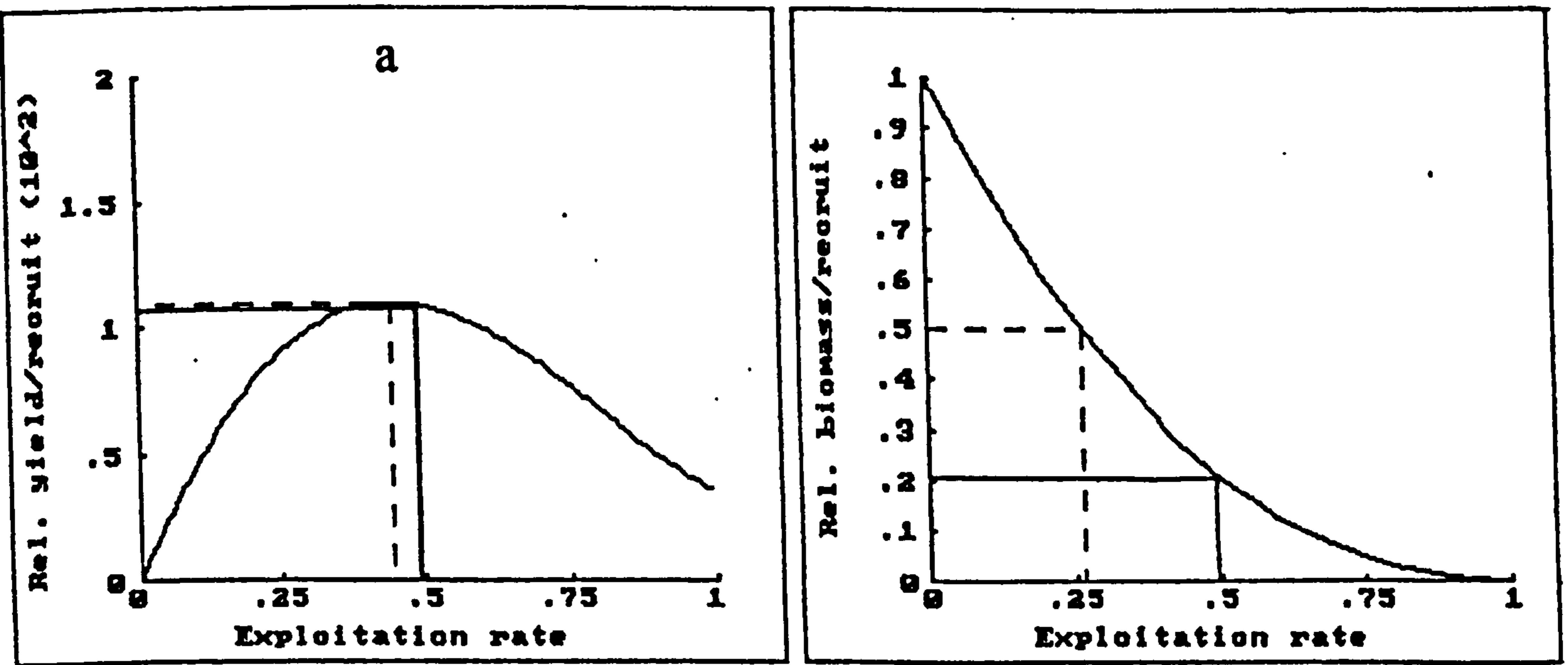


Figure 17: Relative yield per recruit and relative biomass per recruit for the exploited *L. nebulosus* stock at a) $L_c = 15$, b) $L_c = 12$. The dashed lines represent the exploitation rate at maximum sustainable yield, while solid lines the represent Y'/R and B'/R at the present level of exploitation.

DISCUSSION

Hard-parts Analysis

Data on age, on growth and on mortality are key to determining the current level of exploitation of a fish stock, the optimum level of effort for exploiting that stock, and the maximum level of effort which that stock can sustain. Further, it has been clearly established that the hard-parts (otoliths, scales, vertebrae) of temperate fish species grow linearly with body length and can be used to determine age and hence growth rate. However the usefulness of the hard-parts for age determination of tropical fish species has been doubted, since in some tropical species growth rings have been found either not to exist or not to be indicative of seasonal growth (Campana, 1985), and in particular formation of yearly growth bands in species of *Lethrinidae* has only rarely been reported.

On the other hand, a number of recent studies have validated the periodicity of growth-rings apparent in various tropical species (Both & Buxton, 1997; Ferreira & Russ, 1992; Hood & Schlieder, 1992; Lou, 1992; Smale & Punt, 1991; Fowler, 1990; Morales-Nin & Ralston, 1990; Dee & Radtke, 1989; Morales-Nin 1988; Mason & Manooch, 1985 and Johnson, 1983). Further an annual periodicity in growth-ring formation has been validated for various coral reef fish species using several different techniques. Fowler & Short (1998) used the mark-recapture method, following tetracycline injection, to confirm that bands apparent in *Sillaginodes punctata* are formed annually. Similarly Choat et al. (1996) found that in 6 scarid species growth rings are annual in early summer. Also, using marginal increment analysis, Brown & Sumpton (1998) demonstrated that on the Great Barrier Reef *Lethrinus miniatus* growth rings are formed annually.

In the present study of *Lethrinus nebulosus* thin but distinct opaque bands were evident alternating with wider translucent bands in otolith sections. The consistent

differences in otolith-centre to ring distances, the presence of rings in sexually immature fish, and the agreement between the observed and the back-calculated length-at-age data suggest that rings are formed annually throughout their life of the fish, rather than being associated with specific events such as spawning. Morales-Nin (1988) also argued that in *L. nebulosus* both the consistency and regularity of annual ring formation, and the strong correlation between otolith dimension and fish length, are indicative of a regular periodicity in ring formation. Also Sanders et al., (1984) validated the use of scale growth rings in Red Sea *L. nebulosus* by measuring seasonal increment and demonstrating that only one ring is formed per year, towards the end of the winter. Similar conclusions have been reached with regard to other lethrinids, by Wassef (1991) who used fish scales to study the age and growth of Red Sea *L. lentjan* and *L. mahsena*, and by Toor (1968) who investigated age and growth of *L. lentjan* from the Indian waters using fish scales and otoliths.

Based on Edwards (1987), in the northern Red Sea mean annual variation in surface water temperature is about 6 °C. Whether or not this seasonal variation is on its own sufficient to produce annual rings is in doubt. Otoliths are composed of a combination of two main compounds: calcium carbonate and protein (Mugiya, 1984; Campana, 1885). The deposition-ratio of these varies between seasons, generally varying with water temperature (Fowler, 1995). Thus Fowler (1990) also found that annual ring formation in *Pomacentrus wardi* was less clear in the southern Great Barrier Reef than in the northern Great Barrier Reef, a finding he attributed to differences in seasonal variation between these latitudes. Calcium carbonate is deposited more steadily with time, hence its proportion is greater during periods of slower organic growth, resulting in higher density opaque bands, and less during periods of slower growth, resulting in less-calcified translucent bands (Radtke, 1984). However, Fowler (1990) found that a 6°C difference in

mean water temperature between seasons was not enough to induce ring formation in fish species on the Great Barrier Reef. Conversely Shonyakov (1994) found that a 4 - 5 °C difference between seasons is sufficient to cause the appearance of rings. Alternatively temperature variation in the study area may be greater than Edwards (1987) suggests; incidental observation during the study suggests the area experiences surface sea water temperatures varying over a range of nearer 10 °C.

It was also notable that in the present study the clarity of the opaque bands varied slightly between specimens; an explanation for this may be differences in precise conditions across the wide area from which fish aggregate to spawn. However, Fowler (1990) suggested that section orientation may also effect the clarity of the rings

The age and growth data indicate that *L. nebulosus* is relatively long-lived and slow-growing, reaching up to 82 cm and living for up to 20 or more years. Sanders et al. (1984) also based on scale interpretation, found that along the Egyptian Red Sea coast this species live for up to 17 years and reach 73 cm in total length. Similarly Morales-Nin (1988) found that in New Caledonia *L. nebulosus* grow up to 75 cm and live for up to 20 years. These features, longevity and slow growth, appear to be characteristic of many top predators in coral reef environments (Manooch, 1987). In the present study the oldest fish (based on otolith interpretation) was 19 years old and measured 64 cm in fork length. This size and age is smaller but older than that reported by Sanders et al. (1984). Moreover Sanders et al. (1984) measured many fish exceeding 80 cm in total length (corresponding to 75 cm fork length based on the recorded fork-length total-length relationship). However, his samples were collected over some 12 years, well before the present study, since when the population size structure is very likely to have shifted towards smaller sizes as result of the steady increase in levels

of exploitation. Another factor accounting for this slight difference may be that in the present study comparison of the age estimated using scale and otolith interpretation suggests that scale analysis may under-estimate the age of fish, especially of those exceeding 10 years. The same observation has been reported for other reef species; for example Pauly (1976) found that age estimates for the snapper, *Chrysophrys auratus*, using scale-analysis, varied from those based on otolith interpretation. Overall Manooch (1987) suggested that, in respect of age-determination, scales are the least legible of the hard-parts. Nevertheless the maximum size of *L. nebulosus* varies between regions, being 86 cm in Australia, 62 cm in Kuwait, 87 cm in New Caledonia (FAO, 1983), differences which could most obviously be attributed either to sub-specific variation, or more easily, to differences in fishing pressure.

Measurements suggests that *L. nebulosus* achieve about 20, 32 and 41 % of their maximum length during the first three year respectively, before growth slows-down. This growth rate is very similar to that estimated by Sanders et al. (1984) from the Red Sea, but slower than that described by Morales-Nin & Ralston (1990) from New Caledonia. Such differences may be related to differences in mean temperature or to differences in habitats and food supply between areas. In the Red Sea variation in *L. nebulosus* size-at-age was relatively large, especially among the large fish. Again this variation may be partly attributed to the fact that the spawning aggregation is composed of various sub-populations, gathered from a wide area, within which ecological conditions (habitat, food supply etc.) will vary. In addition, even within the same area, individual fish may be genetically predisposed to different growth rates, or may differ in their ability to find or exploit different prey.

The estimates obtained for the *L. nebulosus* growth parameters varied both with the methods used, and with year of sampling. Estimated maximum length (L_{∞}) ranged between 62.1 cm using the Gulland & Holt method and 82 cm using the length frequency based method. The Gulland & Holt method underestimates the maximum length, since the largest observed fish exceeded the estimated maximum length. The differences in parameter estimates between years on the other hand will be consequent upon changes in the population size-frequency distribution occurring as a result of both natural year to year variation and increasing levels of exploitation. It is for this reason that most methods are based on the presence and frequency-contribution within the population of the larger size classes. For example, using the length-based estimation method, in 1995, when fish larger than 60 cm were relatively frequent, maximum length was estimated at 82.2 cm fork length, while in 1997, when no fish larger than 60 cm were recorded, and so maximum length was underestimated. Based on both age and length frequency measures from this study and on historical records (Sanders et al., 1984) the most likely estimated maximum length that *L. nebulosus* can achieve is in fact about 82.2 cm, a value which matches that obtained using the length-frequency method in 1995.

Length-frequency Analysis

It has been suggested that age determination using the length-frequency based methods is more applicable among short-lived fast-growing tropical species, in which size classes may be well separated (Pauly, 1987). By contrast in the long-lived slower growing species, as fish get older, neighbouring cohorts fuse together and separating them becomes ambiguous or impossible. This may lead to over-estimation of the growth coefficient (K), and under-estimation of the time required for fish to reach their maximum length. In the present study age estimates obtained using length-frequency based method were comparable with observed and back-

calculated age at length estimates obtained using otolith analysis up until the age of 9, but for older fish estimates obtained this way were highly variable and unreliable due to the problem of separating age cohorts as described above.

Weight-length relationship

For any given length the weight observed here was low compared to that reported by Sanders et al. (1984). He estimated a and b in the weight-total length power curve equation at 0.016 and 2.97 respectively. The differences between these values and those obtained in the present study may be due to the fact that Sanders' (1984) estimate was based on samples obtained over the whole year, whereas in the present study, fish of 32 cm and above were only obtained during the spawning season, when their condition factor may appear lower due to loss of gonad mass in those fish that have spawned. Nevertheless values obtained in the present study were very similar to those reported from New Caledonia and only slightly lower than those reported from Yemen. Thus total weight appears to be almost a cubic function of fork length. Comparing sexes, females weighed slightly more than males of the same length, principally because of a difference in mean gonad weight.

Mortality

Observed and estimated length-at-age showed that fish of age 6 and 7 years dominated the breeding stock, while fish older than 11 years were rare. Thus, given the maximum observed age and length it is apparent that population size structure is heavily shifted towards the younger age classes as a result of significant mortality. This interpretation is supported by the changes in population size structure over the study period (chapter two), which showed that as exploitation continued fish in the larger size classes became increasingly scarce, any increase in growth rate in the smaller fish size being insufficient to

compensate for this. The length-frequency data were analysed using three different methods of estimating the total mortality coefficient (Z). For the same year, estimated mortality using the Beverton & Holt and Ault & Ehrhardt methods were almost the same, but estimates obtained using the length-converted catch method were always higher. Nevertheless, in all three methods, the estimated mortality coefficient increased with over time with estimated values ranging between 0.51 and 0.56 in 1995 and between 0.68 and 0.88 in 1998.

Using two different models, natural mortality was suggested to be 0.38 and 0.41, which on subtraction from the mean of the total mortality estimated by each method for each year gives estimated mean fishing mortalities of 0.14, 0.30, 0.33 and 0.36 for the years 1995 to 1998 respectively. These estimates will reflect the exploitation level on this stock over the whole year, i.e. both when they are at Ras Mohammed during the spawning season, and when they are on their normal feeding grounds in neighbouring areas. However, historical records show that the yield of *L. nebulosus* during the spawning period (April-June) constitutes some 84 % of the total yield of this species over the whole year, indicating that fishing mortality of the stock is mainly due to fishing during the spawning season. Thus it is reasonable that the opening of the Ras Mohammed spawning grounds to intensive fishing should have led to an increase in overall fishing mortality from 0.14 to 0.36 between 1995 and 1998. These estimates of fishing mortality also indicate a rise in level of exploitation since Sanders' (1984) study. He estimated *L. nebulosus* total mortality along the Egyptian Red Sea in 1980, 1981 and 1982 to be 0.32, 0.49 and 0.65 respectively, suggesting (when suggested natural mortality is deducted) values of fishing mortality of 0, 0.1 and 0.26. These values have a mean of 0.09, markedly lower than the mean estimated in the present study.

Relative Yield per Recruit and relative Biomass per Recruit

In coral reef fishery yield per recruit models provide vital information for fisheries managers, in which population response to different level of exploitation can be predicted, especially for those species that are characterised by very low population growth (Russ et al, 1992). Gayanilo & Pauly (1993) suggested that in coral reef habitat, species characterised by low rate of natural mortality produce maximum sustainable yield (MSY) at low fishing effort (E_{max}). In this study, by using large length at first capture ($L_c=40$ or 35 cm), the values relative yield per recruit plots suggested that maximum sustainable yield can be obtained by increasing the fishing effort indefinitely, which is not realistic, especially for such predatory species targeted during spawning aggregation. Whilst, using the same parameters the relative biomass per recruit showed that the stock biomass is actually reduced to 38 % of the original size.

By using smaller length at first capture the plots produced clearly lower yield per recruit and biomass per recruit values. These appears to be resulted from the fact that exploiting this species in their resident or nursery habitats may increases the risk of stock collapse through growth overfishing, in which many fish are removed before they complete their period of rapid growth. Furthermore, exploitation of the *L. nebulosus* spawning stock during spawning period may put the stock in high dramatic risk through reduced the population size and subsequently the spawning potential below the threshold level at which they can not replace themselves.

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CHAPTER FIVE

**FOOD AND FEEDING HABITS
OF
LETHRINUS NEBULOSUS
ON RAS MOHAMMED, RED SEA, EGYPT.**

ABSTRACT

The feeding habits of *L. nebulosus* were studied, based on the analysis of gut contents of 290 specimens from fish caught from the breeding stock in Ras Mohammed and from an adjacent reef (Al-Konysa). Slight differences were observed in the diet composition between the two areas or either in relation to fish length. Crustacean organisms dominated the diet, forming 71, 81, and 79 % in terms of number, volume and weight respectively, and being recorded in 100 % of investigated samples wherever natural food items were found. This was followed by molluscs, echinoderms, and to lesser extent fish and plants. A high percentage of fish sampled from the breeding stock were found with empty gut. This appears to be influenced by the fishing method, since these specimens were caught using handline.

INTRODUCTION

On coral reefs, as in all ecosystems, determination of feeding interactions between different trophic levels is essential to understanding key ecological processes (Alheit, 1981). Information on the feeding habits and food of different organisms both facilitates modelling of energy transfer through the food web, and is important for understanding the population dynamics of commercial and other species. Predatory fish that specialise in feeding on invertebrate fauna are a major component of coral reef communities. As emphasised by Thresher (1976) the territorial range of coral reef fish is typically related to prey density rather than any other ecological factors, implying an effect of prey density on predator density.

Conversely it has often been suggested that in coral reef environments the abundance, diversity and distribution of invertebrate mobile benthic fauna may be controlled or strongly influenced by predation by such species (Hixon, 1983; Glynn 1988; Bakus, 1983; Carpenter, 1984). McClanahan & Muthiga (1988) in particular has argued that in coral reef environments predation is the key process regulating prey populations, some of which may have a critical effect on the stability of the reef ecosystem. He found that on Kenyan reefs, sea urchin population were regulated by fish predation in lightly fished areas, while in heavily fished areas sea urchin populations exploded, causing extensive bioerosion of reef structure and corals.

The extent of specialisation of predatory fish species in consuming particular categories of organisms has widely been investigated (Bakus, 1964; Wolf et al., 1983; Parrish et al., 1985). Parrish (1985) found that in Hawaiian waters mobile benthic invertebrates were the main constituent of the diet of many predatory fish species, with crustaceans typically accounting for the majority of prey items, accounting for 76 % of the food by bulk. Alheit (1981) and Guzman & Robertson

(1989) observed differences in the species composition of the diet of predatory fish between areas and seasons, which they attributed variation in the abundance of prey organisms. Furthermore, it has been suggested that coral reef fish alter their feeding habits according to prey availability. Reinthal et al. (1984) reported that trigger fish switched their diet from sea urchins (*Diadema antillarum*) to crustaceans and molluscs following the Caribbean mass mortality of sea urchins.

Little is known of the feeding behaviour of predatory fish within spawning aggregations. Robertson (1991a) and Conover & Kynard (1984) proposed that since gonad development is positively correlated with food consumption, the dial pattern of spawning may be influenced by the pattern of fish feeding during the spawning period. Sadovy et al. (1994a) and Domeier & Colin (1997) pointed out that fish that form transient spawning aggregations are mostly large in size and feed on higher trophic level organisms, while smaller fish that feed on zooplankton or small benthic organisms generally spawn locally or form a resident spawning aggregation. Domeier & Colin (1997) suggested that the frequency and duration of spawning aggregations in large predatory fish species may be controlled by the availability of prey, with fish spawning when and where there are sufficient quantities of prey to support a dramatic increase in fish density.

The emperors (Lethrinidae) are among the most common larger fish predators in coral reef environments. They are described as selective carnivorous bottom feeders that take a wide range of benthic organisms (Al- Hussaini, 1947; Walker, 1978; Jones et al., 1992). Amongst lethrinids on Red Sea reefs, one of the most abundant is the Shour or Spangled emperor (*Lethrinus nebulosus*) which is an important component of commercial and recreational fisheries along the Egyptian Red Sea coast. Sanders & Kedidi (1984) recorded that between 1979 and 1981 Shour constituted around 20% and 30 % of reef associated species caught in the

Gulf of Suez and Hurghada fishing grounds respectively. *L. nebulosus* has a wide distribution throughout the Indo-Pacific, being recorded in the Red Sea, Persian Gulf, East Africa, southern Japan and Australia. While the adults are mostly found over sandy sea-bed areas among or close to coral reefs, the juvenile stages generally inhabit either seagrass beds or mangroves (Fishbase, 1997).

Despite its commercial significance, information on the feeding habits of *L. nebulosus* is relatively limited. The information available on its feeding habits is mostly based on the analysis of a relatively small number of stomach contents as part of a broader study of lethrinids and other commercial species. Walker (1978) and Jones (1992) both investigated the feeding habits of *L. nebulosus* in Australia. They confirmed its carnivorous habits, and reported molluscs to be the largest component of the diet. By contrast, based on the examination of 15 *L. nebulosus* specimens from the north-western part of the Red Sea, Al- Hussaini (1947) concluded that crustaceans constituted the largest part by bulk of the diet. Similarly Toor (1964) found that in Indian waters *L. nebulosus* feed on crustaceans, molluscs and echinoderms in descending order of preference.

The food and feeding habits of *L. nebulosus* in the spawning aggregation at Ras Mohammed were investigated by stomach contents analysis. This chapter describes the results obtained for these fish as well as for control fish caught on an adjacent reef.

METHODS

In total the stomach contents of 290 specimens were analysed, including 174 specimens caught at the Ras Mohammed spawning ground in Jackfish Alley, and 116 specimens from Al-Konysa. Fish from the spawning aggregation were caught by hand-line from depths between 10 and 40 m; they included specimens ranging in fork length between 35 and 63 cm. Specimens from the Al-konyasa fishing ground were caught using both hand-lines or trammel-nets, from depths between one and 15 m; they ranged in fork length between 10 and 35 cm. All specimens were studied in fresh condition within two hours after removal from the sea. Each fish was measured to nearest 0.5 mm and weighed to the nearest gram.

To examine each specimen, a cut was made along the ventral side of the abdomen, and the entire alimentary tract then carefully separated. This was dissected longitudinally and its contents removed and preserved in 7% formalin in labelled plastic containers. Food items were sorted either visually or using a low power dissecting microscope. Food items were identified whenever possible but otherwise consigned to the lowest possible taxa. The level to which identification was possible depended on the completeness of the organism and its condition (the stage of digestion). Remains of fishing bait used for hand-lining (squid, sardine, and fish flesh) were easily recognised, and discarded. All pieces identified as belonging to the same taxa were counted as belonging to a single prey item, unless the pieces obviously came from two or more prey individuals. The weight and volume of each food item was estimated, to the nearest 0.1 gram and 0.1 ml³ respectively. Volume was determined by measuring water displacement of the food item in a graduated cylinder.

Based on George & Hadley (1979) and Hyslop (1980), the relative contribution of each food category to the *L. nebulosus* diet was quantified in several forms:

- (1) the percentage frequency of occurrence (F), being the percentage of the fish from among the total number examined in which a given prey item was observed
- (2) the percentage numerical abundance (N), being the proportion of each prey category among the total number of prey items.
- (3) The percentage volumetric displacement (V), being the amount of each food category expressed as a percentage of total displacement volume.
- (4) The percentage wet weight contribution (W), being the amount of each food category expressed as a percentage of total weight.

Using the above measurements, the significance of each of the components in the *L. nebulosus* diet was expressed in terms of absolute importance (A.I) and relative importance (R.I) using the following formulae:

$$AI = F + N + W$$

$$RI = AI / \sum AI$$

Also, based on Pinkas et al. (1971), for each diet category the index of relative importance (I.R.I). was calculated using the following formula:

$$IRI = (N + V) F$$

RESULTS

Of the 290 alimentary canals examined, 116 were found to be either completely void, or to contain only pieces of fishing bait. Most of the fish from the spawning ground (64 %) had an empty alimentary canal. The others had alimentary canals mostly full with natural food items, and information on *L. nebulosus* feeding habits is derived from these specimens. They were found to have preyed on a wide range of food items, mainly coral reef benthic invertebrates. These were grouped in to 10 prey categories including crabs, gastropods, bivalves, starfish, sea cucumber, fish and others.

The overall percentage numerical abundance of items in the *L. nebulosus* diet are presented in figure 1, which shows clearly that the most abundant diet item are crabs, followed by gastropods and bivalves, accounting for 71.2 , 10, and 6 % of prey items respectively. Slight differences were observed in percentage numerical abundance of diet components between the two sampling areas (see figure 2). Comments can be made on the significance and composition of the major categories as follows:

Crustaceans: These were the main component of the diet, by number (71.2 %), by weight (79.4) and by volume (80.5 %). They were also the most diverse component, though most species were Decapods which in some fish accounted for as much as 98 % of the whole diet. Brachyura (true crabs) and Anomura were both present, but largely accounted for by three families: Majidae, Parthenopidae, and Diogenidae. The Majidae (spider crabs) were represented by two species (*Menaethius monoceros*, *Cyphocarcinus ?capreolus*), the Parthenopidae by three genera (*Parthenope sp.*, *Thalamita sp.*, and *Actaea sp.*), and the Diogenidae (hermit crabs) also by three genera, *Dardanus sp.*, *Calcinus sp.*, and *Clibanarius sp.*

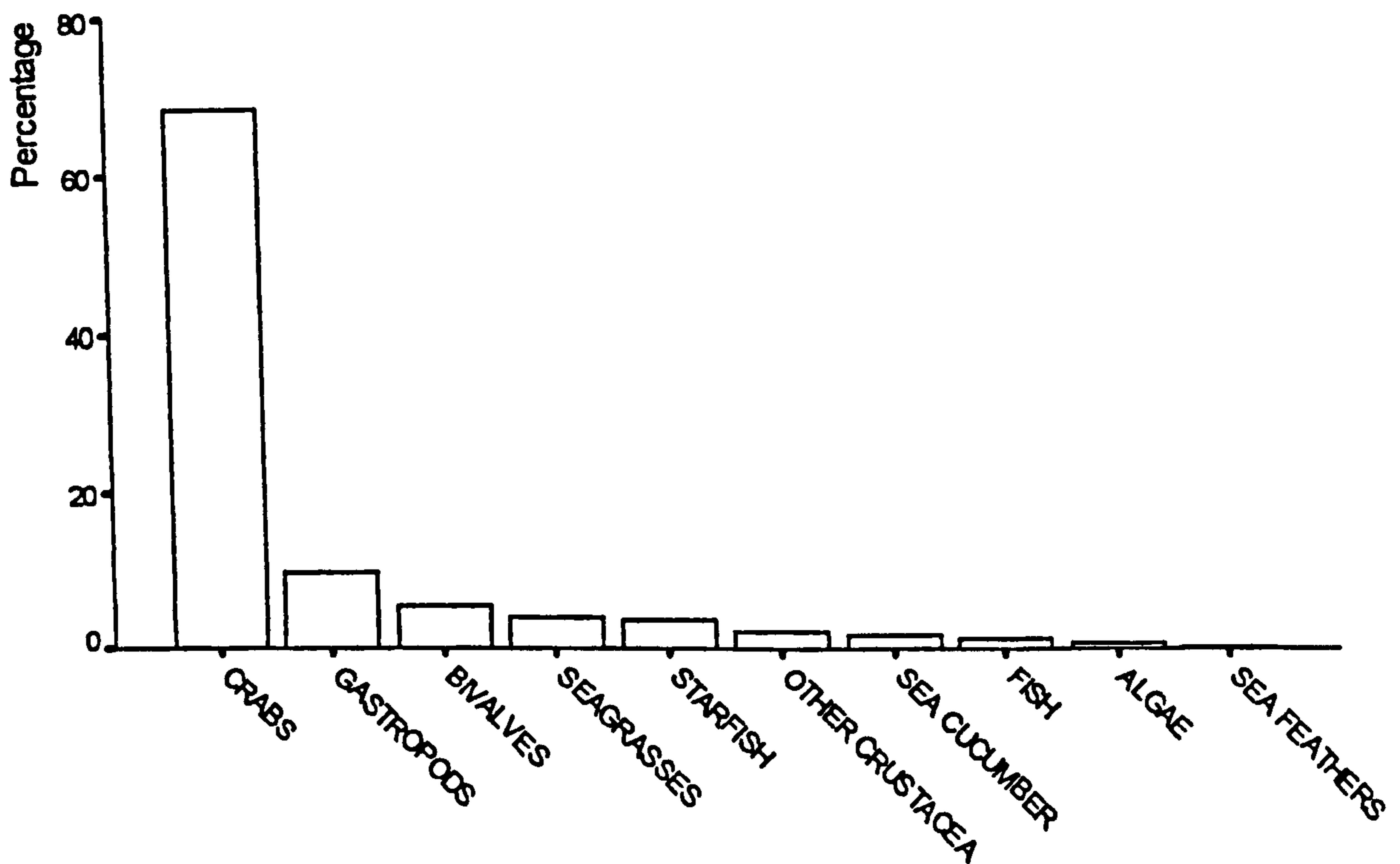


Figure 1: Percentage numerical abundance of different prey groups within the diets of all *L. nebulosus* sampled.

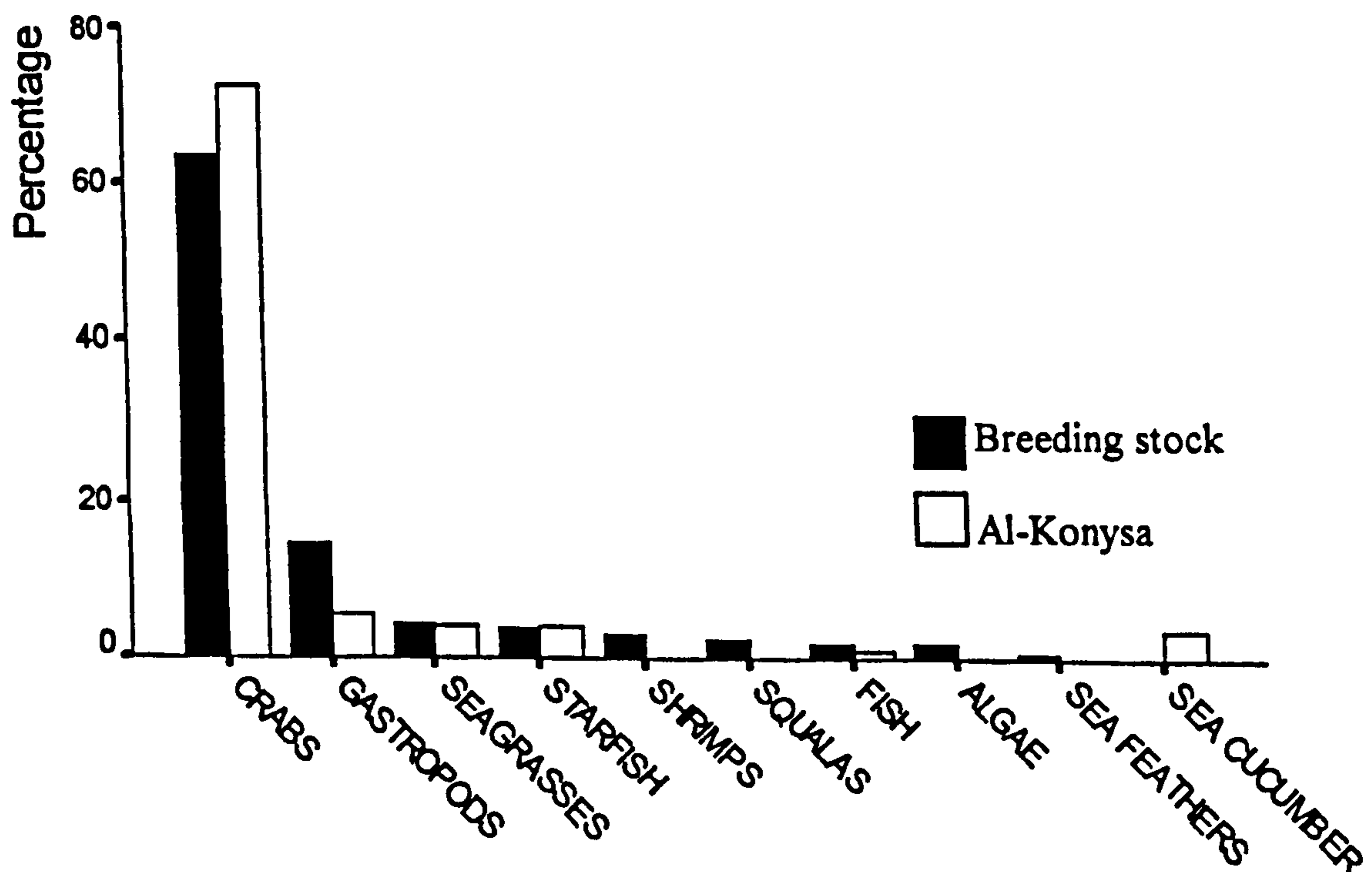


Figure 2: Difference in percentage numerical abundance of different prey groups within the diets of *L. nebulosus* from the spawning aggregation at Ras Mohammed and from the Al-Konysa area.

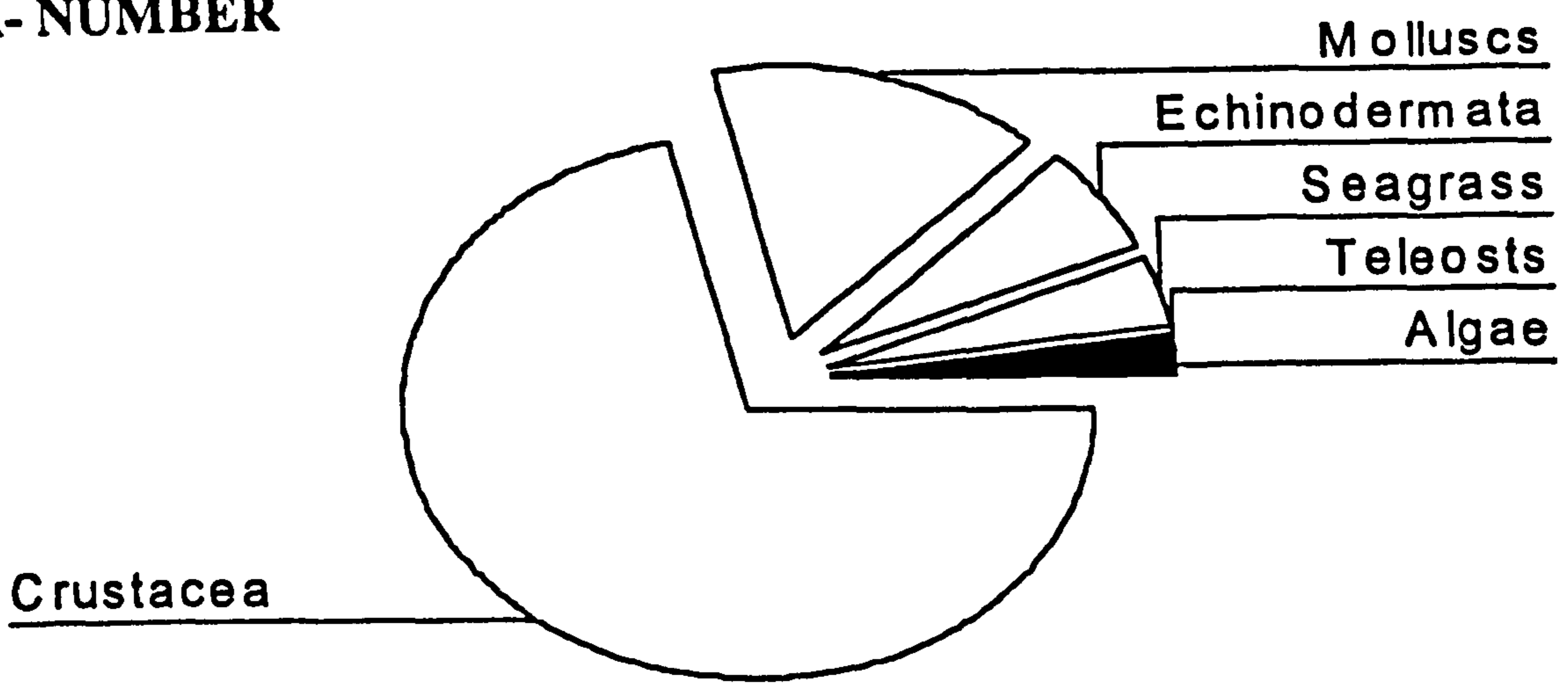
Molluscs: these were generally represented by many small individuals of various bivalve and gastropod species, their apparent significance in the diet thus varying according to the method of measurement. In terms of percentage numerical abundance they were the second most important food category, accounting for 15.4% of food items; they were present in 62 % of the specimens. By weight and volume however, their contribution to the diet was smaller, amounting to 7 and 1.8 % respectively.

Echinoderms: In terms of volume and weight, echinoderms were the second most important category, constituting 13.6 and 11 % respectively of the whole diet. They were represented by three classes: Holothuroidea (sea cucumbers), Asteroidea (starfish), and Crinoidea (feather-stars). The starfish included species of only a single genus (*Asterina sp*), which dominated the echinoderm component group by number. Sea cucumbers were less frequent, but dominated the echinoderm component by volume.

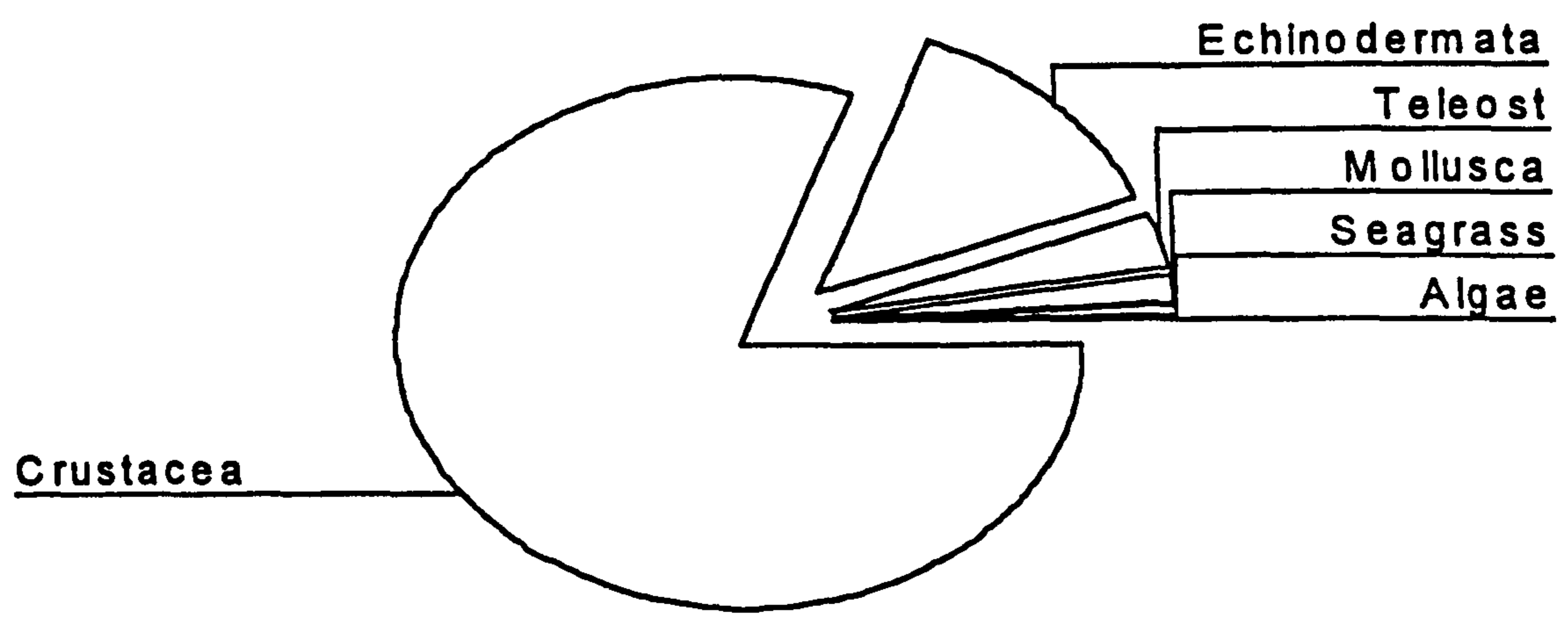
Teleosts: In terms of number, fish were uncommon within the diet, five being recorded which amounted to only 1.4 % of all food items. All were small. Two fish species could be recognised, one a species of triggerfish (Balistidae), the other a seahorse (Syngnathidae), but the others were almost digested, and so unidentifiable.

Plants: Plant material, in the form of small pieces of seagrass or seaweed, were the least important component of the diet, both in term of weight and volume. In terms of volume they contributed only 0.8 % of the whole diet. Four plant species were identified: two seagrasses (*Halodule uninervis* and *Halophila stipulacea*), and two algae (*Dictyota sp.* and *Sargassum sp.*).

A- NUMBER



B- VOLUME



C- WEIGHT

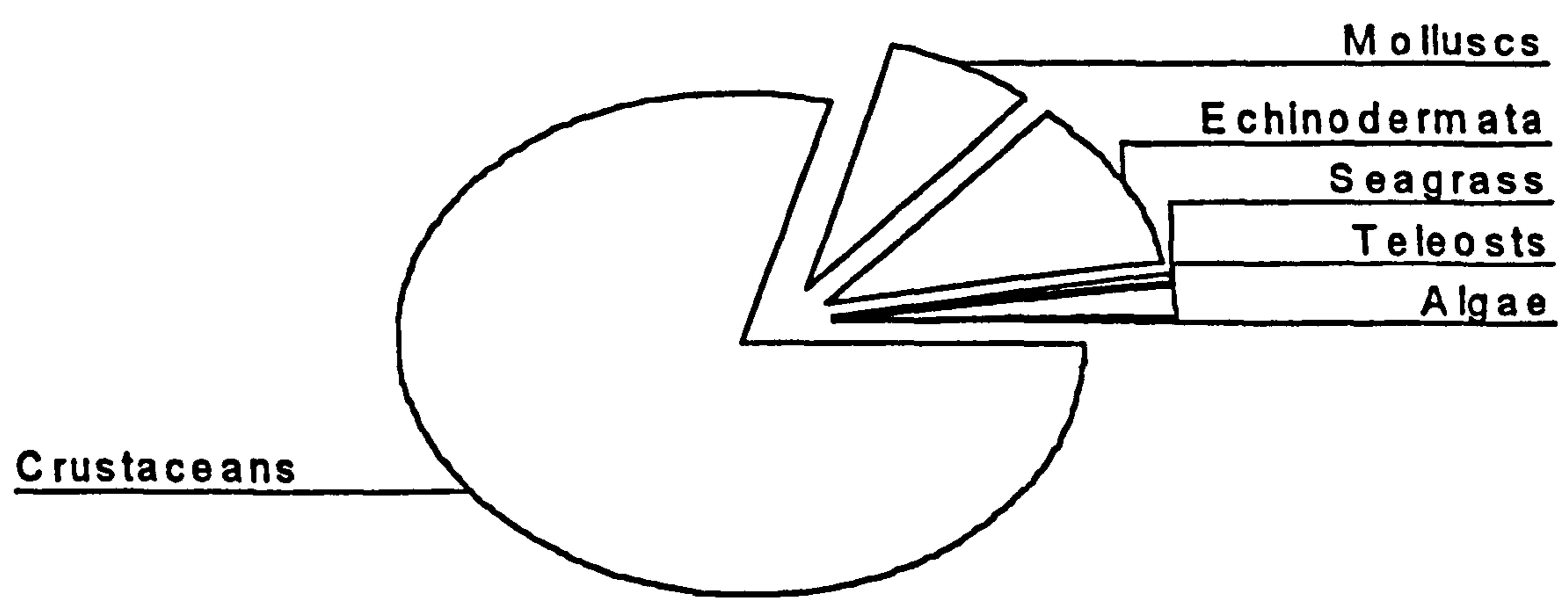


Figure 3: The overall percentage contributions to *L. nebulosus* diet by number (A), by volume (B), and by weight (C).

Using other measurements (W and V) (figure 3) gives slightly different percentage values since some food items occurred in large numbers but were small in size (crustaceans, gastropods, and plants), while others were uncommon in terms of number but large (fish and echinoderms). However, whichever measure is used crustaceans remain the main component of the diet, accounting for 81 and 79.4 % in terms of volume and weight respectively. Crustaceans were also present (F) in 100 % of the specimens wherever natural food items were recorded.

Calculated values of relative importance (R.I.) and index of relative importance (I.R.I.) are shown in figure 4. This confirms the relative importance of crustacea with values of 71.4 and 96.4 % for R.I. and I.R.I. respectively. The I.R.I. values for other food categories were markedly low.

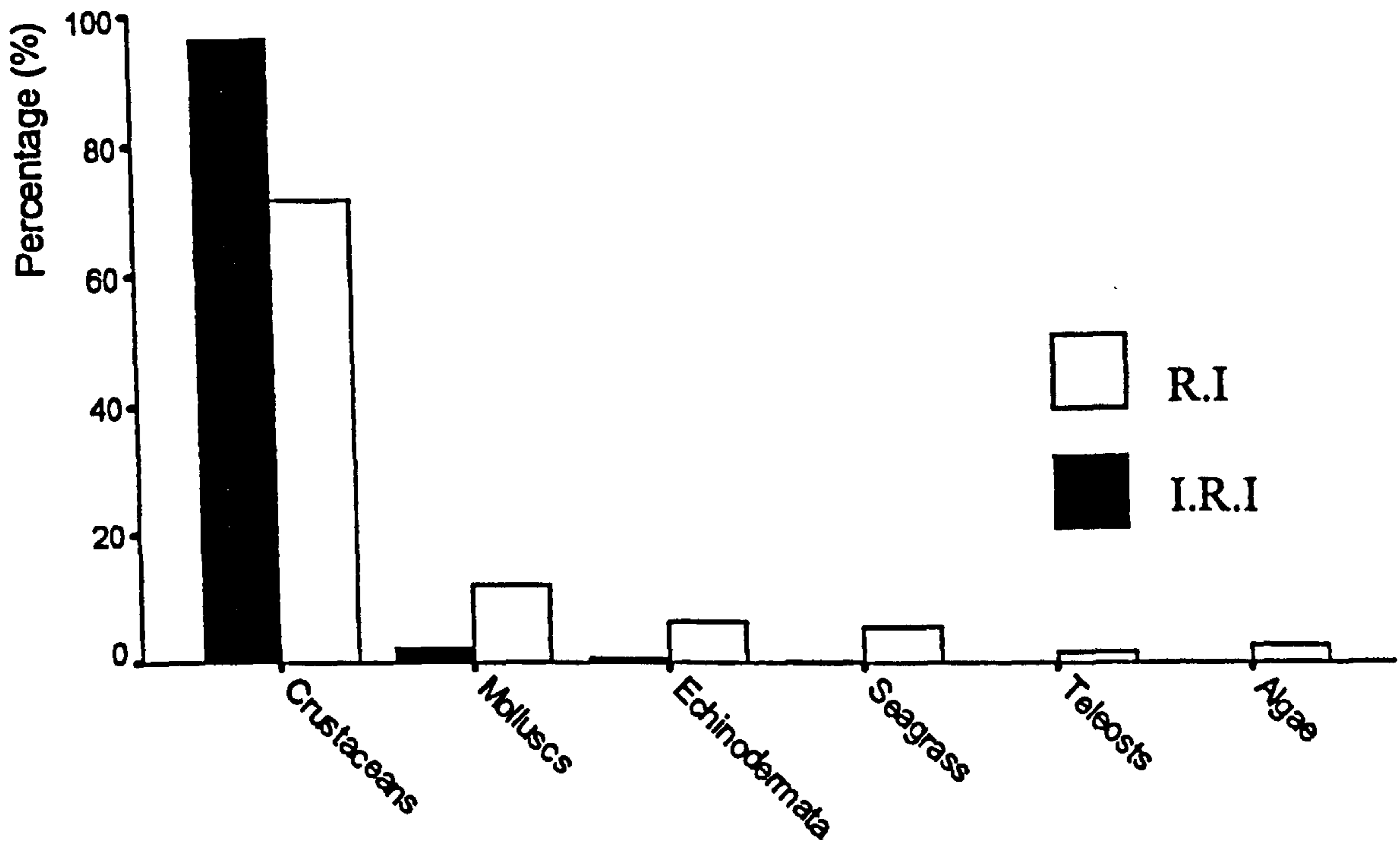


Figure 4: The relative importance index (I.R) and index of relative importance (I.R.I) of *L. nebulosus* diet categories.

DISCUSSION

Until now information on the feeding behaviour of *L. nebulosus* was based on relatively few samples. Al-Hussaini (1947) and Walker (1978) reported in brief after studying a few specimens from the north-west Red Sea and the Great Barrier Reef respectively. However, the diet composition differed markedly between the two areas. In the Red Sea Al-Hussaini (1947) found that *L. nebulosus* feed mainly on crustaceans (mainly crabs), followed by molluscs and small fish, Walker (1978) found that on the Great Barrier Reef they are molluscs and echinoderm feeders. The results obtained in this study, that *L. nebulosus* is carnivorous bottom feeder, with a strong preference towards crabs (69 %), followed by molluscs (15 %), and echinodermata (6.2 %), agrees with those obtained by Al-Hussaini (1947), suggesting that there are probably regional differences in feeding behaviour.

The relative importance of different items in the diet varied according to the method of calculation (by frequency, by volume and or by weight), but this simply reflected the fact that whereas some prey items are numerous but small in volume (molluscs), others are less frequent but often larger. The apparent relative importance of different food types could also be influenced by the level of digestion of the different food organisms. Crustaceans were more digested than any other food items and were represented mainly by the hard-parts (chela, legs, or carapaces), while other organisms, including echinoderms and fish, were much less digested. Similarly Randall (1967) found that the bias in interpretation of feeding data increased if food was obtained from the intestines rather than the stomach.

The method of fishing used to collect samples can also influence the data obtained, since different fish may have different feeding preferences or differ in their willingness to feed. Jackfish Alley specimens were caught only by hand-line, and

so were presumably hungry at the time they were caught. Specimens from elsewhere were caught using a combination of hand-lining and nets. This difference may be the cause of the higher percentage of empty alimentary canals within the Ras Mohammed specimens. Otherwise, despite the large difference in fish size-range between the two sites, there was very little difference in the composition of their diets, suggesting that the diet of *L. nebulosus* does not substantially change with size.

Effects on mobile invertebrate fauna.

Whether or not the diet of *L. nebulosus* is affected by the character of the area in which the fish are feeding (e.g. with high hard coral cover or with extensive sandy substrate) could not be determined. However, Parrish (1985) found that the benthic invertebrate fauna associated with hard substrates in coral reef areas is dominated by crustaceans (75.5 %) followed by worms (11%). Also, based on analysis of the stomach contents of 4400 fish of 108 species from 30 families, all caught in coral reef areas, he found that crustacean organisms dominated their diets and were selectively consumed, constituting 53, 48, 49, and 75 % in terms of numbers, weight, volume and occurrence respectively. Thus it appears that the diet of *L. nebulosus* in the Egyptian Red Sea is typical of fish feeding on invertebrates in coral areas.

Alheit (1981) studied the effects of feeding pressure by four predatory species on biomass and abundance of the zoobenthos. He measured a significant decrease during the period April to September, which he attributed to increase in feeding pressure during this period. Also he concluded that predatory fish were able to remove up to 3 % of benthic biomass per day. Similarly, Gilinsky (1984) demonstrated that predation rates increase during the summer, and that this produces a significant reduction in the abundance of macro-invertebrate species.

Crowder & Cooper (1982) also found that predation reduces prey biomass and mean size and alters prey community structure by removing large, active invertebrate predators in preference to smaller invertebrate predators and herbivores.

It has been suggested that the density of prey is positively correlated with the complexity of habitat structure, since complex habitats provide both food and shelter for prey species and in particular protection from predators (Crowder, 1982). In this study a strong correlation was observed between the feeding habits of *L. nebulosus* and the timing of the development of their gonads during the spawning season. This suggests that the suitability of Jackfish Alley for feeding may be a key factor behind the selection of this reef area as a spawning ground by *L. nebulosus* and some other predatory fish species. However, no data are available to demonstrate the impacts of such a concentration of large predatory fish on the benthic invertebrate community.

The possible effects on coral reef communities of a release from predation of predatory invertebrate species has yet to be investigated. Glynn (1988) demonstrated that predation in coral reef ecosystems is a key factor affecting the population dynamics of many populations. He found that in the Eastern Pacific densities of *Hymenocera picta* (shrimp) and *Pherecardia striata* (polychaete) play an important role in regulating the *Acanthaster planci* population. Furthermore, Keesing & Ralford (1992a) found that predation on *A. planci* larvae during early settlement by benthic invertebrates plays an important role in determining starfish population size. Johnson (1991) proposed that the survival of starfish populations may be enhanced if they settle in areas where predation by epifauna is low. Whether and to what extent density of invertebrate organisms on Jackfish Alley reef may have declined as a result of predation by the large number of predatory

species gathered every year, and whether or not this may influence in turn the numbers of Crown-of-thorns starfish remains difficult to determine.

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CHAPTER SIX

**OUTBREAK OF CROWN-OF-THORNS
STARFISH (*ACANTHASTER PLANCI*)
IN
THE RAS MOHAMMED NATIONAL PARK,
EGYPT.**

ABSTRACT

Since 1994 a growing number of reefs along the Egyptian Red Sea coast have been impacted by outbreaks of Crown-of-Thorns starfish (*Acanthaster planci*) outbreaks. An initial small scale outbreak involving several hundred individuals was found at Jackfish Alley at Ras Mohammed during late 1994. Subsequently during 1998 and 1999, larger outbreaks, totalling tens of thousands of individuals, have occurred on a series of reefs, both in the Straits of Tiran to the north of Ras Mohammed, and on the main Egyptian Red Sea coast, extending from near Ghardaqa south towards the border with Sudan. Samples of starfish collected from outbreak populations were aged using bands apparent in the spines. Age structures indicate that the initial population had resulted from a spawning event 1989, whereas subsequent secondary outbreaks observed in 1988 resulted from spawning of the primary outbreak in 1994. Observations of feeding scars in deep water areas, and on the movement of outbreak populations in 1994, 1998 and 1999, strongly suggests that population had lived for some years in deeper water (65 m plus), and probably recruited there, before ascending to shallower water where they were first detected. This vertical migration could be a response to two factors: the depletion of corals at depth, and the need to increase energy gain prior to spawning. Whether or not fishing activities in Jackfish Alley caused or influenced the 1994 outbreak can not be confirmed. When Jackfish Alley was re-opened to fishing in 1991 the primary outbreak population would have been already one to two years old. An effect due to a reduction in predation by *L. nebulosus* and / or some by-catch species would have had to become effective very soon after re-opening of the fishery. Also, while *L. nebulosus* appear to feed during the spawning period, their diet is dominated by crustacea, particularly crabs. Mobile benthic fauna are also known to be potential predators of juvenile starfish, hence increased starfish numbers could conceivably be a consequence of the previous closure of the fishery!

INTRODUCTION

Large populations of the Crown-of-Thorns starfish, *Acanthaster planci* (Linnaeus, 1758) were first reported on the Great Barrier Reef from the early 1960s (Endean, 1969). Since then it has become apparent that population outbreaks of this starfish can be one of the most devastating phenomena impacting reef communities, leading to massive coral mortality over a relatively short space of time, which typically requires decades to recover (Moran, 1986). Consequently the Crown-of-Thorns has become the subject of a major research effort, to the extent that it has been considered one of the most studied species on coral reefs. This research has especially been directed towards revealing whether or not, and to what extent, human interference with the natural environment has caused this phenomenon. Two potential mechanisms have been identified. First it has been proposed that the removal by fishing of key fish species could have reduced levels of predation on the starfish (Ormond et al., 1991); second it has been suggested that run-off from land of nutrients and pollutants could increase the food available to larval stages, or reduce the numbers of planktonic predators (Brodie, 1992). In spite of an immense research effort the validity of either of these hypotheses remains to be established.

Observations on the pattern of major starfish outbreaks elsewhere indicate that initially there is often a small-scale localised outbreak, referred to as a primary outbreak, which triggers a subsequent series of widespread large-scale secondary outbreaks, almost certainly as a result of dispersion and recruitment of larvae following successful reproduction of the primary outbreak (Reichelt et al., 1990). While the origins of primary outbreaks remain uncertain, it has been concluded that the scale and range of secondary outbreaks is dependent on a combination of two factors. These are the extent of larval production as a result of spawning of the primary outbreak population, and the speed and direction of the prevailing current carrying these larvae to a wider downstream area (Endean, 1986). Dight et al. (1990b) presented hydrographic evidence that Crown-of-Thorns outbreaks

along the whole Great Barrier Reef could have originated from primary outbreaks in the northern sector. This interpretation is further supported by the finding that there is no detectable genetic distinction between starfish populations on different parts of the Great Barrier Reef, despite the wide range of age and locations from which groups were sampled (Benzie et al., 1988, 1992, 1997).

Coral reefs along the Egyptian Red Sea coast are considered amongst the best-developed in the world. To protect the best reef areas together with other associated critical habitats a network of marine and coastal protected areas has been established by the Egyptian Government. These include the whole Egyptian coast of the Gulf of Aqaba, Tiran Islands and all of the off-shore islands along the mainland Red Sea coast of Egypt. However the best known of these reef areas, and the first to be protected, is the dramatic reef around the headland of Ras Mohammed.

In 1994, however, it was found that the fringing reef at Jackfish Alley on the south-eastern side of Ras Mohammed was being damaged by a small-scale outbreak of Crown-of-Thorns Starfish. Subsequently, in 1998, a series of much larger outbreak began which have affected reefs extending from the Straits of Tiran in the north to the region of Qoseir towards the southern border of Egypt with Sudan (figure 1). The Ras Mohammed National Park Authority were concerned to control these populations. Consequently an investigation was initiated into ecological and biological aspects of the outbreak, including starfish population size, population structure, movement, reproduction, and the scale of damage. In particular, in view of the coincidence of the initial outbreak occurring at Jackfish Alley, the site of the fishery for shour, suggested as one of the starfish's key predators, it was important to investigate whether or not this fishing activity had caused or influenced the outbreak.

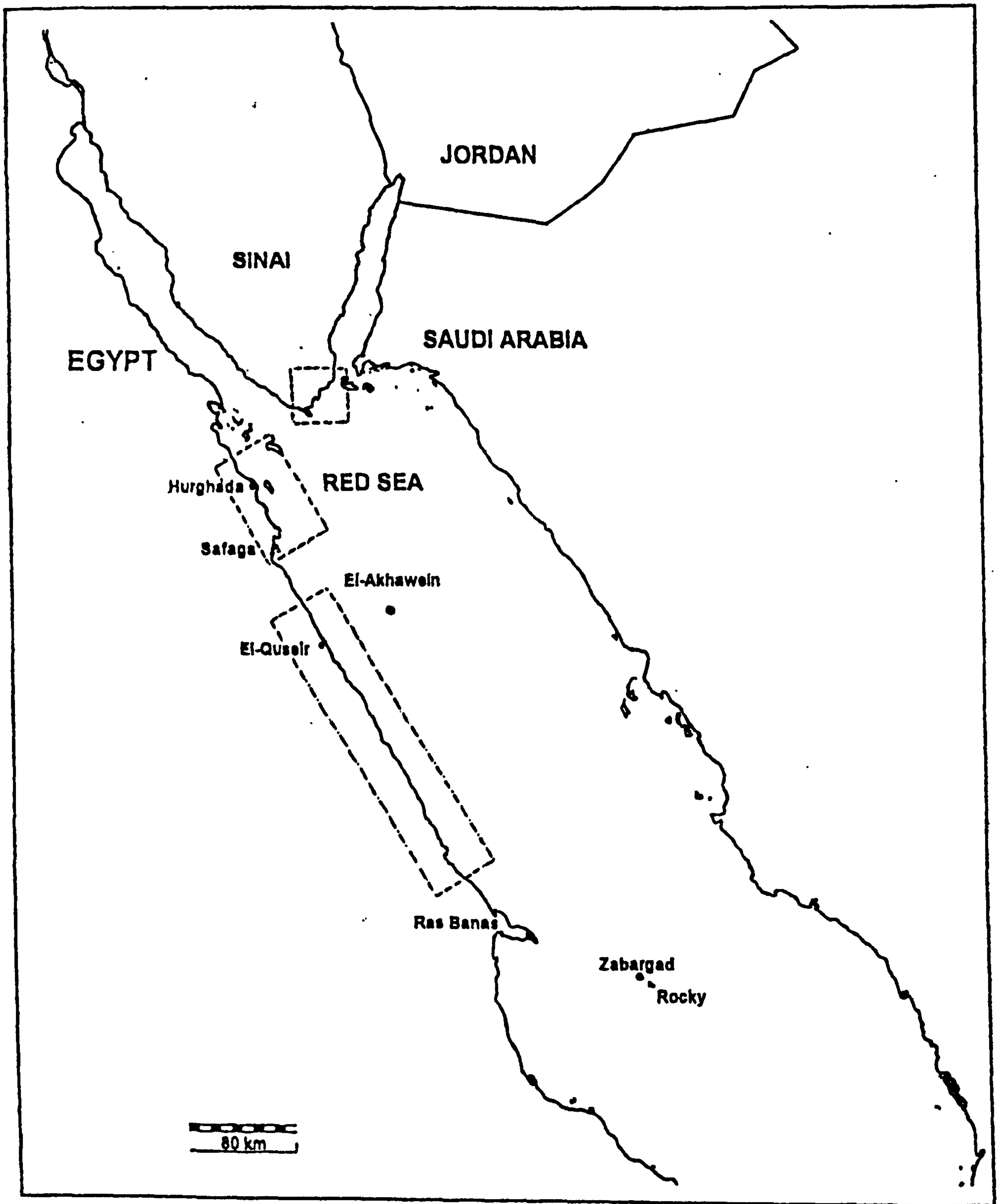


Figure 1: Map of the northern part of the Red Sea showing the main three infested areas by the Crown of Thorns Starfish in 1998.

METHOD

Reporting

In August 1994 the Park authority received from local diving centres reports of a number of Crown-of-Thorns starfish at the Jackfish Alley. Subsequently, a Crown of Thorns Starfish reporting form was designed and distributed among all of the diving centres along the Egyptian Gulf of Aqaba coast. In this form information on the starfish biology, ecology, toxicity and feeding behaviour was included. Subsequently, following the 1998 outbreak event the form was also distributed to all of the diving centres along the Red Sea coast. Dive guides were asked to record on this form the date of their dive, the name of the reef, the number of starfish observed, the depth of any aggregation, and the most frequent size class. Many of the completed forms were faxed to the Park Office.

Surveying

During both outbreak events, infested reefs were surveyed in more detail by SCUBA divers using underwater scooters. Dives were carried out at depths of 3, 15, and 25 meters, each depth being surveyed for 25 minutes by divers covering a distance of 600 to 700 m. The scooters were stopped every 5 minutes, and starfish present in an area of 5×5 m counted. Notes on the starfish feeding behaviour, movement and hiding place were also recorded. Also, the overall damage to the hard coral at different depths was estimated. In addition, a brief deep dive to a depth of 70 m was conducted at each of the infested reefs. In these dives notes made on the vertical distribution of starfish and feeding scars were obtained. In addition, between the two outbreak events, starfish populations along the South Sinai coast have been monitored on a semi-regular basis.

Control Program

Following the first Crown of Thorns Starfish outbreak at Ras Mohammed in 1994, a management decision was taken to control any unusual starfish population as soon as it appeared. Highest priority was given to control any sign of outbreak on

those reefs considered most important in term of ecological and economic (i.e. to tourism) value. Harvesting of Crown of Thorns Starfish manually was chosen as the most suitable method, given the size of the area and divers available. Hooked steel sticks (40 cm long) were used to pick animals out from the reef and push them underwater into large plastic sacks. At the beginning of the control programme experimental collecting dives were undertaken to assess and improve the efficiency of this technique. The control procedures were filmed on underwater video and the film used to instruct participants on the collection method.

Subsequently control work was carried out by two groups of divers: one from the Ras Mohammed National Park (Park rangers), and another from the local diving centres (volunteers). The Park team was fully occupied in this program, while the volunteer team participated on a part-time basis. Each infested reef was subdivided in to 100 m long (sections) with control work proceeding along the impacted area. Diving was carried out in buddy pairs, each carried one steel stick and plastic sack. The total dive time, working depth and number of starfish gathered by each diver were recorded. These records was used to assess the efficiency of this method of controlling starfish populations.

Population Size Structures

A total of 6.5 thousand randomly collected starfish specimens were measured during the course of the study. The number measured from each reef varied between 100 and 1500, depending on the size of the starfish population. On reefs that had small starfish populations, most of the animals collected were measured. Sufficient samples were measured from the more densely infested reefs. Sampling was effected during control work by selecting random plastic sacks that had been filled by collecting the starfish and these were transported to the laboratory within a maximum of two hours after removal from reef. The diameter of each starfish

was then measured as the maximum distance between the tips of two opposite arms (spines not included).

Reproduction

A total of 516 starfish representing a wide range of sizes were dissected during the period between May and September 1998. For each starfish their maximum diameter, number of arms and any sign of injury were recorded. Each specimen was then divided into four equal and symmetrical parts using a sharp knife. One part was picked randomly and all the ventral skin was carefully separated. All of the underlying gonad was then removed with care using a spatula and soft brush. Excess liquid was drained by holding the gonad for ten seconds in a 0.2 mm sieve, when any unrelated material (e.g. digestive system or skeleton elements) were also removed. Gonads were weighed to the nearest gram, and this value multiplied by four to obtain an estimated total gonad weight for each animal. A sample of each gonad was examined for sex determination using a light microscope, and a small part fixed in 7 % formaldehyde for later histological examination and fecundity estimation. Size at first maturity, sex ratio, and mean gonad weight for each size class were thus obtained. Changes in mean gonad weight over the spawning season were also thus obtained.

Ageing

Using the technique first described by Stump & Lucas (1990), a total of 110 starfish sampled were studied for age determination. Part of the dorsal skin including whole aboral spines was removed. Soft tissues were dissolved using 10% sodium hypochlorite solution. All skeleton structures were then washed in fresh water and dried at 60^o C. Periodic pigment bands, visible along the aboral spine were counted. A small number of starfish samples (N=15) collected from Jackfish Alley during the 1994 outbreak event had been similarly aged in Australia by Lassig (1994).

RESULTS.

The 1994 event

In October 1994 it was reported that the reef at Jackfish Alley (Figure 2) was infested by the Crown-of-Thorns starfish. The total number of starfish on this reef was estimated to be 200 individuals. During the day-time, starfish were inactive and hidden under coral colonies, but fresh feeding scars were used to determine the presence and hiding places of the starfish. The starfish were scattered individually over nearly 300 meters along the reef mostly at depths ranging between one and fifteen meters, with only a few individuals being observed in deeper water. They were most frequent in shallow water on the reef slope in areas of high coral cover. Original mean coral cover at Jackfish Alley was estimated at 60 %, but this was reduced within the infested area by the feeding behaviours of the starfish to about 35 %. Moving south towards the head of Ras Mohammed starfish density and feeding scar abundance decreased sharply, and most hard coral colonies remained unharmed. Moving towards the north, groups of 3 to 12 starfish were observed over the drop-off at depths ranging from 15 to 20 m. Further north at the Ras Attar only five individual starfish were recorded, all at about 2 m depth, while in deeper water, all corals appeared healthy and no starfish or even feeding scars were observed.

In November 1994, during a survey of reefs in the southern part of Marsa Bareika it was noticed that a high percentage of hard coral colonies at a depth of 45- 65 m were dead and partially overgrown by algal turf. The shapes and character of the dead patches on coral colonies were typical starfish feeding scars suggesting that this deep reef zone had recently experienced a dense population of starfish. Subsequently this deep reef area was intensively searched for any other starfish aggregation. It was noticed that the algal growth over the dead coral colonies became more dense moving towards Ras Attar and less moving towards the western side of the Marsa Bareika bay. This suggested that a starfish aggregation was moving west-ward. When the feeding scars were tracked, another Crown-of-

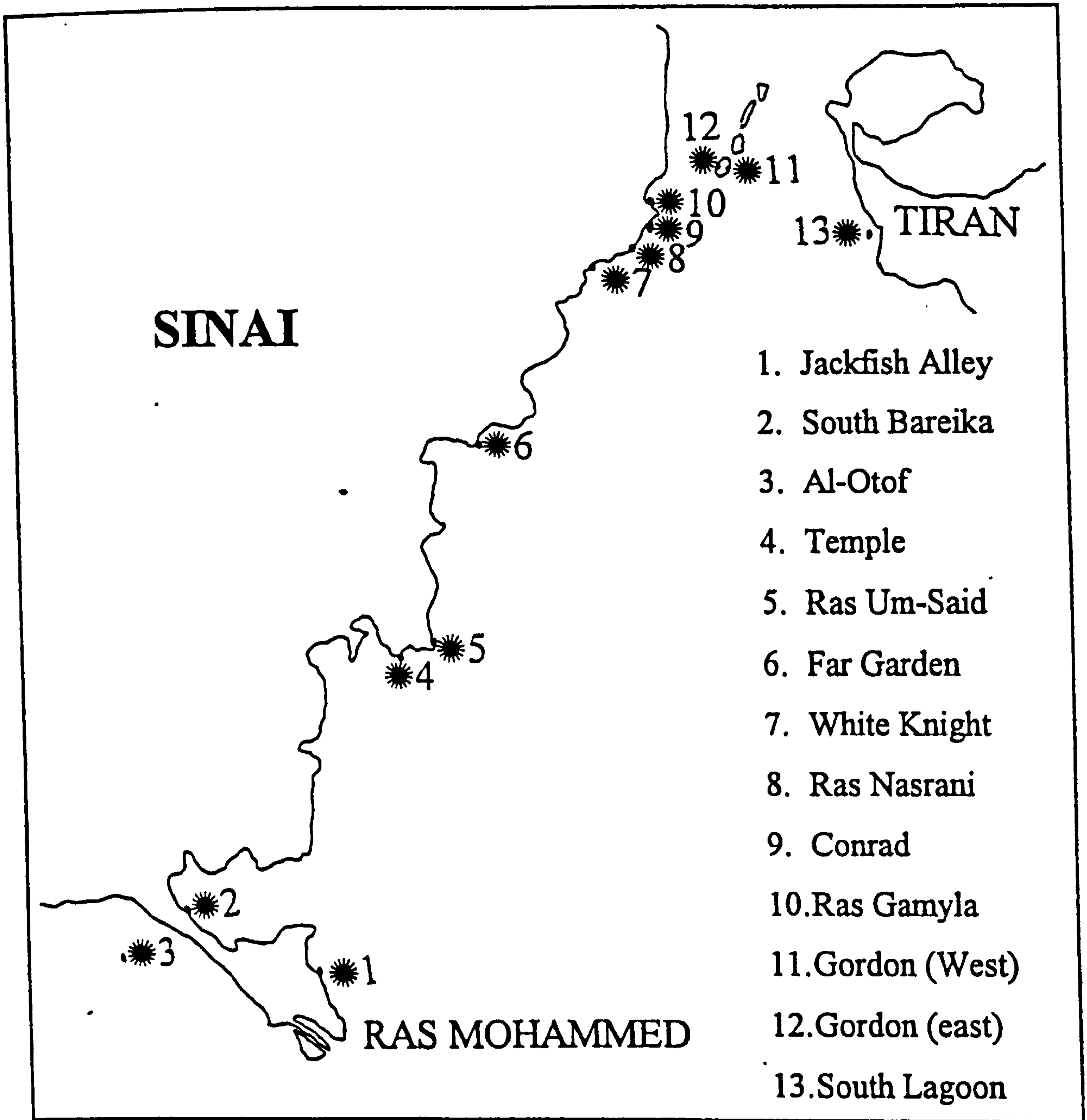


Figure 2: Map shows the infested reefs by the Crown-of-Thorns Starfish in 1994 (Jackfish Alley and South Bareika) and 1998.

Thorns starfish aggregation was discovered at the western end of the Marsa Bareika Reef, at a depth of 45 to 65 m. The starfish were very close to each other, within a 50 meter length of reef, with no starfish at less than 45 m deep.

The total number of the starfish in this population were estimated at 170 individuals. The starfish were very active, either feeding on coral colonies or moving in a west direction. Starfish movement speed was estimated at 15 m per day. The coral cover along the western part of the Marsa Bareika between 45 to 65 m was estimated at 15 to 20 %. Coral mortality resulting from starfish feeding was estimated at about 50% of the original cover at that depth. Observation on algal growth over old feeding scars and the behaviour of the starfish, in moving over the drop-off along the area between Jackfish Alley and the entrance to Marsa Bareika suggests that the Marsa Bareika starfish aggregation had originally migrated from the Jackfish Alley area.

In 1994 no other starfish aggregation was recorded on any reef between Ras Mohammed and the Straits of Tiran. The starfish population density along these reefs appeared to be normal. Nor during the period between January 1995 and the beginning of February 1998 was any sign of expansion in starfish number detected, with the maximum number of starfish counted per 2000 m² being only two individuals.

The 1998 event

South Sinai

In January 1998, during routine surveys of starfish populations in South Sinai, frequent starfish feeding scars were once again observed at Jackfish Alley (the same reef that had been infested in 1994). Observed starfish and feeding scars suggested that the population was dominated by small starfish ranging in diameters from 7 to 15 cm.; no adult individuals were recorded within this area. The total number of starfish was estimated at between 250 and 300 individuals.

They were most common at the bottom of the reef slope at a depth of 15 to 20 meters.

On 27th of April 1998, Gordon reef was surveyed to investigate the size of another outbreak that had been reported to the Park Authority. The Gordon Reef is the most southerly of four off-shore tower reefs, located in the entrance to the Gulf of Aqaba, and separated from the mainland by very deep water. It was found that the reef was seriously infested by a starfish population estimated at 25 thousand individuals. They were aggregated along 500 meters of both the eastern and the western sides of the Gordon reef, at depths of 28-35 m. At depths less than 28 meters no starfish was observed and corals were healthy. The starfish population was dominated by small size individuals, between 7 to 16 cm in diameter. By day they were mostly inactive, accumulated in groups resting next or over each other, hidden inside reef holes. The larger size starfish (about 30 cm in diameter) were however very active, moving in to shallower depths and feeding on coral colonies during the day time.

During surveys of deeper areas on Gordon Reef to investigate the vertical distribution of starfish it was noticed that most of the hard coral colonies between 35 and 45 meters deep were white and freshly dead. At this depth the coral mortality was estimated at 60 %, but increased to 100 % at 60 to 75 m. On the lower part of the reef slope (75 m) all coral colonies were dead and overgrown by dense filamentous algae, which was less evident in shallower areas, suggesting that predation in deep water had taken place earlier and for longer before the starfish aggregation moved in to shallower water. In fact the starfish aggregation appeared to be ascending in a horizontal band at a mean overall rate of movement of 0.7 m per day. Subsequently, thirteen other reefs (dive sites) were reported by dive centres to have unusually high starfish abundance. Surveys of these reefs confirmed that various reefs between Al-Ottof Reef in the south to Gordon reef in the north (Figure 2) were infested by starfish.

Starfish population size varied between reefs, but in general it differed between two regions. In the southern region, between Al-Ottof to Ras Nasrani seven reefs were infested by starfish with the total number of the starfish on each reef ranging between 150 and 600. In the northern region between Baron Reef to the Gordon reef, in Straits of Tiran, population size was much higher with the estimated number of starfish ranging between 5 and 25 thousand. The results of surveys of the infested reefs along the south Sinai coast, including the estimated population size, impacted area, mean starfish size and location of each infested reef, are summarised in Table 1. Marked differences in mean size and size range of starfish individuals between the southern and northern regions were observed. In the northern region, starfish diameter range was considerably larger but mean diameter smaller than in the southern zone (see the population structures).

Western Red Sea Coast

Along the western side of the Egyptian Red Sea coast a total of fifteen reefs were reported having a starfish population outbreak. Because of shortage of time only four reefs were surveyed in detail during early September 1998, but information on starfish population size, distribution, behaviour and population size structure was obtained via park staff in the Red Sea Islands Protectorate Department. In general all of the infested reefs along this region were off-shore reefs, with population size much lower than those recorded on the South Sinai reefs. The location of the reported population outbreaks are shown in figure 3, and in Table 1 is given summary of reef type, size of area affected, population size, and mean starfish size.

With only one exception, starfish aggregations at all of the infested reefs in South Sinai and along the Red Sea Coast showed identical behaviour in moving over time vertically from very deep water to shallow water, exactly as observed on Gordon reef. The coral cover in deep water on all of the infested reefs were severely reduced. The only exception was at Al-Ottof Reef, where no drop-off

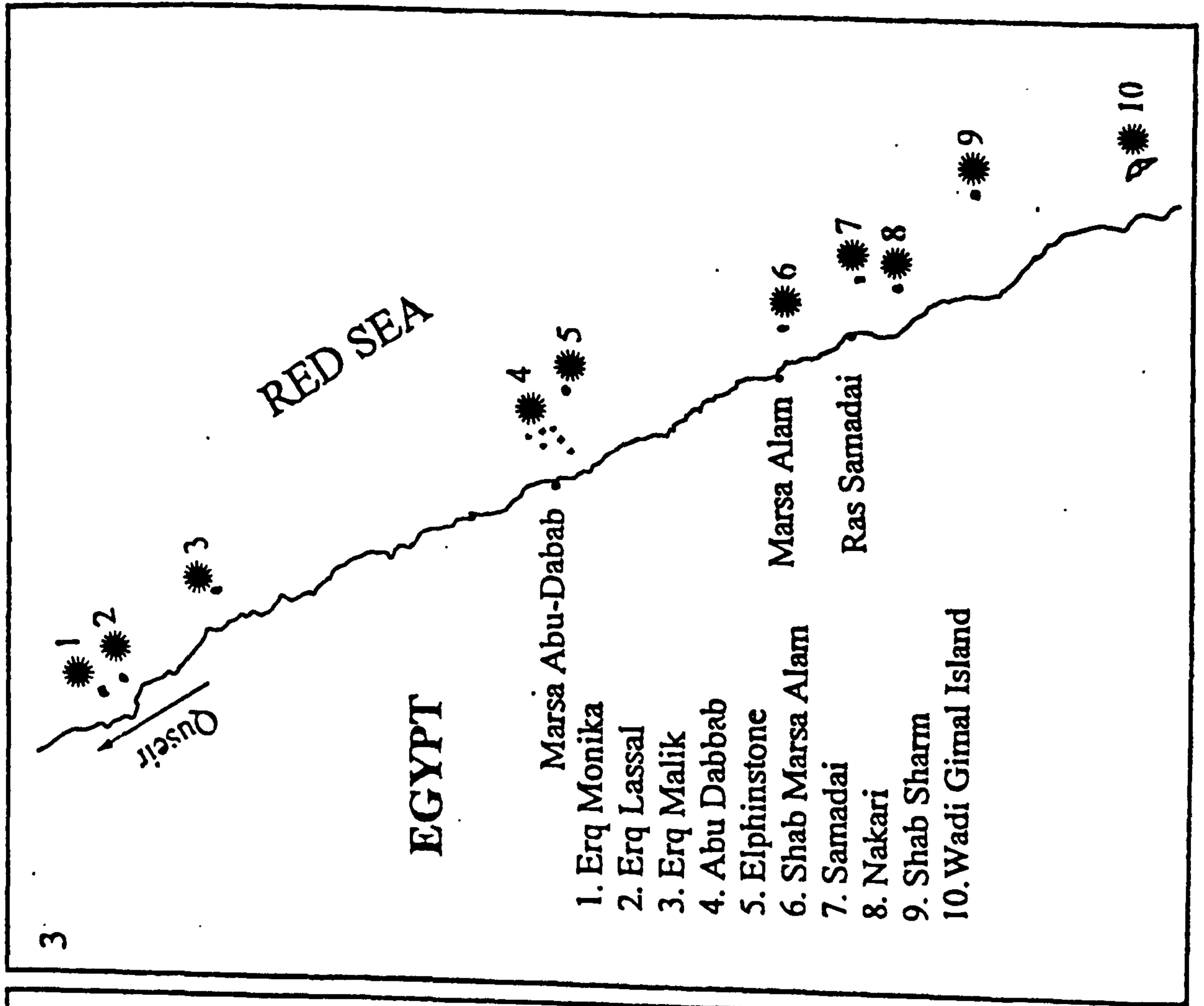
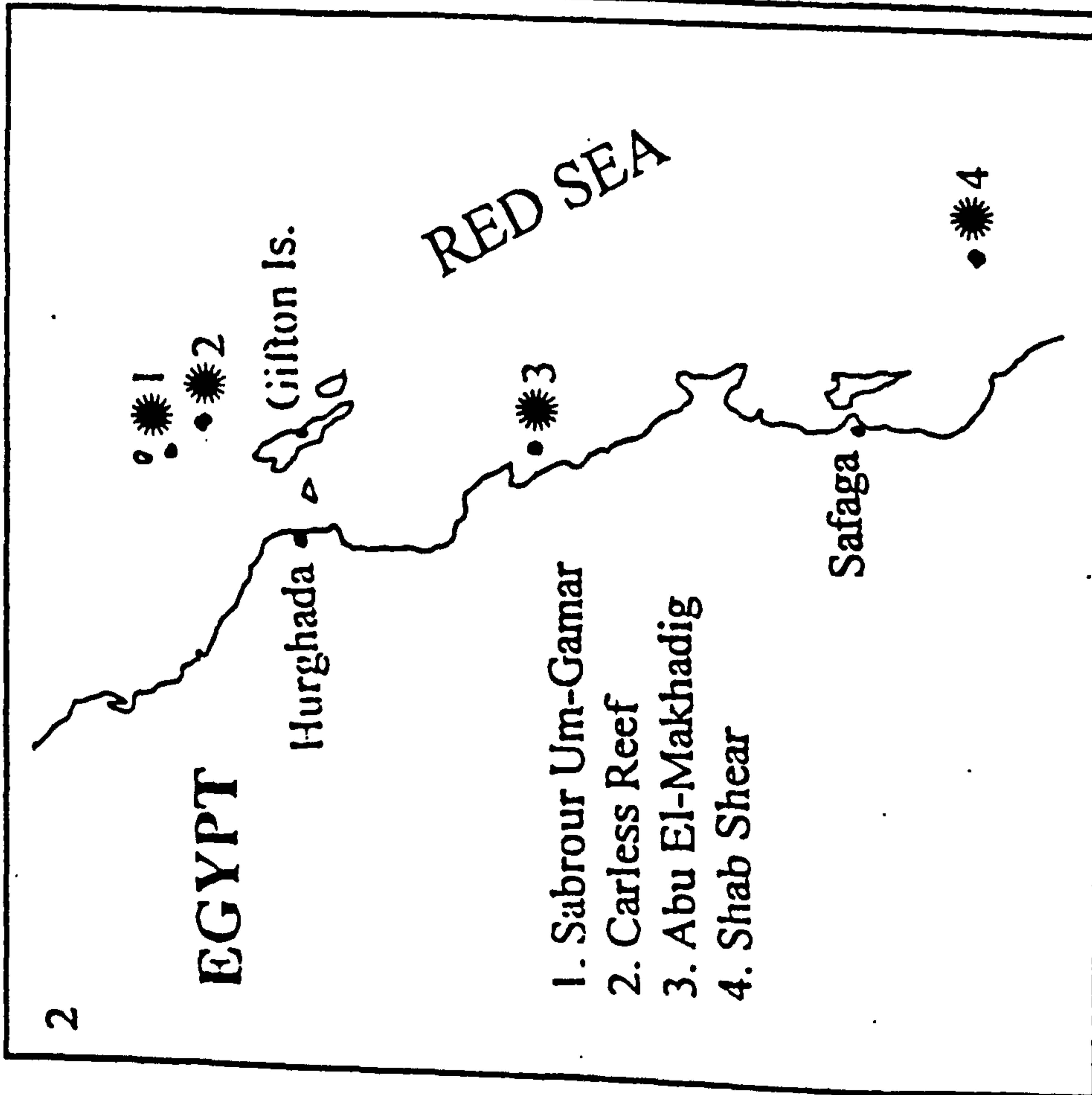


Figure 3 : Maps show the infested reefs along the western coast of the Egyptian Red Sea coast during the 1998 starfish outbreak event.

Table 1. List of the infested reefs, length of the impacted area, estimated population size, number of the starfish collected, starfish mean size and controlling effort, in the Egyptian Red Sea coast in 1998.

REEF NAME	LOCATION	REEF TYPE	IMPACTED REEF LENGTH (IN METERS)	ESTIMATED NUMBER OF THE STARFISH	COLLECTED NUMBER OF THE STARFISH	MEAN DIAMETER (cm)	CONTROLLING EFFORT (DIVES)
AL-OTTOF	27° 45' N 34° 09' E	PATCHES	100	900	301	23.85	10
JACKFISH ALLEY	27° 44' N 34° 16' E	FRINGING	400	300	0	(11)	0
TEMPLE	27° 51' N 34° 20' E	FRINGING	150	400	217	(28)	6
RAS UM-SAID	27° 51' N 34° 18' E	FRINGING	75	650	567	27.71	44
FAR GARDEN	27° 51' N 34° 20' E	FRINGING	50	70	50	(28)	4
WHITE NIGHT	27° 55' N 34° 22' E	FRINGING	150	3500	2957	(28)	38
RAS NASRANI	27° 58' N 34° 25' E	FRINGING	200	3500	2481	26.61	53
BARON	27° 58' N 34° 25' E	FRINGING	450	4500	3726	(17)	33
CONRAD	27° 51' N 34° 18' E	FRINGING	550	5000	3428	17.56	82
RAS GAMYLA	27° 58' N 34° 25' E	FRINGING	750	7000	6028	(17)	95
GORDON (WEST)	27° 59' N 34° 28' E	BARRIER	500	11000	9489	16.73	117
GORDON (EAST)	27° 59' N 34° 27' E	BARRIER	450	12000	10080	16.68	202
SOUTH LAGOON	27° 57' N 34° 30' E	FRINGING	100	800	560	(17)	7
SHABROUR	27° 21' N 33° 55' E	BARRIER	350	3500	2759	19.42	180
CARLESS	27° 09' N 33° 57' E	SUBMERGED	250	3500	1559	20.12	110

ABU EL-MAKHADIG	27° 01' N 33° 55' E	PATCHES	?	?	157	?	9
SHAB SHEAR	26° 39' N 34° 07' E	BARRIER	?	?	0	?	
ERQ MONIKA	25° 55' N 34° 26' E	BARRIER	200	1300	750	20	27
ERQ LASSAL	25° 55' N 34° 26' E	BARRIER	?	?	0	?	0
ERQ MALK	25° 46' N 34° 38' E	BARRIER	?	?	229	(20)	8
ABU DABAB	25° 21' N 34° 45' E	PATCHES	?	?	1300	(20)	83
ELPHINSTONE	25° 20' N 34° 51' E	BARRIER	?	?	0	?	0
SHAB MARSALAM	27° 21' N 33° 55' E	BARRIER	?	?	500	?	10
SAMADAI	24° 59' N 34° 01' E	BARRIER	?	?	0	?	0
NAKARI	24° 21' N 34° 00' E	BARRIER	?	?	0	?	0
SHAB SHARM	24° 48' N 34° 11' E	BARRIER	?	?	0	?	0
WADI GIMAL Is.	24° 41' N 34° 01' E	FRINGING	?	?	0	?	0
Rocky Is	23° 34' N 36° 14' E	FRINGING	250	350	60	?	6

* Information based on diving centres reports and Red Sea Island Protectorate staff.

? Confirmed infested reefs but no clear information has been obtained.

() Mean Diameter base on underwater estimation.

was located near the infested area, and the area was mostly sandy with a few coral patches. Because of the character of the area the whole reef could not be surveyed properly, but from the starfish population size and pattern of damaged coral it seemed likely that the starfish had migrated to Al-Ottof reef from another area.

Population Control

1994 Outbreak

In the 1994 event, 163 and 149 starfish were collected from the Jackfish Alley and south of Marsa Bareika respectively. Jackfish Alley was mostly cleared within 6 days by two divers, two dives being carried out by each diver every day. In Marsa Bareika, two professional divers using trimix gases were involved for two days. Both reefs were re-surveyed after starfish removal and no starfish recorded. The only starfish left after collection were those observed below the drop-off along the reef between the Jackfish Alley and Ras Attar, estimated at 90 individuals.

1998 Outbreak

In the 1998 event a total of 39.9 and 6.6 thousand starfish were collected between May and August 1998 from 18 infested reefs in South Sinai and along the Red Sea coast respectively. The number of starfish collected from each reef ranged between 150 to nearly 20000 individuals, varying not only with the size of the outbreak, but also with the depth of aggregations and the controlling effort. In South Sinai, a total of 331 and 297 dives were carried out by the Park staff and volunteer teams respectively between May and August 1998. For the Park team, the mean total number of dives and mean number of dives carried out by each diver per day were 17.4 and 2.7 respectively. While for the volunteer team the figures were 6.8 and 1.0 respectively.

A total of 22.6 thousand starfish were collected by the Park team in 17 working days giving a mean of 1.34 thousand starfish per day. The volunteer team

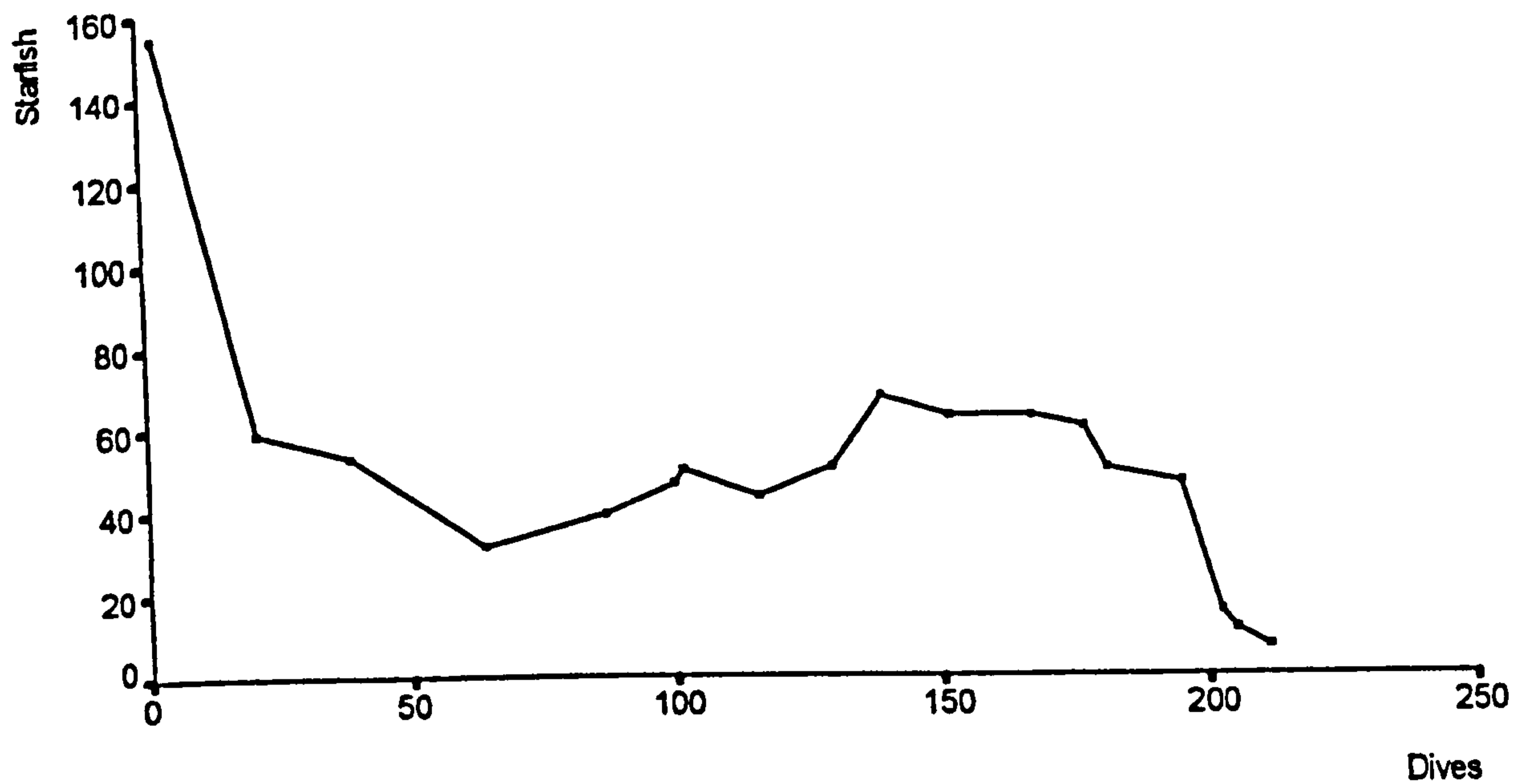


Figure 4: The relationship between the mean number of starfish collected by each diver and the accumulative number of dives on Gordon Reef.

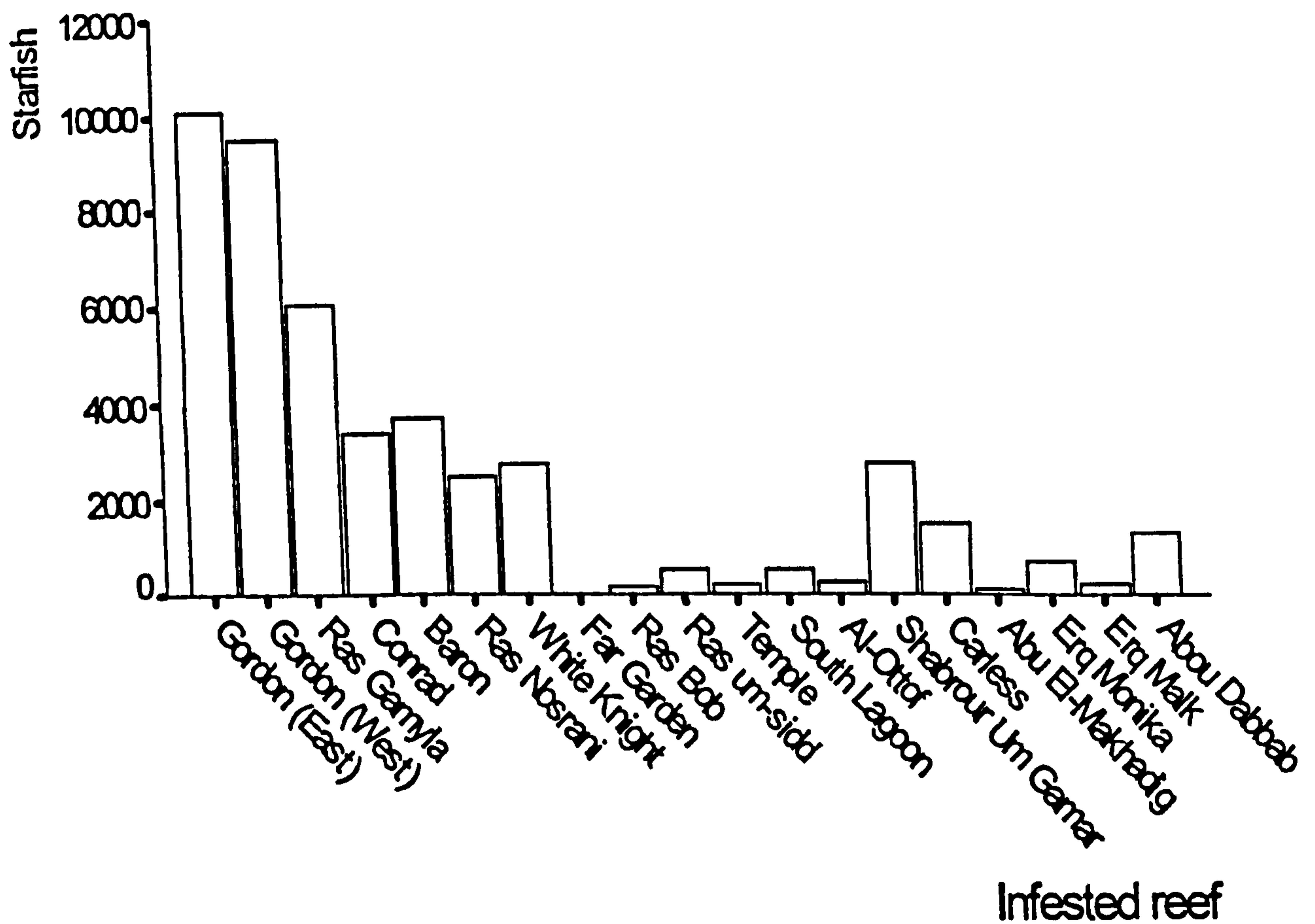


Figure 5 : The number of starfish collected from each infested reef in the Northern Red Sea during the 1998 outbreak event.

collected a total of 17.3 thousand starfish in 44 working days giving a mean of 0.4 thousand starfish per day. It was found that for the more experienced divers (in terms of diving skills and biological background) the mean number of starfish collected per dive was higher (127 starfish/dive/diver) than for less experienced divers (54 starfish /dive /diver).

Control effort on a reef varied according to the apparent size of the outbreak. Special effort was directed at reefs with large starfish populations or high ecological or economic value (in terms of tourism). Some 34 % of the effort (210 dives) in South Sinai was given to control the starfish population on the eastern side of the Gordon reef. Not only was this considered the most impacted reef, with about 12000 starfish present, but this part of Gordon reef is one of the sites most visited by divers and snorkelers. The starfish were very active and the participants were briefed on the changes in starfish aggregation location before each dive. The relationship between the mean number of collected starfish by each participant and cumulative number of dives is shown in figure 4. A total of 10,800 starfish were collected. At the beginning of the control activities three dives were carried out by the Park staff, and the mean number of starfish collected per dive was 155. This number dropped to 59 per dive when the two controlling teams started to collect. The mean number fluctuated between 40 and 68 before dropping gradually to reach 7 individuals per dive after conducting 210 dives. After two weeks the reef was surveyed and only four starfish recorded along a 200 × 10 m belt transect . The total number of starfish collected from each reef is shown in figure 5.

Population Structure

1994 event

The size frequency distribution for the whole population and for each reef separately are shown in figure 6. The distribution ranged between 15 and 40 cm. in diameter but was dominated by 25, 30 and 35 cm size classes. Starfish smaller

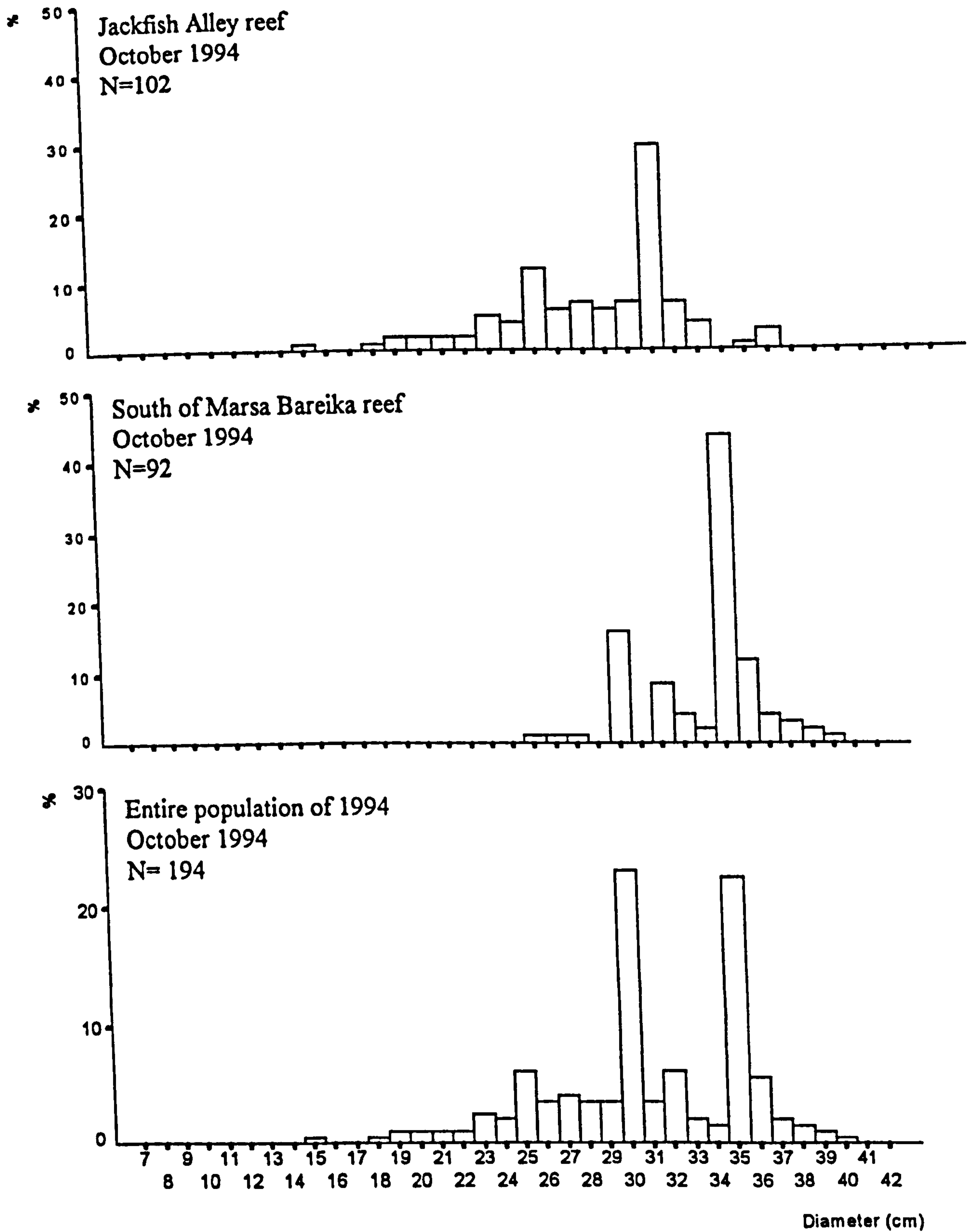


Figure 6: The diameter frequencies of the starfish of the 1994 outbreak event from Jackfish alley, Marsa Bareika and both of them combined together.

than 22 cm diameter were rare, constituting less than 5% of the total. At Jackfish Alley the starfish population was dominated by two size classes 25 and 30 cm, giving a mean of 27.4 cm.. Starfish larger than 30 cm were rare. In Marsa Barieka 97% of starfish were between 30 and 40 cm. in diameter, with the 35 cm size class constituting about 45 %. Starfish smaller than 26 cm in diameter were not recorded within this reef.

The 1998 event

The size frequency distributions of starfish populations in the 1998 event from South Sinai and from the main Red Sea coast combined together is shown in figure 7. Starfish diameter ranged between 7 and 39 cm. Three size modes at 15, 25 and 30 cm appeared within the measured sample (N = 4701). The population was dominated by small size animals ranging between 12 and 18 cm in diameter, which together constituted 42.5 % of the population. Starfish larger than 32 cm were rare, constituting only 0.8 % of the population. The starfish population was not normally distributed but skewed toward the smaller size classes.

On the South Sinai reefs the percentage size frequency, as well as the size range of starfish, varied between reefs (see figures 8 and 9). A high degree of similarity in population structure was observed between the Conrad and Gordon Reef. Starfish diameter ranged between 7 and 39 cm, and starfish larger than 32 cm were rare. The populations were dominated by smaller size classes of between 7 to 18 cm, which formed 74 and 63 % of the whole population on Gordon and Conrad reefs respectively. In the southern region (from Al-Ottof to Ras Nasrani) starfish diameter varied between 11 and 32 cm, but starfish smaller than 18 cm were rare constituting less than 2% of the population. The population was dominated by larger size classes between 22 and 32 cm diameter, which constituted 94% of the population. No juveniles were recorded.

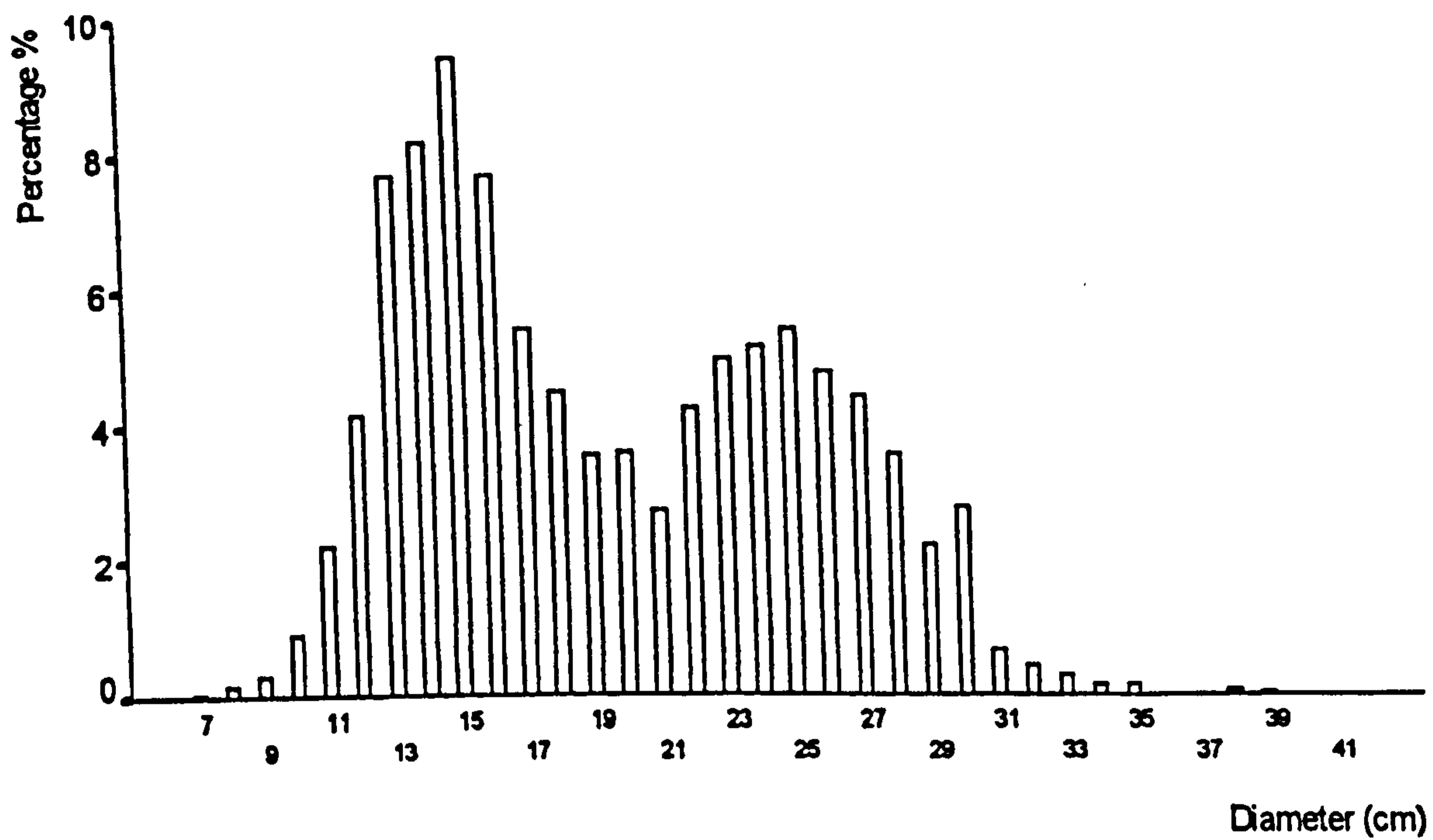


Figure 7: The percentage frequency of the starfish diameter from the South Sinai and north-west cost of the Red Sea combined together (N = 4701)

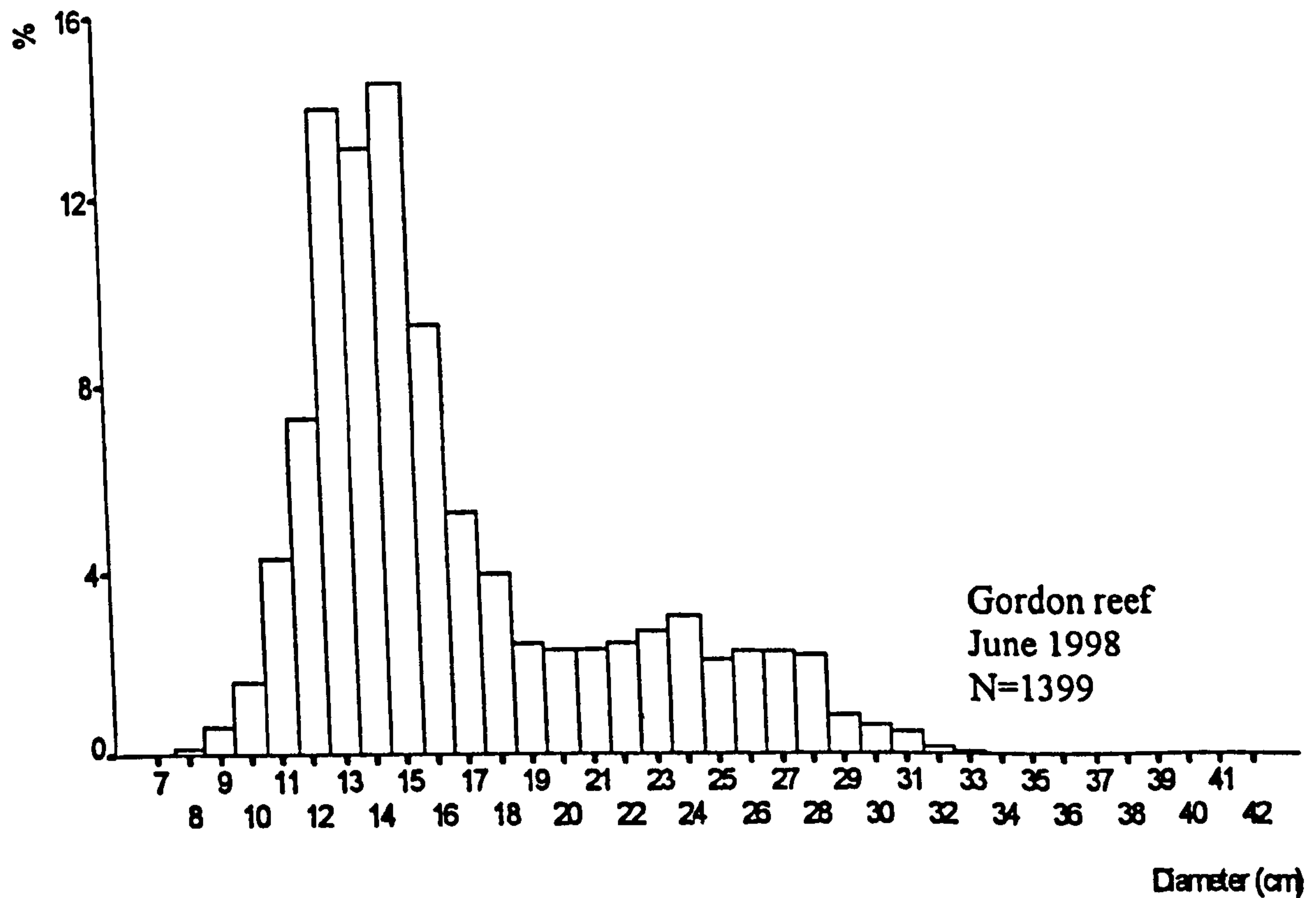
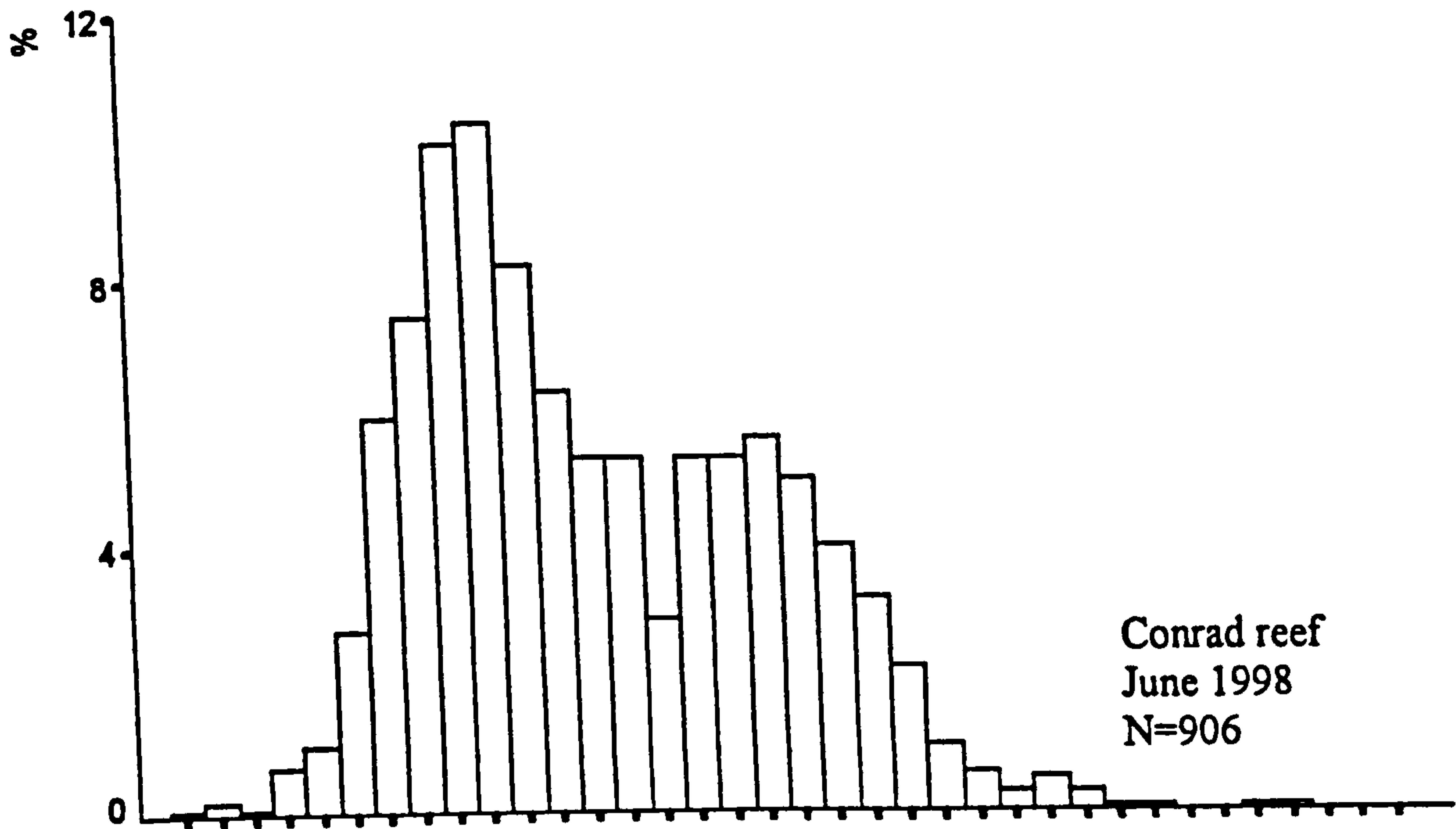


Figure 8: The percentage frequencies of the starfish diameter from the northern zone at South Sinai in 1998.

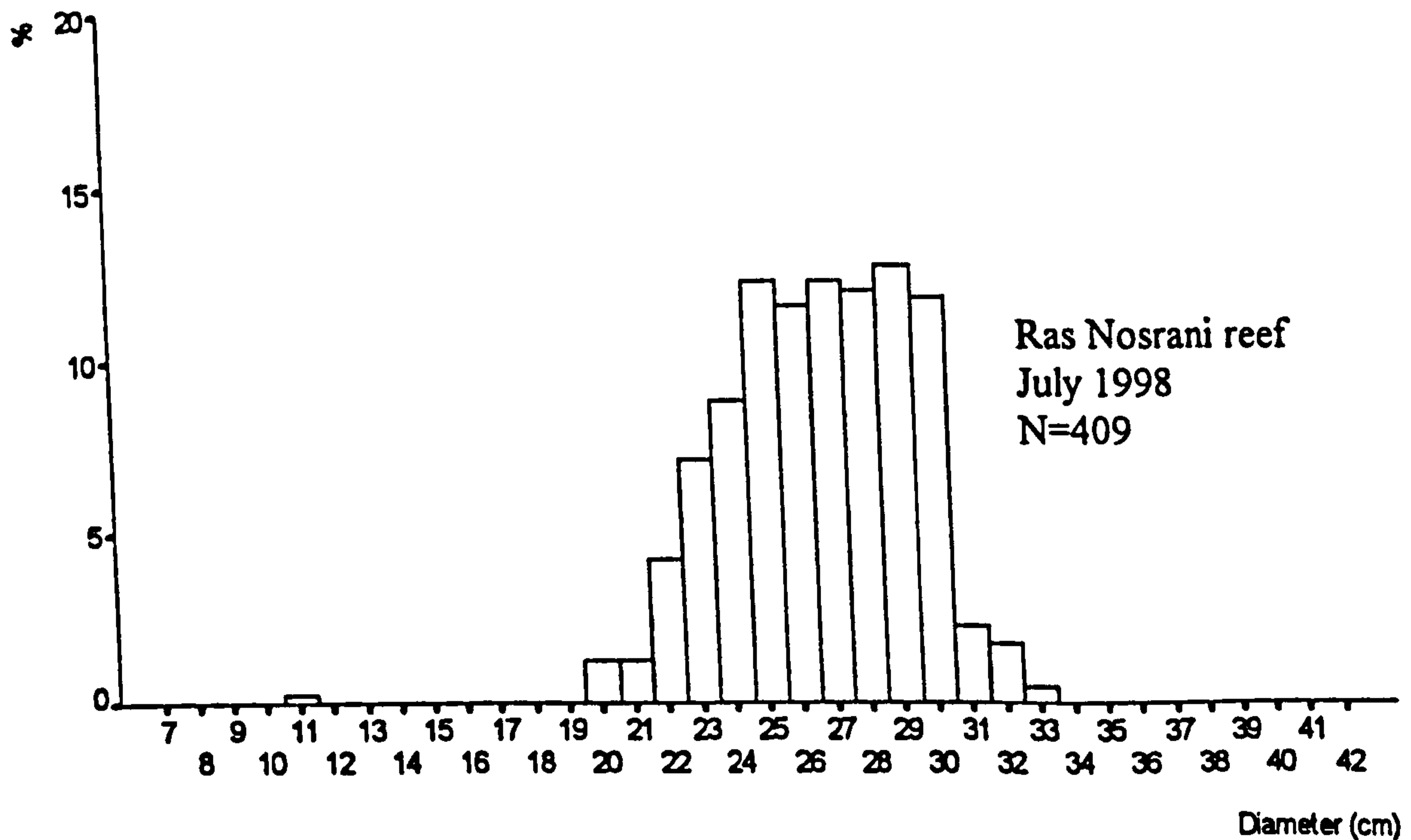
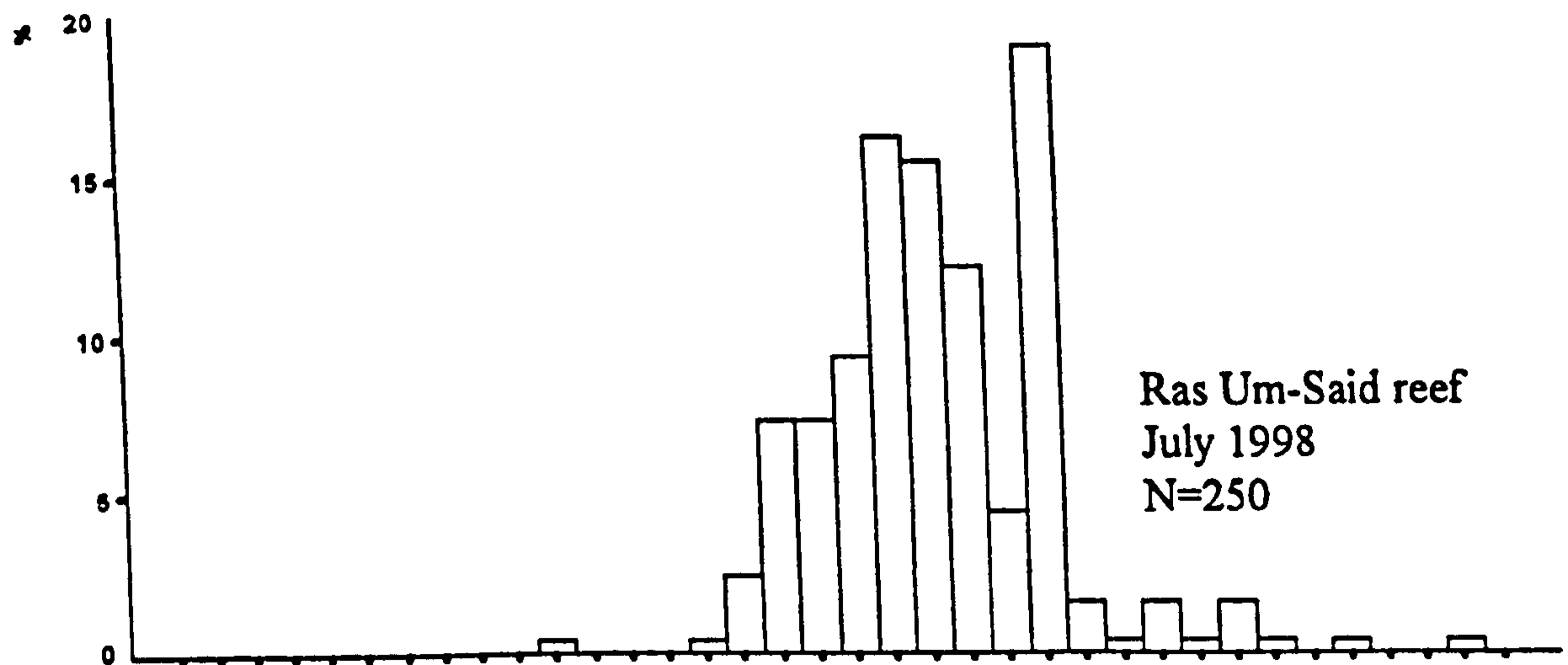
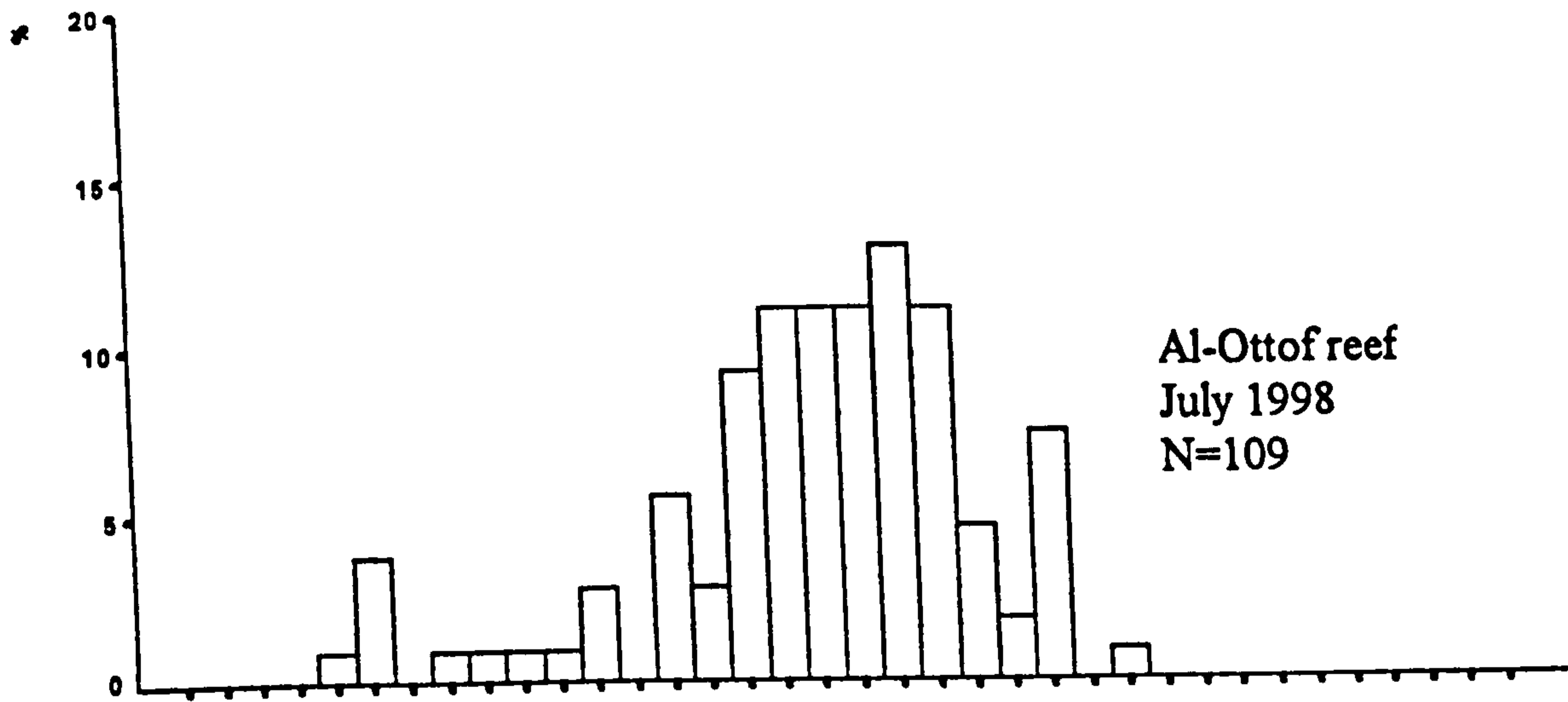


Figure 9: The percentage frequencies of the starfish diameters from the southern zone at South Sinai in 1998.

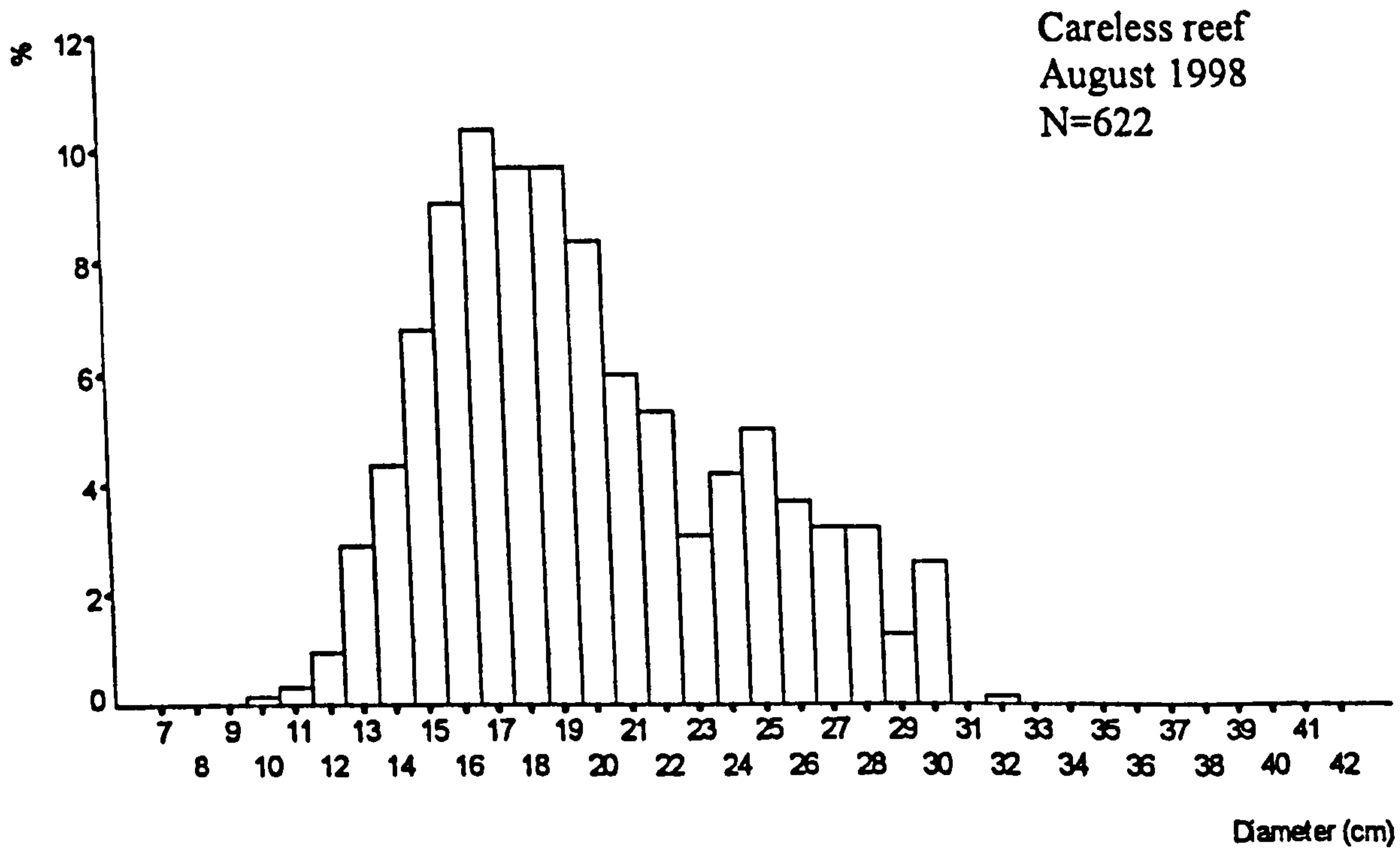
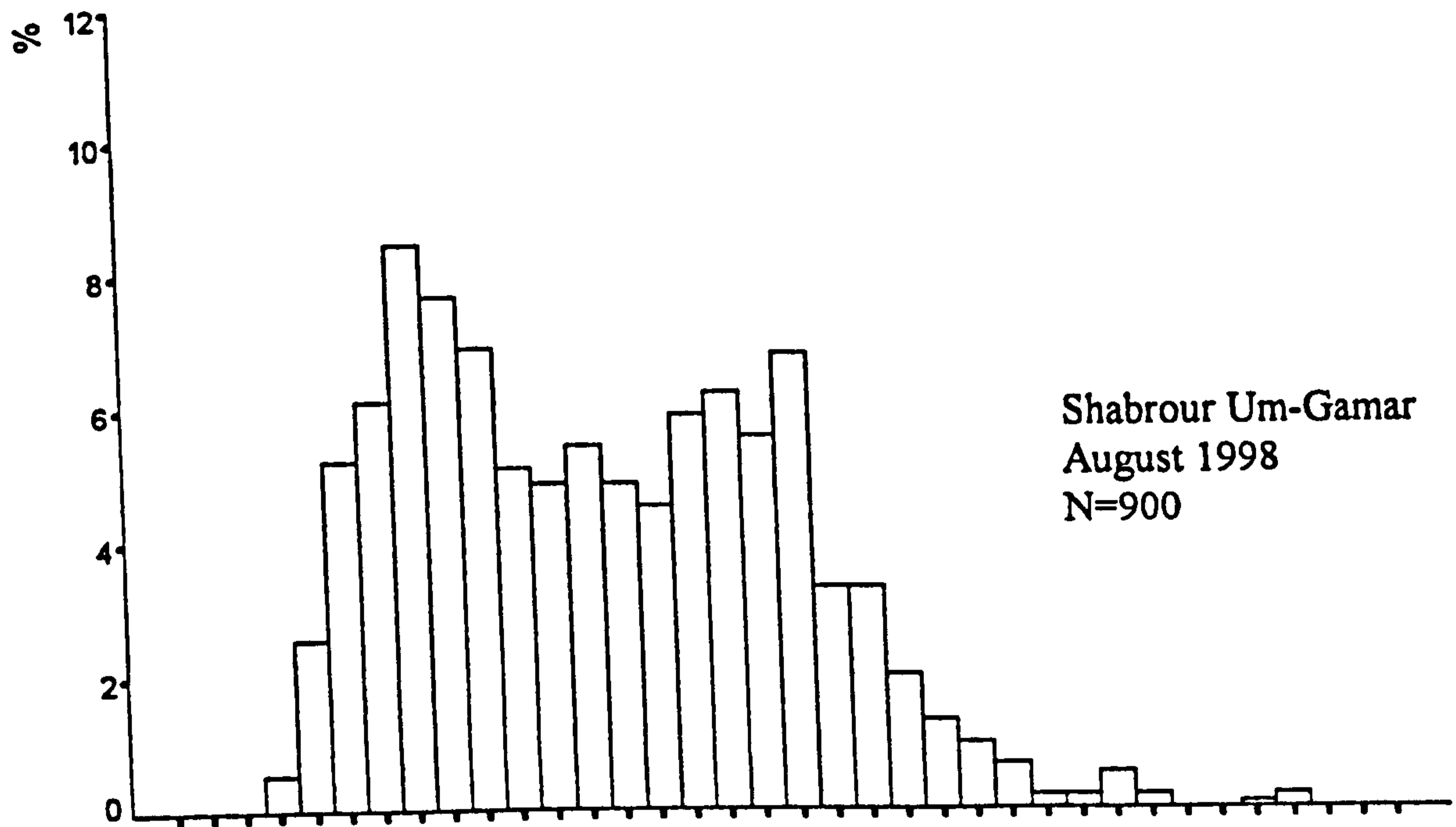


Figure 10: The percentage frequencies of the starfish diameter from the north-west coast the Red Sea in 1998.

The starfish populations along the main Red Sea coast showed size-frequency distributions similar to those on the northern region of the South Sinai reefs. Starfish diameter ranged between 7 and 40 cm with a mean of 19.7 cm. Populations were dominated by small size classes, although at Shabrour, the northern limit of the outbreak on the main Red Sea coast, larger size classes were more frequent than in the southern populations. Size-frequency distributions of the starfish on Shabrour and Careless reefs are shown in figure 10. From underwater observations, no differences in population structure were apparent among southern populations, all appearing to be dominated by small size classes, although no measures were obtained.

Reproduction

No gonad structure was observed in any starfish smaller than 11 centimetres diameter. Starfish between 11 and 17 cm showed very little gonad growth, the mean gonad weight for these sizes being 5 g. Starfish between 24 and 31 cm diameter had much larger gonads, with a mean weight of 142.5 g. No differences in sex ratio were observed between populations, the ratio of females to the males being close to 1:1. Also, there was no difference in sex ratio between starfish sizes. However mean gonad weight differed significantly between sexes, with female mean gonad weight higher by nearly 28 % compared that of the male.

The changes in mean gonad weight suggest that the spawning season of *A. planci* in the northern Red Sea is between early and mid-August. During the period from late April to early August, no reduction in the mean gonad weight was observed, but by mid-August, mean gonad weight of mature starfish had decreased to 18.4 g, constituting only about 13 % of gonad weight before the spawning season. No mass spawning was observed underwater during survey and control work, although on the 4th August a volunteer diver participating in control activities following a night dive reported that a few starfish were spawning on top of large

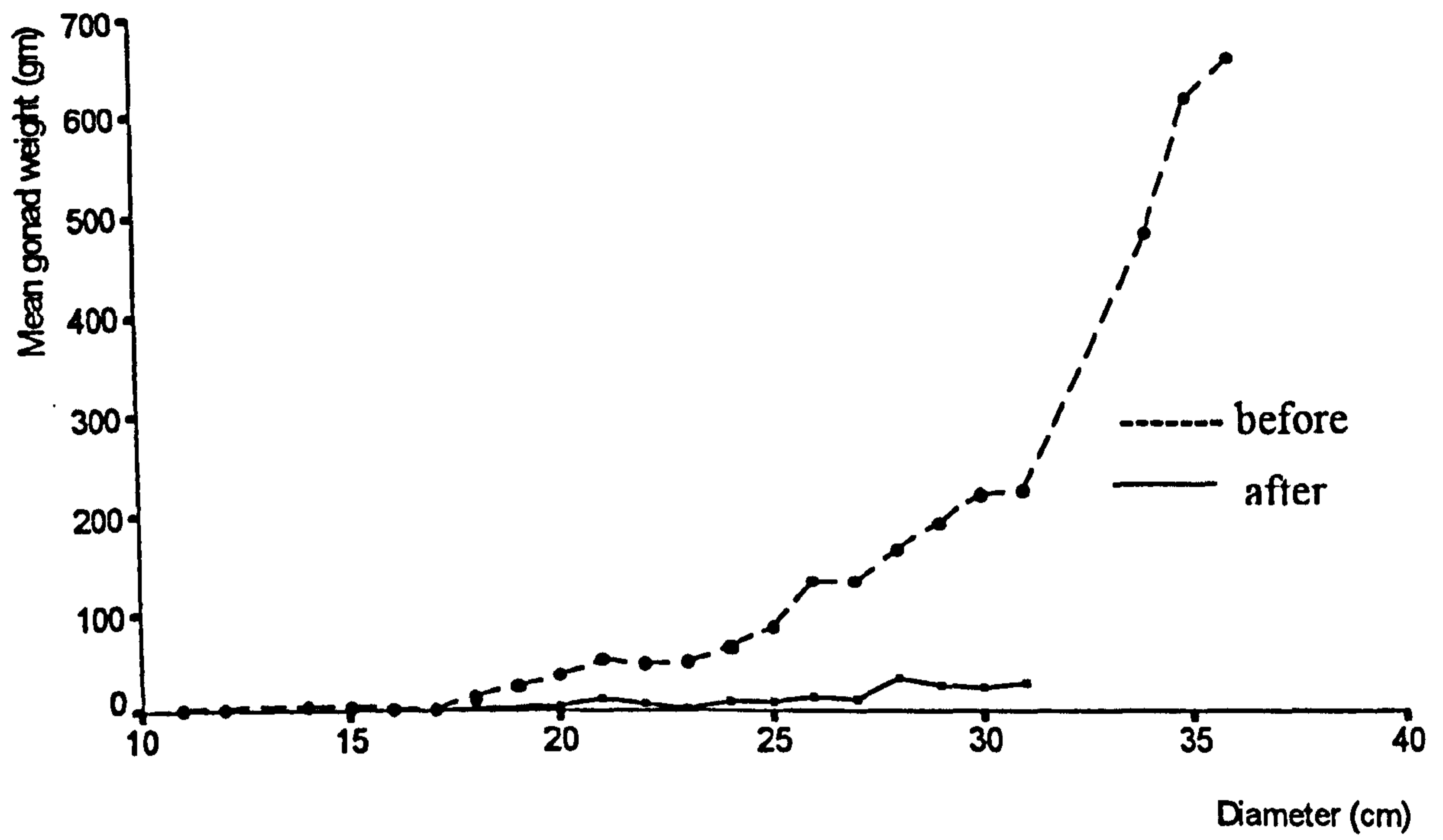


Figure 11: Relationship between starfish diameters and mean gonad weight before (beginning of August) and after (mid-August) spawning.

coral heads at about 21:00. The relationships between starfish diameter and the mean gonad weight before and after the spawning season are shown in figure 11 .

Predation

The highest percentage of starfish with injuries was recorded among the Jackfish Alley starfish during the 1994 outbreak event when 72 % (N =102) had showed some form of body injury. The extent of injury varied from losing a tip of one arm to loss of about quarter of the whole body. The starfish injury among the Marsa Bareika aggregation was much lower, estimated at 11% (N = 101). In 1998, by contrast, the injury rate among starfish was very low, being only 1.7%. These injuries were more frequent among larger starfish, with no injures being recorded among starfish smaller than 15 cm diameter. On five occasions during control work in 1998, one or other of two species of trigger fish (*Balistoides viridecens* and *Pseudobalistes flavomarginatus*) were seen attacking and feeding on large starfish. On each occasion the starfish was picked up from the reef by the fish which swam nearly twenty meters before dropping it upside down. The fish then ate the starfish from the centre of the disc leaving only the tips of the arms. Three large *Charonia tritonis* were also recorded at Jackfish Alley Reef during survey work, but none was seen feeding on starfish.

DISCUSSION

1994 outbreak

The starfish population at Jackfish Alley in the 1994 was the first recorded starfish aggregation in the Northern Red Sea. Nutrient additions, pollution by pesticides and predator removal have each been suggested as the form of human impacts on the marine environment that possibly initiated *A. planci* outbreaks in the Indo-Pacific over the last 30 years (Moran, 1986). The Red Sea is surrounded by large very arid areas characterised by a low rate of run-off, and its coastal areas are still not heavily populated, so that the amounts of nutrients and pesticides entering the marine environment are low and unlikely to be factors causing or influencing the recent starfish population outbreak along the Egyptian Red Sea coast. However Jackfish Alley is the only permitted fishing ground within the Ras Mohammed National Park boundary. Fishing has been permitted there since 1991, whereas before that time the area was closed to all forms of fishing. The changes in the total catch and as well as catch-per-unit-effort both of target migratory *Lethrinus nebulosus* and of resident by-catch species indicate that the area is now heavily exploited (see chapter two).

Predator removal as the cause of starfish population outbreak has been tested using different approaches including underwater visual observation, stomach contents analysis of predatory fish species and field experiments. Underwater observations confirm that some predatory fish species, as well as some invertebrate species, feed on adult starfish. Ormond & Campbell (1974) reported that on several occasions the pufferfish *Arothron hispidus* and the trigger fish *Balistes viridescens* were observed feeding on adult *A. planci* on a Sudanese reef, where 20% of starfish showed various degree of body injury. During survey and control work in 1994 no predation by predatory fish was observed in spite of the high rate of body injury recorded among the Jackfish Alley population. This may be because starfish populations at both infested reefs were not vulnerable to predation by diurnal fish species, although attacks by predators could take place

during night time when the starfish move out of their hiding places to feed. The Jackfish Alley starfish population was cryptic and well hidden during the day time, while, the Marsa Bareika population was at almost 65 m, at which depth the abundance of predatory fish species is very low. Recorded injuries suggested that the Jackfish Alley population experienced more attacks by predators than the Marsa Bareika population. This could be explained by the higher abundance of predatory fish in shallow as compared to deep water.

Sweatman (1997) studied the feeding habits and the gut contents of *Lethrinus miniata* and *L. nebulosus* caught on Australian reefs infested by adult starfish. No *A. planci* remains were recorded. In the present study a total of 174 *L. nebulosus* caught at Jackfish Alley were examined. The *L. nebulosus* diet was dominated by crustacean species (mostly crabs), which constituted 71 % of the total identified food items (see chapter five), and no starfish remains were recorded. However this does not prove that *L. nebulosus* does not feed on starfish, because the samples were obtained during the 1995 and 1996 Shour fishing seasons, following removal of all of the adult starfish population from the reef in late 1994.

Many of the reefs infested during the 1998 outbreak have not experienced intensive fishing. The density and abundance of predatory fish species within these reefs were high compared with many reefs unaffected by starfish. In spite of the long time spent surveying infested reefs during the 1998 starfish outbreak event only on five occasions were predatory fish (*Balistoides viridecens* and *Pseudobalistes flavmarginatus*) observed feeding on adult starfish. Also the percentage of starfish with body injury within the 1998 starfish population was very small (less than 2%). These observations suggest that predators were unable to control the large adult starfish populations, because of a low rate of predation on the starfish by comparison with starfish numbers. This study has not found evidence that predatory fish populations can control large outbreaks of adult starfish.

Population structure

Starfish population size modes over the period 1994 to 1998 suggest that the size modes of the 1994 starfish population (35, 30 and 25 cm) represented five, four and three year old starfish respectively. Similarly, the 1998 starfish population was constituted mainly of four, three and two year old starfish. This interpretation is supported by estimation of the age structure of the 1994 Jackfish Alley population using the periodic pigment bands visible in the aboral spines (Lassig 1994). This confirms that the oldest starfish in the original 1994 Jackfish Alley population were 5 years old and so settled in the area in late 1989. Following this, similar pulse settled in 1990 and a smaller pulse in 1991. Thus it appears that the starfish population discovered in October 1994 recruited to Jackfish Alley two years before the area was legally opened for fishing, with the population being dominated by two and one year old starfish when the area was opened for the first time to fishermen in May 1991. Thus it is difficult to be certain whether or not the fishing activities at Ras Mohammed National Park caused or influenced the survival of the starfish population of 1994. The size structure of the 1998 starfish population suggests that the population then consisted of four age classes (one, two, three and four years old individuals). This means that these starfish started to recruit to the reefs in 1994, with further successful recruitment pulses occurring subsequently. It was in 1994 that the Jackfish Alley population was dominated by four and five years old starfish, by which age the population would have reached a high level of spawning potential (as is demonstrated in the reproduction section in this chapter). Thus it seems likely that the 1998 population was generated by the 1994 population as a direct result of its large spawning potential, with starfish recruitment rate during the second outbreak event rising exponentially with the maturity of the starfish spawned by the initial outbreak.

Black & Moran (1992), Dight et al. (1990a), James et al. (1990), and Moran et al. (1992) suggested that major starfish population outbreak events originate from mass larval recruitment produced by a previously small aggregated population,

and the wide range of reef infestations during secondary outbreak episodes has been attributed to water mass hydrodynamics during the planktonic stage of the starfish larvae. A total of thirty reefs between 23° 34' N (Rocky Island) and 27° 59' N (Gordon Reef) experienced different levels of starfish infestation during the 1998 starfish outbreak episode. This wide range of infestation seems likely in the same way to be influenced by the current regimes along the northern Red Sea coast. The main current pattern is powered by differences in water temperature and salinity between the south and the north, and by the consequences of global rotation water turns towards the east after entering the Strait of Bab El-Mandab, flowing along the eastern side of the Asian Red Sea coast before being deflected to the west at the entrance to the Gulf of Aqaba and then head south along the African coast (Morcos, 1970). Benzie et al. (1988, 1992 and 1997) demonstrated that there were no significant differences in genetic structure of the starfish population throughout the Great Barrier reef, and starfish populations are more likely to have arisen from one source. This fits with Moran's (1986) account of how the Great Barrier Reef has experienced three main starfish outbreaks since early 60s, each of which started in the region of Green Island (northern zone) before spreading toward the southern reefs over subsequent years.

Deep water settlement

One of the main uncertainties concerning starfish population outbreaks is the ecology of starfish during the early settlement stage. All previous major outbreak episodes have been discovered as adult starfish populations, and starfish juveniles were either very rare or apparently absent within population outbreaks despite considerable effort being invested in both searching for and investigating the ecology and behaviour of the early metamorphic stages. Yokochi & Ogura (1987) detected a low density of starfish juveniles (<15 mm) on crustose algae at depths between 6 and 19 meters in the Ryukyu Islands. Zann et al. (1987) observed massive mortality (99.3 %) in a starfish population aged between 8 and 23 months previously discovered as juveniles (< 20 mm) in shallow water along Suva Reef in

Fiji. This mass mortality was attributed to disease, rough sea conditions and predation pressure. While these works suggested that starfish larvae normally settle into coralline algae rich habitats near the reef top, both Ormond & Campbell (1974) and Johnson (1991) hypothesised that starfish settle in deep water before ascending to shallow water after reaching the corallivore stage. Both based on availability of coral rubble habitats and starfish outbreak behaviour patterns.

In this study along the Egyptian Red Sea the evidence is that all of the detected dense starfish populations had lived for a period of 3 to 4 years at the base of the reef slope in depths between 60 and 75 meters before apparently moving in to shallower water. Observations on hard coral mortalities in deep water, on shape and size and algal growth over starfish feeding scars at different depths, and on starfish vertical movement on all of the infested reefs, supports view that in this region starfish settle, metamorphose and grow to the adulthood phase in deep water before moving to shallower depths. The lower part of all infested reefs during the 1998 outbreak event was dominated by crustose algae occupying up to 60% of substrate with hard coral cover ranging between only 15 to 10 %. This suggests that the deep water reef slopes provide an ideal habitat for post-settlement starfish populations in terms of food availability. In addition, all of the infested reefs during the secondary outbreak were characterised by having a deep reef slope, and reefs with shallow reef slopes did not experienced any starfish infestation. No starfish infestation has occurred on any of these fringing reefs along the mainland Red Sea coast where a shallow reef slope ends at about 25 m on a sandy bottom.

Factors affecting survival of a starfish population during and after post-settlement phases are poorly understood. The planktonic phase of the starfish may extend to a few weeks before it loses its buoyancy and settles on the reef substratum (Olson 1985; Yamaguchi, 1974). In laboratory experiments Johnson (1991) found that starfish larvae prefer to settle on the surface of crustose algae. An ability of

starfish larvae to avoid settling in shallow water areas or selectively chose to settle in deep water at reef slope bases is possible, given that vertical migration of zooplankton is a well-known phenomenon, though untested. By contrast an ability to migrate to deep water after settling in shallow water along a whole reef is unlikely. Yamaguchi (1973b), for example, estimated the speed of starfish juveniles during early post-settlement phase to be about 1 mm per minute. The present study is, however, compatible with the suggestion that during the early stages of secondary outbreaks mass settlement of starfish larvae occurs at all depths along reef slopes, but that two main factors influence survival of starfish larvae in deep water areas. First, availability of food resources required for the early life stages (abundance of crustose algae with some hard coral) is ideal. Second, a relative lack of general starfish predators in deeper water where abundance of coral reef associated invertebrates and fishes is much lower.

Possible causes of the primary outbreak.

Various scientists have hypothesised that the removal of predators of starfish through human interference with the coral reef ecosystem may be cause of starfish population outbreaks (Ormond et al, 1991). In this study, size and age structure of the 1994 starfish population suggested at first that fish removal from the Jack fish Alley is not the cause of the starfish population expansion. The area was closed to all forms of fishing for nearly ten years before it became legally open in May 1991. In the first fishing season nearly forty tons of this species, constituting nearly 25 thousand fish were caught, giving an indication of the population size at this time. The total area of the spawning ground was estimated at 0.8 km² (surface water area). The *L. nebulosus* feeding habits during the spawning season is strongly correlated with the spawning process (see chapter two and three). The feeding behaviour could cause a dramatic reduction in the abundance of the benthic epifauna which constitute the main diet of the *L. nebulosus*. One of the possible signs of habitat modification within the Jackfish Alley fishing ground was the differences in the two set of *L. nebulosus* stomach contents caught from

the fishing ground and from nearby reefs. Abundance of natural food items within the *L. nebulosus* breeding stock was lower since stomach contents were dominated by fishing baits. On the other hand *L. nebulosus* mostly take prey of a size that would correspond to 1 to 2+ year old starfish and the 1989 year would have been 2 years in 1991 and three years old in 1992. Further, as described in chapter two, there was a large by-catch associated with the fishery, which may have reduced the abundance of other predatory fish species, including large triggerfishes which feed on adult (3 years plus) starfish. Thus the predation rate of fish on sub-adult and adult starfish would decline from 1991 and so first have influenced the 1989 spawned *A. planci*.

The interaction between starfish and other benthic epifauna during the settlement stages is poorly studied, but it is thought that predation on starfish larvae during the settlement period plays an important role in determining starfish population size, and that the survival of starfish populations may be enhanced by settling in areas where predation by epifauna is minimal (Keesing & Ralford, 1992a; Johnson, 1991; Yamaguchi, 1974;1973 and Lucas, 1975). More study is needed on the effects of predation by large breeding stock on coral reef ecological balances within spawning ground areas.

Yamaguchi (1974) found that crabs feed on juvenile starfish and cause significant mortality during the early post-settlement period. A series of experiments by Keesing et al. (1992a; 1992b; 1995) have also demonstrated that a significant mortality rate ($6.5\% \text{ day}^{-1}$) within a one month old starfish population was due to predation by epibenthic fauna. This rate declined sharply among the older starfish, reaching only $0.5\% \text{ day}^{-1}$ at 7 months. Such results suggested that if starfish larvae settled in an area where predation by epibenthic fauna is low, this could lead to a local starfish population explosion. In this study crabs constituted up to 82 % of the *L. nebulosus* diet. Also it is important to note Jackfish Alley reef is a spawning ground to two other fish species, *L. bohar* and *P. gaterinus*, which both have a

similar feeding habits to *L. nebulosus*. So it is possible that gathering large number of predatory fish in a small area could lead to starfish predator release as result of the feeding of these fish on crabs and other mobile benthic fauna.

Vertical and horizontal movement.

All of the dense starfish populations discovered during the 1998 outbreak episode started to emerge in to shallow water in late March 1998. By then corals in deep water reef areas had mostly been consumed by starfish, with coral mortalities at 60 to 75 meters close to 100 % on all heavily infested reefs. It is hard to relate the vertical movement of the starfish only to a lack of food resources in deep waters, because in some lightly infested reefs, such as the Ras Um-Said Reef, the population size was small and coral mortality in deep water was much less than on other heavily infested reefs. It suggests that the vertical movement of starfish may be driven by a combination of lack of food resources in deep water and starfish maturation. In support of this interpretation the reproduction study of the starfish population in the Northern Red Sea showed that the starfish gonad starts to grow sharply at a size of 25 to 30 cm. Theoretically, at this stage, starfish need to gain energy to support gonad growth before spawning. Because food resources are lower in deeper water especially as a result of starfish feeding during the previous years, starfish may be expected to move to shallower water to search for areas of high coral coverage at the time when they start to develop gonads, four months before the main spawning season. Babcock et al. (1992), and Lucas (1973) both found that in the Great Barrier Reef starfish start to develop gonad structure in early September, four months before major spawning events were observed in mid-December.

During the 1994 outbreak appeared, a large portion of the population, constituting the larger size classes, migrated from Jackfish Alley towards the north, entering Marsa Bareika Bay. These large starfish were seen in very deep water (almost 65 meters deep). Such behaviour is difficult to explain, but it could be a strategy to

decrease feeding competition between generations. Alternatively the existence of this starfish group in deep water could be related to reef topography in the area between Jackfish Alley and the southern part of Marsa Bareika. Many starfish were observed migrating toward Ras Attar from the northern part of Jackfish Alley. The reef face at first slopes gradually towards deep water but moving towards Ras Attar the reef face drops more steeply. Moving inside Marsa Bareika, to a point nearly 500 m from Ras-Attar, the reef face becomes vertical dropping to a depth more than 100 m. Further, the reef substrate on this stretch has much less coral growth (<1 %). These features may have driven the starfish in to deeper water, before being able to ascend to a shallow depth further in to Marsa Bareika.

Ormond & Campbell (1974) reported that the overall rate of starfish movement on reefs in Sudan was typically between one and three meters per day, with average of 100 m per month for the population. In this study, starfish movement was nearly 15 m per day when the population was discovered in deep water on south Marsa Bareika reef, and their speed along the southern part of Jack fish alley was nearly double this rate. This difference in starfish movement speed between these two reefs is probably because, in the southern part of Jackfish Alley, there were only a few corals on which starfish could feed. In fact no starfish was recorded feeding on coral and coral cover along this stretch is extremely low (<1 %). In the southern part of Marsa Bareika most of the starfish were feeding on coral colonies during the day time, suggesting they had been short of food. Talbot & Talbot (1971) proposed that starfish migrate from an infested reef to another searching for more food.

Starfish Control

The control programme of the starfish population along the Egyptian Red Sea coast during the period between 1994 and 1998 was aimed at saving the aesthetic beauty of the coral reef habitats and their associated biota, from dramatic disturbance caused by the feeding habits of the starfish populations. A total of 47

thousand starfish were collected from the Egyptian Red Sea coast between May and September 1998 from 19 infested reefs, and control activities are still being undertaken. Since the starfish population outbreak phenomenon was discovered in the late 50s, many attempts have been made throughout the Indo-Pacific to control outbreak populations. Gladstone (1992) stressed the importance of controlling the starfish population during the primary outbreak phase, before the outbreak spread to wider areas during successive years. This study suggests that it is not only important to control the starfish population during the primary outbreak stage, but that it is also critical to remove such an aggregation before it reaches full maturity, because once a starfish population has spawned nothing will stop the population spreading over a much larger area.

A wide range of methods have been used to control starfish population explosions in different parts of the Indo-Pacific over the last thirty years. Poisoning starfish underwater using dry acid or copper sulphate has been considered the most efficient, cheapest and swiftest technique. However, Zann & Weaver (1988) found that copper concentrations in macro algae (*Chlorodesmis fastigiata*) and bivalve shell (*Tridacna maxima*) tissues increased dramatically after copper sulphate was used to control starfish populations on Grub reef; also divers who participated in this activity experienced high levels of copper in their blood. These results emphasised environmental and health risks of using such compounds for controlling starfish populations.

For the first attempt to control the starfish population on Gordon reef harvesting the starfish manually was chosen as the most convenient technique. Kenchington & Pearson (1982) described that on a highly infested reef each diver is able to inject up to 130 starfish per dive. In this study number of starfish collected by each diver per dive varied between the participants. For the most experienced participants the mean number of starfish collected by each diver per dive was 127.3. But for the volunteer group the number was much lower (58.2 starfish

/diver/dive). The full time divers collected in 17 days nearly the same amount of starfish that were collected by volunteer divers in five months. This difference mainly resulted from the fact that volunteer divers were not available every day so that the number of dives conducted by each diver was low. This affected the efficiency of their detecting and collecting the starfish. The number of starfish collected by most divers increased with their continuing participation in the control programme. In conclusion, volunteer divers and dive centres played an important role both in identifying the location of infested reefs along the Egyptian Red Sea coast during the 1998 outbreak event, but depending on part-time unpaid volunteers to control large starfish populations is unrealistic.

Control efforts were more efficient on reefs that had a small starfish population outbreak rather a larger one. With minimum effort on such reefs it was possible to remove all adult starfish. The starfish populations on these reefs were dominated by large size classes and because these sizes were not cryptic during the day time it was easier to find and collect the starfish. The success of control work on heavily infested reefs was affected by the level of control effort and by reef accessibility. Changes in the mean number of starfish collected per diver per dive was used as an indication of the decline in the starfish population on each reef. The only sustained progress was achieved on the eastern side of Gordon Reef, where some ten thousand starfish were collected over nearly 200 dives. At the later stage of the work the mean number of starfish collected had declined to seven starfish per diver per dive. The initial estimate of population size on this side of the reef was approximately twelve thousand starfish. At this stage starfish mean size had declined markedly, the population being dominated by very small size classes of approximately 10 cm in diameter. Due to their small size they were mostly hidden and so difficult to locate. Also their impact was much less than that of larger starfish. Hence control efforts were directed to other reefs with larger starfish sizes. Control of starfish populations along the Egyptian Red Sea will

require a long-term programme that will need to be monitored until at least the end of 2000.

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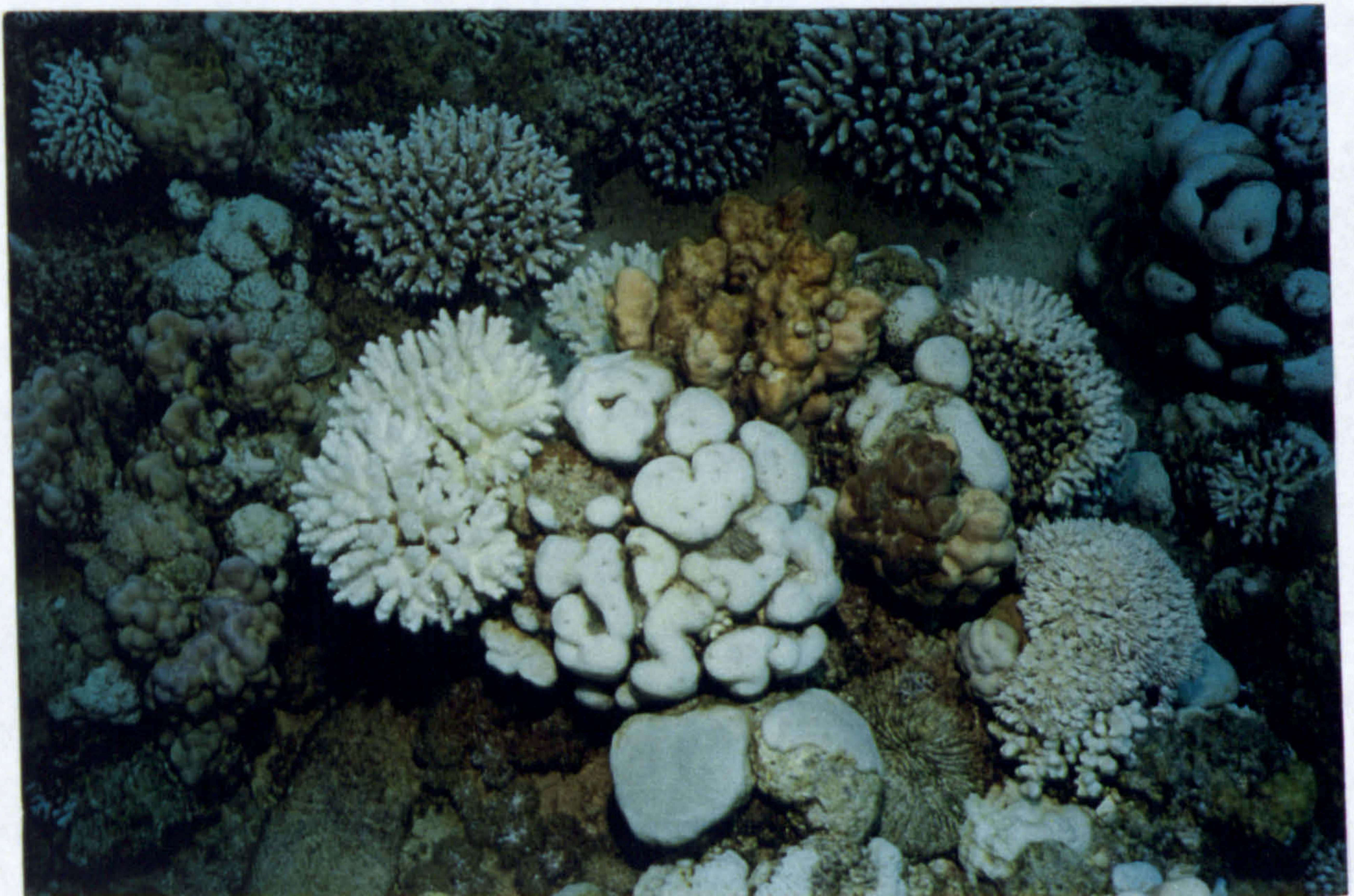
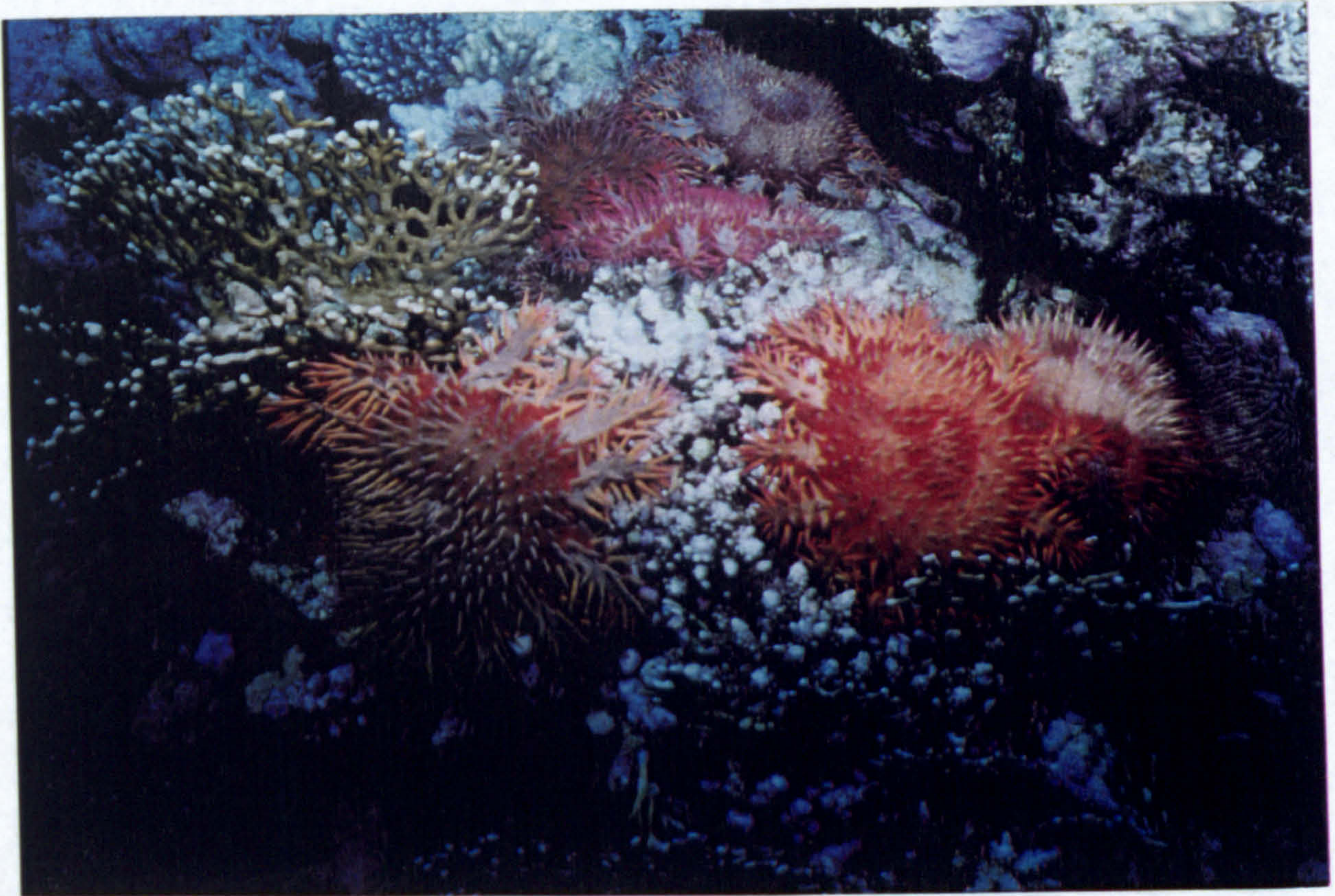


Figure 1. (top) Photograph of starfish aggregate, feeding on *Acropora* sp. colony during the day time in Gordon reef. (bottom) Photograph shows the devastating effect of the starfish feeding habit on hard coral cover (note that almost all colonies are partially or entirely consumed).

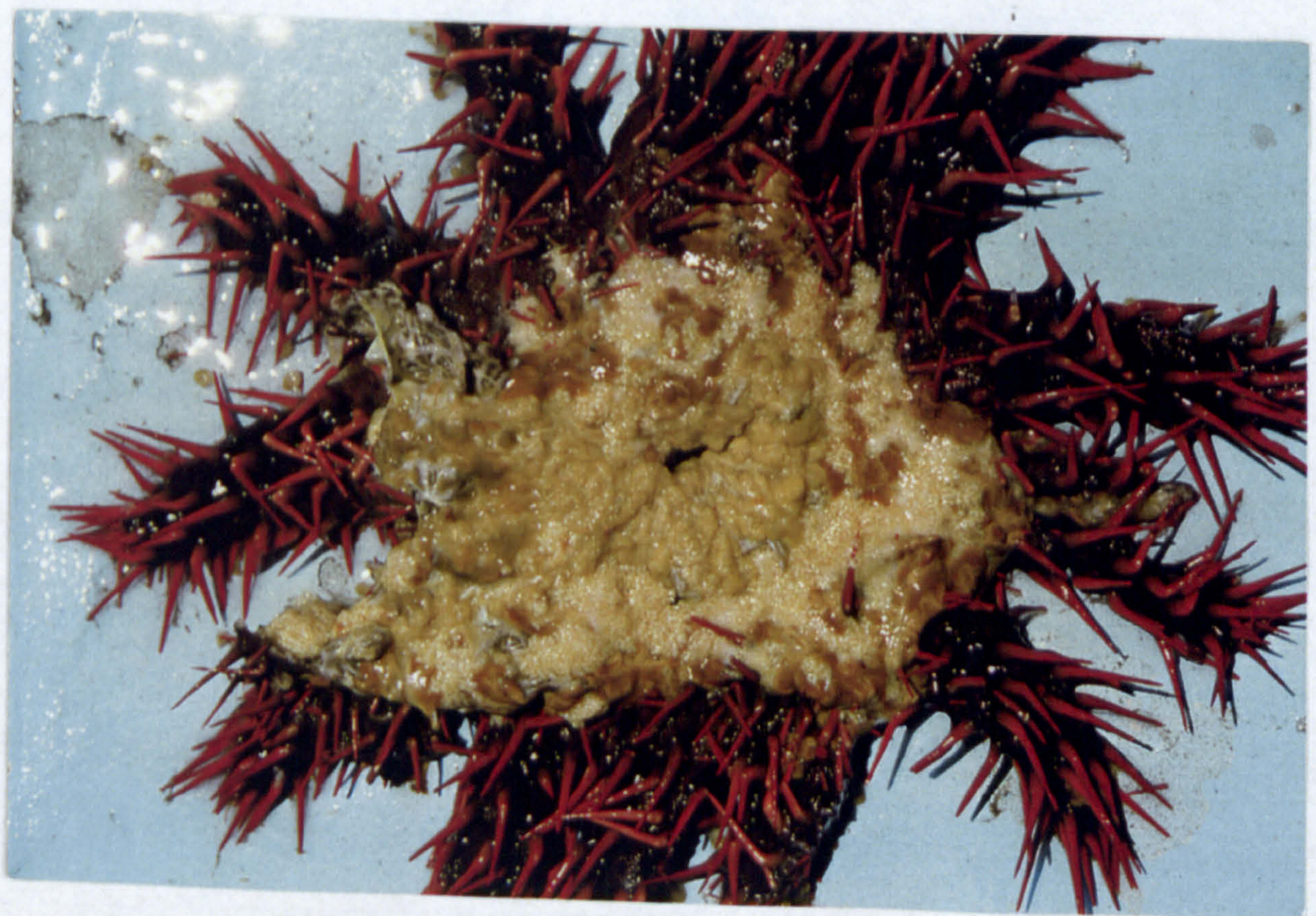


Figure 2. (top) Photograph shows the typical size classes of *A. planci* population during the 1998 outbreak event. (bottom) Photograph shows the *A. planci* gonad development during the early June 1998.

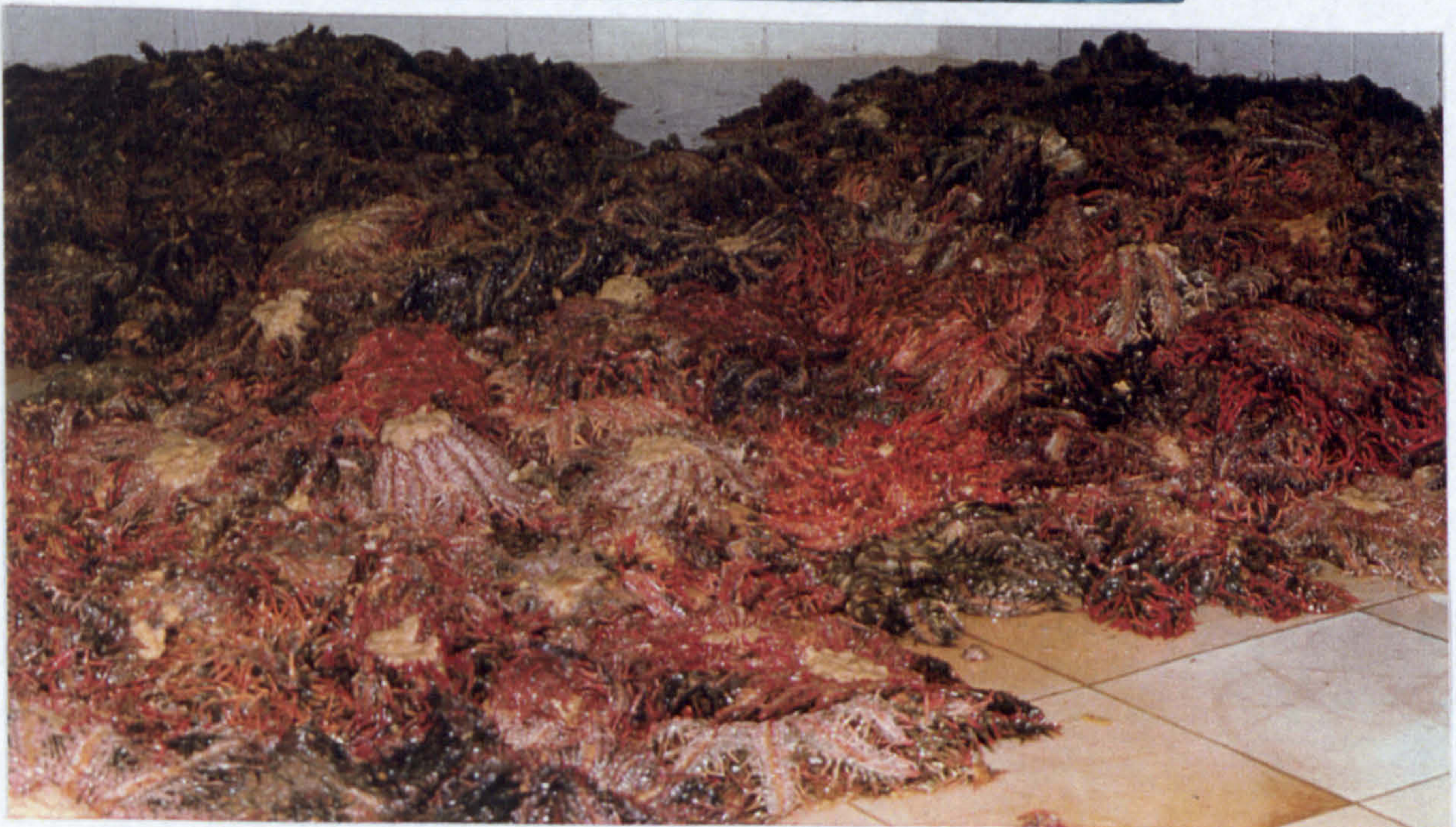


Figure 3. (top) Photograph of a trigger fish *Balistoides viridecens* attacking adult starfish in Gordon reef. (bottom) Photograph shows the amount of starfish collected in one day from Gordon reef.

CHAPTER SEVEN

**GENERAL
DISCUSSION**

As previously explained, the main purpose of this study was to gather sufficient information about the shour (*L. nebulosus*) fishery to allow a management decision about its future to be taken, based on scientific grounds. In particular it has been argued that fish populations that aggregate at a specific location and time to spawn are more vulnerable to over-exploitation than other fish stocks (Olsen & LaPlace, 1979; Sadovy, 1994). In different cases heavy exploitation of spawning aggregations has resulted in a rapid reduction in population size (Munro, 1983), a change in sex ratio (Coleman et al., 1996), and the loss of the most productive size classes (Shapiro, 1987). In the most dramatic cases exploitation has resulted in the complete loss of the population from their traditional spawning ground (Colin, 1992). In the Egyptian Red Sea coast spawning aggregations of several commercially important species, including *Lethrinus nebulosus*, *L. mahsena*, *L. elongatus*, *Lutjanus bohar*, and *E. tauvina* have been well-known to local fishermen and targeted for since at least the early years of this century. However, traditionally fishermen used to fish largely for their own later consumption, most fish being salted and dried for later use. Only in recent years, as result of dramatic coastal development and the consequent steep rise in market demand, has fishing pressure on these populations become so severe. Thus current fishing effort on the *L. nebulosus* spawning aggregation has the potential to impact both the stock of fish, and indirectly the whole reef ecosystem, in ways that were not previously likely.

Yield

Over five years of fishing both total yield and catch-per-unit effort of *L. nebulosus* have declined by 40 and 50 % respectively. Historical records for the *L. nebulosus* fishery on reefs adjacent to the Gulf of Suez for the years 1979 to 1981 show that at that time, total seasonal yield during May and April averaged 135 and 42 tons respectively, amounting to 84.3% of the annual total yield of this species, and 61.1

% of the total catch of reef associated species during this period (Sanders & Kedidi, 1984). This estimate was based on measuring the catch at fish landing sites, and the fishing grounds involved were not identified. However, as mentioned in chapter 1, there are only two well-known spawning grounds for *L. nebulosus* in the northern Red Sea, Jackfish Alley at Ras Mohammed, and Um-Gumar Island in the north western Red Sea. The Um-Gumar site has not been studied, but according to fishermen it is the Ras Mohammed site which was more productive and more generally preferred. This suggests that Sanders & Kedidi (1984) data is very likely to be of fish harvested principally at Ras Mohammed. The implication that the recent yield of shour from Ras Mohammed is well below that obtained historically is supported by the accounts of fishermen, who say that they used to catch much more fish there during the early 1980s than they do now.

Such a reduction in seasonal total yield is known for spawning aggregations of other species. Colin (1992) found that catches of *E. striatus* declined significantly over just a few years. Landed yield suggested that nearly all the *E. striatus* originally observed had been caught by fishermen, and underwater observations indicated a complete disappearance of the spawning aggregations, perhaps linked to the use of a destructive fishing method (dynamite). Similarly Bannerot et al., (1987) documented that in Bermuda many spawning aggregation stocks were entirely demolished after only few years of fishing.

Population Structure

Even during the 4 years of the present study there has been, according to the data presented, a marked reduction in the proportional frequency of larger size classes (chapter 2), with the proportion of individuals exceeding 10 years old becoming very low (chapter 4). Similar effects on the sizes and age structure of exploited populations are increasingly well documented for other slow-growing predatory

species. Craik (1981a) found that along the Great Barrier Reef the mean weight of *L. miniatus* (Lethrinidae) and *Plectropomus sp* (Serranidae) declined by nearly 50 % after 15 years of exploitation by recreational fishermen using hand-lines. Similar effects have been detected when fished and unfished population were compared using under water visual census, (Bohnsack, 1982; Russ, 1984, 1995; Samoily, 1988; Ayling & Ayling, 1986; Beinssen, 1988; Watson & Ormond, 1994). In all cases the larger size classes of exploited fish species were significantly more abundant on unfished reef than on exploited ones. Such an effect can be especially marked if larger fish are targeted by fishermen or if they are more vulnerable to the fishing method used. However a reduction in mean individual size will occur even if all size classes are equally vulnerable, since as a result few fish will live to reach a large size. The key issue is whether the *L. nebulosus* breeding stock has been exploited to the point of growth overfishing. The present study suggests that it has, although without more substantive evidence of the rate of natural mortality it is not possible to be certain on this point.

Recruitment

Whether and to what extent the recruitment process is threatened by the reduction in spawning population size is even less clear. Sadovy (1996) has emphasised that recruitment success in fish populations can depend on the number of reproductive adults. Munro & Thompson (1973) and Koslow (1988) attributed recruitment failure of commercially important species to a lightly fished reef (Pedro Bank, Jamaica) to over-exploitation of parent stocks on upstream reefs. Further, because large fish carry many more eggs than smaller ones, the decline in reproductive output of a stock may be proportionally much greater than the reduction in fish numbers. Thus Bohnsack (1990) found that more eggs are produced by a single large *Lutjanus campechanus* (13 kg) than by more than two hundred small (1 kg) ones. In the present study the data on gonad mass and egg number indicates how

egg production must have been dramatically reduced as result of continuing exploitation.

Beddington, (1984) suggested that regular failure of recruitment becomes likely to occur if population size of an exploited stock is reduced to less than 20 % of its original size. Roberts & Polunin (1991) also argues that recruitment may fail if a population is exploited to a critical level, but suggests that this level must vary between species, according to their biological and ecological characteristics. No information is available on the original size of the *L. nebulosus* population at Ras Mohammed. But if only 50 % of the fish recorded by Sanders & Kedidi (1984) were caught at Ras Mohammed, and assuming that total yield is proportional to population size, then it appears that the spawning population has been reduced to only about 13 % of its original size. In addition however, Sanders & Kedidi (1984) found that during 1979 to 1981, *L. nebulosus* larger than 50 cm constituted 36.1 % of the population, whereas in the present study these sizes constituted only 12.3 % of the population. The relationship observed between fish length and absolute fecundity shows that the mean absolute fecundity of fish larger than 50 cm in fork length is nearly double that of smaller fish (105 % more) From this it appears that the reproductive output of the current population may be as little as 6 % of that of the original (early 1980s) stock.

Other Impacts

As also maintained previously the *L. nebulosus* fishing ground at Ras Mohammed contains several dive sites considered to be among the most important in South Sinai. In this study the marked difference observed in total yield, mean fish size, and species composition of the by-catch, between the spawning ground and adjacent reefs (chapter 2) suggests that the reef fish population on Jack Fish Alley must have already been significantly depleted as a result of previous incidental

exploitation. The effects of this depletion may extend beyond reducing the aesthetic attractiveness of the dive sites within the area. McClanahan & Obura (1995) found that removal of fish that were invertebrate predators led to a large increase in abundance and biomass of sea urchins, with a consequent reduction in algal productivity and coral growth. Similarly, if there is a link between the fishing of Shour at this site, and the fact that the primary outbreak of Crown-of-Thorns starfish occurred there, it could be that the outbreak was consequent on the reduction of other species, for example triggerfishes, present in the by-catch.

Intensive fishing at Jackfish Alley also had other effects. Physical damage to coral colonies along the reef edge and in deep water areas as result of anchoring was unavoidable, despite the precautions taken. General observations indicated that the reef edge zone has the greatest abundance of coral colonies, so placing tens of anchors into this area every day throughout the spawning season must cause some reduction to coral cover within this area. A final effect, which reduces the aesthetic appearance of the site and may risk the National Park reputation, is the considerable number of fishing lines tangled among the corals and left on the site at the end of the fishing season.

In conclusion the data collected during this study suggest that it is very likely that the current level of exploitation of the *L. nebulosus* spawning aggregation is having a deleterious effect both on the overall yield and the actual value of *L. nebulosus*. It also seems probable that the fishing is having some direct and indirect impact on the coral reef habitat of the area. On balance therefore it is recommended that the fishery at Ras Mohammed should now be closed, to protect the remaining portion of the spawning stock, and so ensure adequate reproductive output by the stock as a whole.

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