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Lessepsian Migrant fish Species
of the Coastal Waters of Libya: Status, Biology, Ecology

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1 Introduction

1.1 Necessity of the study

Since the opening of the Suez Canal in 1869, at least 300 Indo-pacific marine animal species penetrated the Mediterranean Sea. They are known as Lessepsian migrants (POR 1978, BOUDOURESQUE 1999, GALIL 2000). About sixty five fish species were recorded among them in the Mediterranean Sea with new immigrant species regularly being added to the list (GOLANI 2006). These introductions have produced important changes in the species composition of Mediterranean communities and have resulted in mixed Red-Mediterranean communities (FISHELSON 2000, GALIL 2000). Although it is clear that Lessepsian fish migrant species have had an enormous impact on the eastern Mediterranean ecosystem, there has been no special study to assess this impact. GOLANI AND GALIL (1991) compared the feeding habits of the two indigenous mullets *Mullus barbatus* and *Mullus surmuletus* to that of the two confamilial Lessepsian migrant *Upeneus moluccensis* and *Upeneus pori*. They found a high rate of similarity in diet in all four species. In 1994 the niche partitioning of the eastern Mediterranean mullets is conduced on the bathymetrical axis: Lessepsian mullets occupy shallow waters (20-50 m) while indigenous species dominate in greater depths. However, there is insufficient knowledge concerning the bathymetric distribution of the indigenous mullets in the eastern Levant, prior to the Lessepsian invasion (GOLANI 1994). The last decade has observed an increase of comprehensive studies on the phenomenon of Lessepsian fish migration; both general studies and studies of a more specific nature have been published. For example Turkey, its southern coast being a major pathway of westward distribution of Lessepsian migrants, has provided important scientific studies of this phenomenon, e. g. studies by BILECENOGLU and TASKAVAK (1999), TASKAVAK and BILECENOGLU (2001), ZAITSEV and OZTURK (2001) and BILECENOGLU and KAYA (2002). In the south of the Mediterranean Sea (Libyan coast) no comprehensive study of the Lessepsian species is available up to now, particularly of the fish species.

1.2 Previous work

Many surveys have been done along the Libyan coast. The first trawl fishing survey of the western part of the Libyan coast was achieved by the Tunisian research vessel

DAUPHIN from April 17 to May 19, 1965 (ZUPANOVIC and EL-BUNI 1982). The next fishing survey was carried out by the French research vessel THALASSA, in November 1969 (MAURIN 1973, ALDEBERT and PICHOT 1973, BONNET 1973). In 1972 the survey of the Libyan territorial waters and the adjacent international waters in the central Mediterranean was carried out by Japanese fishing vessel HOYO-MARU (GORGY *et al.* 1972). During the period from September 1973 to October 1974 a survey was done by a French firm of consulting engineers (SOGREAH) using the research vessel and facilities provided by the Libyan Marine Biology Research Center (MBRC). In this survey a study of the living resources on the Libyan continental shelf of the Tripolitanian coast west of 15° E was performed (SOGREAH 1977). From January to May 1975 an exploratory fishing survey was done by German fishing vessel MEIKE in the Gulf of Sirt (INSTRUPA 1975). From May 1975 through August 1976, extensive studies of oceanography and fisheries were carried out by both Libyan and Romanian research teams on board of the vessels DELTA DUNARII and GILORT in the eastern territorial waters (between Ras Azzaz and Ras Karkura) (CONTRANSIMEX 1977). In 1993 a survey along the Libyan coast was done on the fisheries and oceanography by FAO and Marine Biology Research Center (MBRC) (LAMBOEUF and REYNOLDS 1994). In 2000 an artisanal fishery in Libya census of fishing vessels and inventory of artisanal fishery métiers was carried out along the Libyan coast by FAO and facilities provided by Marine Biology Research Center (MBRC) (LAMBOEUF 2000).

1.3 Objectives

The aim of this thesis is to present a monographic study on the present status of immigrant fish species in Libyan coastal waters, focusing on Lessepsian migrants. This fills a gap of nearly 2000 km of the African coastline of the Mediterranean Sea. Information is contributed on the history and the development of stocks of exotic fish, to the actual and forthcoming situation. For selected species of commercial value their identity and genetic pattern are compared with the region of their origin. Their biology, life cycles, ecology are explored, their actual and future commercial value presented resp. discussed. Details to deal with are:

- The identification of Lessepsian species, investigation about their distribution and characterization of stocks, mainly of species of commercial value along the Libyan coast.
- Assessment of the exploitation and value of Lessepsian fish for the Libyan coastal fishery. Identification of the important fishing gears and the fishing crafts, assessment of the amounts and values of catches.
- Comparative food ecology of Lessepsian herbivorous fish species in the coastal area of Libya and comparison of the results with data available from different localities of the Mediterranean and Red Seas.
- Investigations on the reproduction and on some biological aspects, mainly by studies of the both Siganids. The results were compared with data available from different localities of the Mediterranean and Red Seas.
- Investigations on the gene flow and genetic variation within and between immigrant *Siganus* spp. (Mediterranean Sea) and source populations (Red Sea) using the mitochondrial DNA (Cytochrome b and control region).

1.4 Characterization of habitats

1.4.1 Actual geographic situation

The Mediterranean Sea is an almost closed marine basin between Europe, Asia and Africa. It is connected with the Atlantic Ocean by the strait of Gibraltar, with a width of fifteen kilometres and an average depth of 290m to a maximum 950m. In addition to this natural connection it is connected to the Red Sea since 1869 by the Suez Canal, which is one hundred and twenty meters wide and twelve meters deep.

1.4.2 Brief geological and biological history of the Mediterranean Basin

The Mediterranean Basin has a long and complicated history which left traces in the actual status of its fauna and flora. Its immediate forerunners were Tethys and Paratethys during the late Cretaceous and Paleogen (Lower Tertiary). Early connections to the Indo-pacific Ocean existed via the Gulf and possibly the earliest states of the Red Sea. Most important was the separation of the brackish water Paratethyan fauna, e. g. the mollusc genera *Corbicula, Dreissena, Congeria*, and the fish genera *Acipenser* and *Clupealosa.* Their relic species are found beside the Mediterranean mainly in the Black Sea, Caspian

Sea and Aral Lake. The situation was considerably changed by the Messinian salinity crisis. This is one of the largest environmental disasters that occurred during the earth history, in the Miocene period (6 Ma BP), when the Gibraltar strait closed. It was caused by subduction, a tectonic event due to the shifting of the African plate to the north.

The relatively sudden disconnection of the water supply of the Atlantic ocean led to a deficit of the water balance and the Mediterranean sea level dropped down to 1500m below the present level, entailing a considerable increase of salinity and an intense erosion of all Mediterranean rivers (LOGET *et al*. 2003). The Messinian crisis is recorded by three signatures, (a) the presence of evaporates (e. g. gypsum) in the level of today's' abyssal plains, (b) the deepening in of canyons on margins and also on European and African hinterlands (c) and, in between, the apron built by coalescent canyon fans (CLAUZON *et al*. 2003). The deep water fauna of the Mediterranean is characterized by a relative impoverishment; both are a result of events after the Messinian salinity crisis; there are still some relic basins as the Dead Sea and depressions in North Africa.

In the late Tertiary (Neogone) the Straits of Gibraltar were opened again and the Mediterranean Basin was filled with water and with life from the Southern Lusitanian Sea and from the Northern Atlantic. This situation was again modified by sequential faunal changes during the Pliocene and thereafter in particular by those during the Quaternary glaciations and still in progress. For details see POR 1978, EMIG and GEISTDOERFER 2004 and HOFRICHTER 2001.

Recent faunal change as part of global change, is man-made, either by the Suez Canal connection, the main subject of this thesis; or by invasion of the Mediterranean Sea by species of the neighbouring Lusitanian part of the Atlantic Ocean, finally by punctual import of animal stocks by mariculture, aquaria, ship traffic (ballast and fouling).

1.4.3 Topography and geography of the Libyan coast

According to SOGREAH (1977), bathymetrically speaking three areas, may be distinguished along the coast of Libya, all are closely associated with major structural features of the African continent. The first and largest of these areas contains a relatively even central terrace of about 50.000 km^2 constituting an extension to the Gulf of Gabes, Its depth is less than 200m while its slope is less than 1%. The two other areas are more broken or deeper. The more northerly consists of an underwater basin of particularly rugged relief connected to the Pantelleria and Linosa trenches. The other area east of the longitude 13 E forms the Tripolitanian precontinent which joins the Libyan land mass to the Malta and Medina banks by a ridge varying in depth from 200 to 500m. The Tripolitanian precontinent is a fairly even area at a depth always greater than 200m. It is cut into two large but narrow underwater valleys, one from Tripoli running SE to NW and the other one closer to Medina bank. Along the coast, a series of fairly regular rocky ledges is to be found down to a depth of about 30m, a platform which is concealed in certain places by sand deposits of varying thickness. The eastern part of the Libyan coast, the Gulf of Sirt and Cyrenaica is mainly rocky and the continental shelf is steep and narrow (ZUPANOVIC and EL-BUNI 1982) (Fig. 1).

1.5 Characterization of the fish fauna

1.5.1 Mediterranean fish biodiversity

A rough estimate of more than 8.500 species of macroscopic marine organisms should live in the Mediterranean Sea, corresponding to somewhat between 4% and 18% of the world marine species (BIANCHI and MORRI 2000); this is a conspicuous Fig. if one considers that the Mediterranean is only 0.82% in surface area and 32% in volume as compared to the world ocean. Its fish biodiversity is relatively high; about 6% of the marine species can be found within it (QUIGNARD and TOMASINI 2000). The greatly diversified Mediterranean fish population possesses few dominant species (BAS *et al.* 1985). The Mediterranean Sea fauna and flora have evolved over millions of years into a unique mixture of temperate and subtropical elements, with a large proportion (28%) of endemic species (FREDJ *et al.* 1992). The biota of the Mediterranean Sea consist primarily of Atlanto-Mediterranean species (62%) derived from the adjacent Atlantic biogeographic provinces beyond the strait of Gibraltar. Many Mediterranean species are endemic (20%) while others are cosmopolitan, circumtropical (13%) or Indo-Pacific (5%). These proportions differ for different major taxonomic groups and also for different parts of the Mediterranean Sea, but the pattern remains essentially the same (KETCHUM 1983). Within the Mediterranean there is a gradient of increasing species diversity from east to west. The number of species among all major groups of plants and animals is much lower in the eastern Mediterranean than in the western and central parts of the sea. The southeast corner, the Levant basin, is the most impoverished area, the benthic and littoral populations show a similar change in species diversity and abundance, which decrease from west to east and from the northern Adriatic to the south (KETCHUM 1983). The majority of Mediterranean sea species are of Atlantic origin (about 67%), migrants through the Suez canal represent 5% of the total but 12% of the south-eastern part of the Mediterranean, Endemism is about 28%, the western part of the Mediterranean includes 87% of the total number of species recorded, 91% of the non-endemic species and 77% of the endemic species; the Adriatic Sea includes 49%, 55% and 35%, respectively; and the eastern Mediterranean 43%, 52% and 23% (FREDJ *et al.* 1992). The Mediterranean fish biodiversity has been estimated at 562 for species and sub-species (QUIGNARD 1978 a, b). From 1984-1986 the FNAM writers estimated the fish biodiversity of the geographical area, located between latitude 30° and 80° north, longitude 30° west and longitude 60° east, including Mediterranean and Black Sea, at 1256 species, including 125 chondrichthyes. A total of 540 fish species was listed for the Mediterranean Sea, including 362 shore dwellers, 62 of which being endemic (TORTONESE 1963). Many studies have been done about fish biodiversity in many different regions. In the Catalan Sea from Balearic Islands to the French border the richness can be estimated, adding at 463 species, 64 of them are chondrichthyes 67% of the 126 families represented show a maximum of three species, while 45% are monospecific; these values are higher than those obtained for the Mediterranean as a whole (MORENO 1995). In the Adriatic Sea, JARDAS (1985) listed 399 species and sub-species including 52 chondrichthyes and three Cyclostomes. The same author listed 407 species and sub-species in 1996. In North Africa, coast of Tunisia, the fish diversity is of 267 species, including 54 chondrichthyes, 48% of the families are monospecific and families made up of a maximum of three species represent 75.5% (BEN OTHMAN 1973, FNAM 1984-1986, ABDELMOULEH 1981, BRADAI *et al.* 1992). In the Levant Sea, that includes the eastern sector of the Mediterranean, stretching east of a line Antalya (Turkey), Port Said (Egypt) 405 species were listed including 57 chondrichthyes. 74% of 125 families represented comprise one to three species, while 44% are monospecific (GOLANI 1996, 1998a, b). In the Aegean Sea, the fish diversity is estimated at 351 species, including 41 chondrichthyes. 77% of the 133 families represented possess a maximum of three species, while 46% are monospecific (PAPACONSTANTINOU 1990b, PAPACONSTANTINOU *et al.* 1994, 1997, UNSAL and KABASAKAL 1998). Some studies have been conducted in the eastern Mediterranean Sea; the first one was published by FOWLER (1923) who listed 15 fish species from Beirut (Lebanon). In 1927, 65 species were collected in Palestine (STEINTTZ 1927). In 1931 two fish lists were published; one of them by GRUVEL (1931) who listed 95 species, of which 45 were not previously recorded from Syria, Lebanon and Palestine. The second list was of SPICER (1931) who reported a list of 55 commercial marine fish species in Palestine. The most comprehensive ichthyofaunistic study in the Levant was published in 1953 and listed 211 species, of which 69 were first records (BEN-TUVIA 1953). MOUNEIMNÉ (1977, 1979) studies of Lebanese ichthyofauna increased the known species by eight new records, including four Lessepsian migrants. In 1996, a checklist of eastern Levantine marine ichthyofauna including 405 species within 125 families was presented (GOLANI 1996). In 2002 a total of 650 fish species have been recorded in the Mediterranean Sea, of them 90 fish species, representing 56 families, are arrivals originating from distant seas (GOLANI *et al.* 2002).

A number of studies have been conducted in the Libyan waters. The first was by VINCIGUERRA in 1881 who recorded seventeen species when reporting on the ichthyofauna of Libya. The number of species known increased rapidly in the early 20th century (NINNI 1914, VINCIGUERRA 1922, TORTONESE 1939). More detailed studies were conducted in the second half of the 20th century, for instance ALDEBERT and PICHOT (1973) concentrated on some flat fishes, DUCLERC (1973) on Scorpaenidae. Some other surveys resulted in check lists, for example in the western part in 1972 sixty two species have been listed (GORGY *et al.* 1972). A total of 131 fish species was registered (SOGREAH 1977). Also in (1977), 39 cartilaginous fish species and 185 osteichthyes species were listed (CONTRANSIMEX 1977). ZUPANOVIC and EL-BUNI (1982), using the demersal fishing gear, reported that the Libyan waters are potentially moderately productive in fish. They also stated that the Libyan fish fauna mainly was related to the one of the eastern part of the Mediterranean Sea, the Levant Basin. In the eastern part of Libya (Benghazi region) the bony fishes were listed with a total number of species of 201 belonging to seventy one families and fifteen orders (HASSAN and SILINI 1999). In 1993 a survey was done about the fishing fleet along the Libyan coast (LAMBOEUF and

REYNOLDS 1994). Recently an investigation was conducted along the Libyan coast on artisanal fisheries in Libya (LAMBOEUF 2000). Assuming that the whole Mediterranean Sea has the same species composition is impractical due to the evident regional specification in this Sea (WHITEHEAD *et al*. 1984-1986).

1.5.2 What is an exotic fish species?

The worldwide exchange of faunas is one of the most important impacts on the regional ecosystems. Especially in fish, starting with freshwater species, there is an old tradition of dislocation, in the hope to improve the yield of individual or commercial fishery. There is a confusing terminology for the newcomers. The pair of scientific terms "allochthonous" and "autochthonous" is not used in this context since considering the long term past, nearly all species have a long history of migration; so nearly none are situated still on the locality of their primary isolation. The main definitions actually are:

Neozoans: "animal species, which expanded into a new area, not accessible to them before, by direct or indirect participation of man, purposely, or involuntarily, and which built up new populations ("neopopulations"). Animals which reproduced successfully in the wilderness for at least three generations are considered to be integrated and are subject of laws for the conservation of nature." The term is an adaptation, paralleling the much older term „neophytes" of botany. It was used since 1971 in lectures and public presentations of R. Kinzelbach at the University of Mainz and published for the first time in KINZELBACH (1978). Later on the definition was stepwise adapted and became more precise. It was accepted rapidly in the German literature (28.000 hits in Google), later in the English one. The term neozoans was thought as a neutral substitute for approximately 20 aggressive or chauvinistic words, which were used before to characterise newcomers and newly imported animals. Additions to the biological definition were made by the lawmakers, who needed definitions for the minimum time an animal had to live in a new area in the wilderness to be considered as indigenous, as part of the indigenous nature and thus as a part of nature protection laws.

Exotic: This term is used for animals which obviously were imported from outside. It suffers from the lack of a defined historical starting point. In the northern countries usually it suggests a provenience from tropical countries, so it is not suitable for all newcomers.

Invading, invasive, invaders: This more aggressive term originally in the zoological literature refers to irregular winter visitors among the birds, like the waxwing. It now describes sudden expansion of a - frequently noxious - species, which geographically not necessarily originates from outside. The special role of man by displacement activities is not taken into consideration or, at least, part of the definition.

The definition of the special case of **Lessepsian migrants** is given by POR (1978). It is a sub-term of neozoism, since man triggered the migration after 1592, by building a canal, which allowed migration of animals into areas, which under natural conditions they would not have reached. The may expand very rapidly and be big competitors for the indigenous fauna. They may set a considerable impact on the ecosystem. Therefore an identification of a part of the Eastern Mediterranean Sea as Lessepsian Sea basin was taken into consideration (GOLANI *et al*. 2002).

In any case the indigenous, autochthonous species substrate has to be characterized in contrast to the immigrants.

1.5.3 Exotic species

Most studies characterizing successful biological invaders emphasize traits that help a species establish a new population. Invasion is, however, a multi-phase process with at least two phases, dispersal and introduction, that occur before establishment, characteristics that enhance survival at any of these three phases will contribute to invasion success (WONHAM *et al*. 2000). The distribution patterns of species and subspecies of organisms have been determined by three kinds of factors: historical episodes, dispersal abilities and niche requirements (WOODLAND 1999). There are some factors such as temperature, Salinity, turbidity, bottom type and biological factors such as interspecific competition which are known to be able to influence the distribution of marine species (CONNELL 1961, TOBIAS 1976, RACE 1982). Temperature and salinity, which are very important factors that influence the distribution and reproduction of organisms, are strikingly different in the Red Sea and the Mediterranean Sea (BEN-TUVIA 1966). Many species have invaded the Mediterranean Sea, through Suez Canal from the East and Gibraltar strait from the west as well as the casual transport by shipping. This has made change for the dominated species stock, certain from these changes including many advantages such as the increase to the stock. The word exotic, for many, implies (from different location) but that is not a requirement. Exotic, in ecological terms, means (non native or non-indigenous) to the natural geographic range to which it has been introduced (either accidentally or intentionally), the term non native is confusing since it includes new non native and naturalized non native species, because of the way humans value species over others, (desirable) exotics (naturalized or not), such as brown trout, may be given similar or more management protection as native species, on the other hand, naturalized (undesirable), therefore, introduction of non native strain of a native specie would make it an (exotic). This is an important ecological concept because it recognizes that introduced non native strains hybridize with the native species and alter the behaviour and/or survival of the native strain (DIETER *et al.* 1999).

1.5.4 Lessepsian fish species

The term "Lessepsian migration" was coined by POR (1978) for the migration of organisms from the Red Sea into the eastern Mediterranean through the Suez Canal. Three zooecological areas must be taken into consideration to study the immigration through the Suez Canal: the northern Red Sea, the Mediterranean Sea and the Suez Canal itself in which marine animals from the two neighbouring areas have found a permanent habitat (STEINTTZ 1967). Many species, which were able to adapt to the new environment rapidly, spread into the Mediterranean and built up new populations. Information on the comparative life histories of the immigrants is necessary (a) for understanding the selective mechanisms controlling the passage through the Suez Canal, (b) for assessment of the adaptive changes of the newly established "neopopulations", and (c) for an evaluation of the extensive ecological changes which invading species may produce in their new areas of distribution (BEN-TUVIA 1978). The fish fauna of the Mediterranean is already subject to considerable changes, as is proved by the following selected case studies. PAPACONSTANTINOU (1990a) reported that eleven species had reached the Aegean Islands (Dodecanese, Cyclades) by following the coast of Anatolia. Twenty-two Lessepsian fish species live on the coasts of the Eastern Mediterranean and Aegean Sea, with some of them becoming commercially important (TORCU and MATER 2000). In 2002 thirty three Lessepsian fish species were documented on the Anatolian coast (BILECENOGLU and TASKAVAK 2002). For the Egyptian coast, several authors recorded

Lessepsian fish species (TILLIER 1902, KREFFT 1963, BEN-TUVIA 1976, NORMAN 1929, EL-SAYED 1994). Two Lessepsian fish species were recorded in Italy: *S. luridus* appeared along the shallow waters of Pelagic Islands (AZZURRO and ANDALORO 2004); *Fistularia commersonii* was recorded on the eastern coast of Lampedusa (AZZURRO *et al.* 2004). KTARI and BOUALAL (1971) reported *S. luridus* for the first time on the Tunisian coast. In 1974 *S. luridus* and *S. rivulatus* were registered for the first time in the gulf of Gabes (KTARI and KTARI 1974). After that six Indo-Pacific species were recorded in Tunisian waters as newcomers (*Parexocoetus mento, Pempheris vanicolensis, Stephanolepis diaspros*, *S. luridus, S. rivulatus, Priacanthus hamrur*) (BRADAI *et al*. 2004). The cornet fish *F. commersonii* was also recorded along the Tunisian coast (BEN-SOUISSI *et al*. 2004). Many Lessepsian fish species have been recorded in Libyan waters (STIRN 1970, TORTONESE 1938, ZUPANOVIC and EL-BUNI 1982, BEN-ABDALLAH *et al*. 2005, SHAKMAN and KINZELBACH 2006, SHAKMAN and KINZELBACH 2007a, b, c). In addition, some Lessepsian fish species have been listed in general surveys that have been carried out (LAMBOEUF 2000, HASSAN and EL-SILINI 1999). In the Adriatic Sea *Sphyraena chrysotaenia* was recorded in 2001 (PALLAORO and DULCIC 2001), afterward S. *rivulatus* was recorded a first time in the same area (DULCIC and PALLAORO 2004). Recently the Japanese threadfin bream *Nemipterus japonicus* was recorded in the Mediterranean Sea (GOLANI and SONIN 2006). Overall ninety alien fish species have been identified up to March 2002. Of them 59 Lessepsian migrants from the Indo-pacific through the Suez canal and 28 species of tropical and 3 species of boreal origin from the Atlantic Ocean through the Gibraltar strait (GOLANI *et al*. 2002). Up to now the Lessepsian migrant fish include 65 species, with new species regularly being added to the list (GOLANI 2006). The species entering the Mediterranean affected the species diversity of the Eastern Mediterranean, which has fewer species compared to the Western Mediterranean, and in particular in the Levant Sea and caused important changes in the ecological balance and in the commercial fishing in this area (CEVIK *et al*. 2002).

1.5.5 Anti Lessepsian fish species

The number of Lessepsian migrant species exceeds by far the number of the species which passed from the Mediterranean to the Red Sea; they are named anti-Lessepsian migrants (CEVIK *et al.* 2002). It seems that there are very few species which migrated from the Mediterranean to the Red Sea. This fact cannot be simply ascribed to the circumstance that the number of autochonous species is so much higher in the Red Sea than in the Mediterranean Sea, as the biota of the Red Sea is several times richer than that of the Mediterranean. These facts and Fig.'s indicate that the number of Lessepsian migrants could be three (or more) orders of magnitude higher than of the anti-Lessepsian, as stated above. Many factors facilitate the transport of organisms through the canal in a predominantly northward direction, the discovery of Mediterranean species *Sphaerodiscus placenta* in the lagoon of El Bilaiyim, situated 180 km south of the entrance to the Suez Canal, is one of the few indisputable evidences of the anti-Lessepsian migration (BEN-TUVIA 1971a). The salinity in El Bilaiyim is much higher (50-60 ‰) and most probably the seasonal and diurnal fluctuations are greater than those of surrounding waters, in particular biotope. Less competition is expected than in the open coastal water (BEN-TUVIA 1978). *Dicentrarchus punctatus* is known to inhabit the Bardawil Lagoon on northern Mediterranean coast of Sinai, where salinities may reach 80 ‰. It was noted by TILLIER (1902) that this fish was common in the Suez Canal and reached its southern entrance. It settled in the Canal soon after its opening. *Liza aurata* is known to be euryhaline and it could have crossed the Suez Canal or an earlier fresh water connection that was established by the ancient Egyptian pharaohs and Persian kings between the Mediterranean Sea and the Red sea using the arm of the River Nile (BEN-TUVIA 1978). This fish species was noted in the Suez Canal in 1902 (TILLIER 1902), and it was found as common fish species in Great Bitter lake (Ben-Tuvia 1975). Sandbar shark *Carcharhinus plumbeus* is common on both sides of the Atlantic and is well known in the Mediterranean Sea (BEN-TUVIA 1971b). It was found in the northern Red Sea perhaps due to immigration through the Suez Canal although the possibility of penetration from the western Indian Ocean should not be excluded (BEN-TUVIA 1978). Up to 1995, only seven Mediterranean species have crossed the Sues canal in the opposite direction (BEN-TUVIA 1971a, GOREN and KLAUSEWITZ 1978, BRÜSS 1987, RANDALL and GOLANI 1995). TORTONESE (1984) estimated that around 50 Mediterranean fish species are to be found in the Suez canal, while only 5 to 6 of them have reached the Red Sea (*Dicentrarchus punctatus*, *Argyrosomus regius*, *Liza aurata*, *Gobius cobitis*, *Gobius paganellus*, and perhaps *Carcharhinus plumbeus*). The movement of *Seriola* *dumerilli* and *Scomber japonicus* need to be confirmed. These emigrants occupy only the most northerly part of the Red sea, mainly the Gulf of Suez (QUIGNARD and TOMASINI 2000). GOREN and DOR (1994) reported fourteen anti-lessepsian fish: *Argyrosomus regius, Dicentrachus labrax, D. punctatus, Engraulis encrasicolus, Serranus cabrilla, S. dumerilli, Scorpaena porcus, S. scrofa, Solea vulgaris, Umbrina cirrosa, Stromateus fiatola, Uranoscopus scaber, G. cobitis,* and *G. paganellus.* Perhaps *Lithognathus mormyrus* and *Liza aurata*. *Pleuronectes platessa* should be added to these species (HENSLEY 1993).

1.5.6 Siganids

The distribution patterns of species and subspecies of organisms have been determined by three kinds of factors: historical episodes, dispersal abilities and niche requirements (WOODLAND 1999). The Suez Canal, which was opened in 1869, linked the Red Sea with the Mediterranean Sea, and resulted in the invasion of the Mediterranean by many marine species (POR 1978, BOUDOURESQUE 1999, FISHELSON 2000, GALIL 2000, QUIGNARD and TOMASINI 2000, GOLANI *et al.* 2002). Temperature and salinity are the most important factors influencing the distribution and migration of organisms over large zoogeographical areas (BEN-TUVIA 1978), and both are higher in the Red Sea than in the Mediterranean (BEN-TUVIA 1966).

The Siganidae form a small family of herbivorous, widely distributed fishes in the Indo-West Pacific Ocean (WOODLAND 1983). Four *Siganus* species live in the Red Sea. Two of them (*S. rivulatus* and *S. luridus*), invaded the Mediterranean Sea through the Suez Canal and have established themselves in the eastern Mediterranean Sea (BEN-TUVIA 1966). The first record of *S. rivulatus* in the eastern Mediterranean was in 1927 (STEINTTZ 1927). It is widely distributed nowadays in the central and western parts of the Mediterranean and was first recorded in Libya in 1970 (STIRN 1970). It is distributed and established along the Libyan coast and it competes with the native herbivorous fish species *Sarpa salpa* (Sparidae) and *Sparisoma cretense* (Scaridae), especially in the eastern part of the Libyan coast and the Gulf of Sirt (SHAKMAN and KINZELBACH 2007b). In 1974 it was recorded in Tunisia (KTARI and KTARI 1974). Recently it occurred for the first time in the Adriatic Sea (DULCIC and PALLAORO 2004). *S. rivulatus* has established large populations in its new environment and can be considered as one of the most successful Lessepsian fish (GEORGE 1972, BEN-TUVIA 1985, PAPACONSTANTINOU 1990a, BARICHE *et al*. 2004). It has become a commercial species in many areas of the Mediterranean (PAPACONSTANTINOU 1990a, GOLANI 2002, BILECENOGLU and TASKAVAK 2002, TORCU and MATER 2000, SHAKMAN and KINZELBACH 2007a).

S. luridus is one of the fish species that invaded the Mediterranean, coming from the Red Sea through the Suez Canal after its opening in 1869; the first record was in 1956 (BEN-TUVIA 1964). After that it spread in the eastern Mediterranean and was recorded by many authors (GEORGE *et al*. 1964, KAVALLAKIS 1968, DEMETROPOULOS and NEOCLEOUS 1969) in southern-central areas of Mediterranean; it was recorded in Libya 1970 (STIRN 1970); it is distributed and established along the Libyan coast and it has become of commercial value, especially in the western part of the Libyan coast and the Gulf of Sirt (SHAKMAN and KINZELBACH 2007a). In Tunisia it was recorded in 1971 (KTARI and BOUHALAL 1971, KTARI and KTARI 1974). Recently a newly settled population of *S. luridus* was recorded on the Italian island of Linosa (AZZURRO and ANDALORO 2004). It has become to be commercially important in many areas of the Mediterranean (PAPACONSTANTINOU 1990a, GOLANI 2002, BILECENOGLU and TASKAVAK 2002, TORCU and MATER 2000, SHAKMAN and KINZELBACH 2007a).

There have been attempts to breed *S. rivulatus* in different areas (BEN-TUVIA *et al*. 1973, POPPER *et al*. 1973, 1979). In the Jeddah region (Saudi Arabia), it reaches 200 to 300 g body weight after nine months feeding in cages (THEBAITY *et al*. 1984). In all Siganid species the larval life span is three to four weeks and larvae actively maintain themselves near the water surface (WOODLAND 1999). In the fry stage, both *S. rivulatus* and *S. luridus* are easy prey for many carnivores such as *Synodus variegatus*, *Fistularia* spp. and even larger goatfish (Mullidae), as with many fish species, this is probably the main reason for the substantial decrease in number, of schools and of individuals in each school, during the first few days after their appearance (POPPER and GUNDERMANN 1975). *S. rivulatus* is a schooling species and was usually observed in schools of dozens or hundreds of individuals, while *S. luridus* is mostly found in smaller groups of two to Ten in coral reefs or among coral heads (GEORGE 1972, POPPER and GUNDERMANN 1975).

The reproduction of *S. rivulatus* was intensively studied in the Red Sea (POPPER *et al*. 1979, HASHEM 1983, AMIN 1985a, b) and also in the eastern Mediterranean (GEORGE 1972, MOUNEIMNÉ 1978, HUSSEIN 1986, YELDAN and AVSAR 2000, SAAD and SABOUR 2001, BARICHE *et al*. 2003). There are a few studies on the reproduction of *S. luridus* in the Red Sea (POPPER and GUNDERMANN 1975, GOLANI 1990) and a few studies also in the eastern Mediterranean (MOUNEIMNÉ 1978, GOLANI 1990, BARICHE *et al*. 2003).

2 Materials and methods

2.1 Commercial fishery

This study was conducted from February 2005 to March 2006; the survey was performed along the Libyan coast in an area extending from Farwah in the western part of Libya up to the Al Bardiyah Gulf on the Libyan border with Egypt (Fig. 1). The aim of this survey was to find out the number of boats, the type of boat and type of fishing gear used in the coastal area. Seventy six active landing sites were visited; the latitude and longitude of the region, the number of boats, and the types of fishing gear were recorded for each region. Important information about fishing vessels and fishing gear was collected from local fishermen and fishermen's unions.

The study area was divided into three main regions according to topography and environment (eastern region, Gulf of Sirt, western region), two sites were selected in the eastern region (Tubruk, Benghazi), one site in the Gulf of Sirt (Musrata) and two sites were selected in the western region (Tripoli, Zwara); these were considered to be the most active catching sites and were investigated monthly, Al-Bardiyah in the eastern region and Farwah in the western region were also selected in the border areas and were investigated seasonally (Fig. 1). A total of 130 samples were collected from the Libyan coast, 53 samples from the eastern region, 52 samples from western region and 25 samples from the Gulf of Sirt region using the trammel nets (inner mesh 26 mm, outer mesh 120 mm) used by fishing vessels of the type "flouka" (Fig. 2). In order to standardize sampling bases and fishing effort, two fishing boats of the same size and fishing gears were considered from each sampling site. Each sample collected was washed in fresh water and sorted, then identified and classified according to WHITEHEAD *et al*. (1984-1986) for the native fish species and GOLANI *et al*. (2002) for the non-native fish species. The individual numbers of each fish species were counted and the estimated weights for each species were recorded. Information was collected about the length of fishing gear, the depth, the type of habitats, the catch, the first observation of newcomers, the season, and the Libyan names of fish.

2.2 Distribution and characterization of Lessepsian fish species

This study was carried out on samples collected between February 2005 and March 2006 along the Libyan coast at 1-50 m depth. The pelagic and benthic samples were collected with trammel net (inner mesh 26 mm, outer meshes 120 mm). The study area was divided to three main regions according to topography and environment (East region, Sirt Gulf, West region). Two sites were selected in the east region (Tubruk, Benghazi), one site in the Sirt Gulf (Musrata), and two sites in the west region (Tripoli, Zwara); these were considered to be the most active sites for catches and were investigated monthly. Al-bardiah in the east region and Farwah in the west region were also selected as border sites and were investigated seasonally (Fig. 1) in order to standardize sampling bases and fishing effort, two fishing boats of the same size and fishing gears were considered from each sampling site. A total of 4273 specimens were collected, including 1901 specimens of *S. luridus*, 1885 specimens of S. *rivulatus*, and 487 specimens of fourteen other Lessepsian fish species. The samples were immediately washed with fresh water, and were identified using WHITEHEAD *et al.* (1984-1986) and GOLANI *et al.* (2002). Specimens from each sample were kept in a mixed solution of formaldehyde and ethanol. The samples were subsequently washed with fresh water and stored in five percent formaldehyde. Standard morphometric measurements and meristic counts were taken (Fig. 3) and documented. The abundance, habitat type, depth range, maximum size and commercial value were recorded.

The abundance is divided into two levels: rare and common, according to BILECENOGLU and TASKAVAK (2002). If the species is represented by less than one percent of the total Lessepsian fish collected during the field work, the species is designated as rare. The general habitat type for each sample was classified as vegetated (including rocks with algae, sand with algae and grass with algae), pelagic, rocky and sandy. The sizes (maximum total lengths) were placed in three categories, as small (TL < 10 cm), medium (10 ≤ TL < 50 cm) and large (TL ≥ 50 cm). The commercial value was based on commercial information received from the fishermen’s union and was roughly divided into “commercial value” and “no commercial value”.

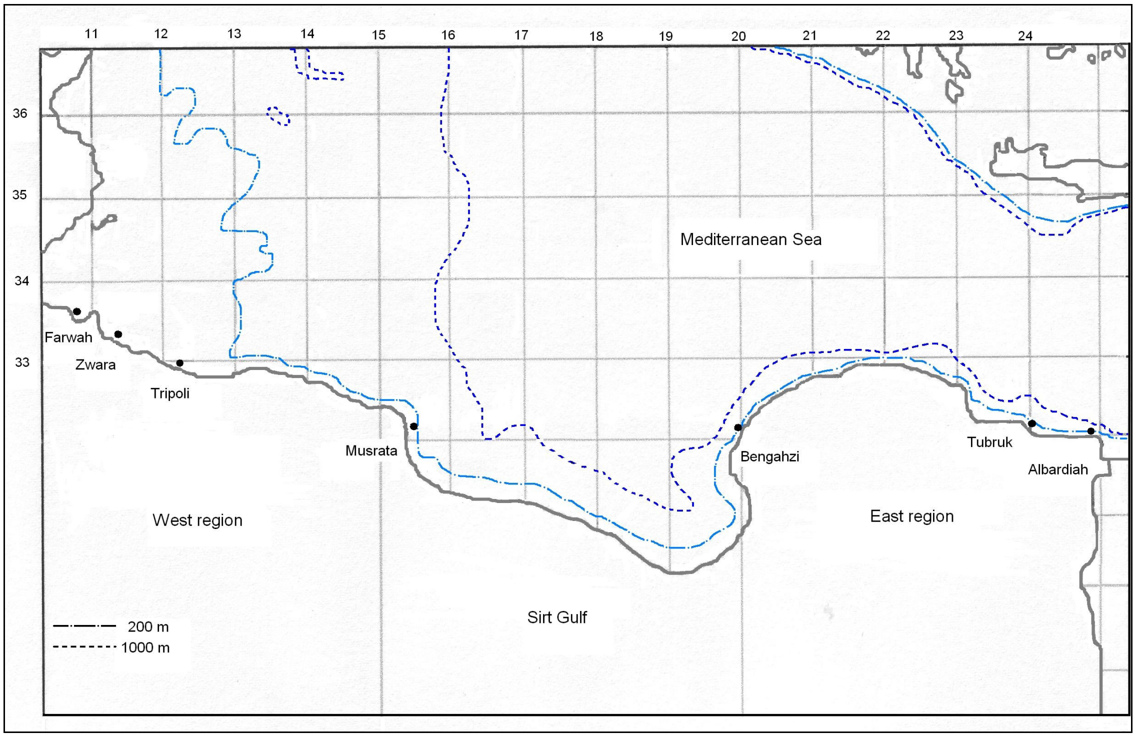

Fig. 1. Map of Libya, sampling sites

Fig. 2. The fishing vessels using in the coastal area of the Libyan coast (1: Mator, 2: Batah, 3: Lampara, 4: flouka

2.3 Biological characteristics of *Siganus rivulatus* and *S. luridus*

Samples of this study were monthly collected by trammel nets (inner mesh 26 mm, outer mesh 120 mm) in the coastal area with a water depth between 1 and 30 m along the Libyan coast (Fig. 1). A total of 1,672 individuals of *S. rivulatus* were sampled in the east Region (Tubruk, Benghazi) between March 2005 and February 2006. Additionally, a total of 1,756 individuals of *S. luridus* were sampled in the Sirt gulf region (Musrata) and in the west region (Tripoli, Zwara) between March 2005 and March 2006. Samples of *S. rivulatus* were collected from habitats like sand, rock and grass while *S. luridus* were collected from rocky habitats. The samples were transported in ice boxes to the laboratory immediately after the capture. Total length (L_T) and morphometric parameters were measured to the nearest mm (Fig. 3). Total weight (W_T) was measured with accuracy of 0.1 g and digestive system (W_D), liver (W_L) and gonads (W_G) were removed and weighed to the nearest 0.01 g. The meristic counts were counted for Subsamples (45 *S. rivulatus* and 55 *S. luridus*). The x-rays were made for 28 individuals of *S. rivulatus* and 22 individuals of *S. luridus* to count the vertebras of the vertebrate column. Most of individuals were sexed (1,229 individuals of *S. luridus* and 1,216 individuals of *S. rivulatus*). Both otoliths (Sagittae) were removed, cleaned in water and alcohol (Ethanol) and were stored for age determination after drying and further study. The otoliths were treated by Xylol under reflected light to account the annual rings, but the growth rings were clear visible when the whole otoliths moistened with camomile oil (BARICHE 2005). Counts of rings and measurements were always preformed in the same direction from the nucleus and the edge of the otolith antirostrum. The opaque and translucent zone was considered as annual ring. The counts were done by two independent readers (without checking the fish size); the otoliths that were difficult to read were discarded. Back-calculation of total length at the time where the production of hyaline zone was finished is based on the relation between total length and the distance between the centre and edge of the otolith using the equation $Li = Ln + (Oti - Otn)\,(Ln - L^*) / (Otn - Ot^*)$, where L^* is the length of hatching, Ot^* is radius of the otolith of hatching, Ln is the length of capture, Otn is radius of the otolith at capture, Li is the estimated length at time ti and Oti is the radius of the otolith at time ti (CAMPANA 1990).

Von Bertalanffy equation: $L_T = L_\infty (1- e^{-k\,(t-to)})$ was used to describe growth in size, where L_T is the total length at time t; k is a growth constant; L_∞ is the asymptotic length; and t_0 describes the theoretical age where L_T is zero. The length weight relationship was estimated based on the multiplicative regression model $W_T = a\ L_T{}^{b}$. Relations between total length and the different morphometric parameters were described by the linear regression model Parameter = a + b * L_T. Additionally, the coefficient of determination R^2, and the standard error, SE were estimated for each regression. Generalized linear models (GLM) were used to analyse whether sex and the area significantly influence the relations between length and the different parameters. Non linear regression models were used to describe the temporal development of parameters like the condition factor, etc. Parameter = a * cos (Month - b) + c. Hepato Somatic Index (HSI) was calculated with the following equation: HSI = liver weight (g) / total weight of fish (g) × 100 (FACEY *et al.* 2005). Fulton's factor (k) was calculated by K = total weight of fish W_T (g) / total length of fish L_T (cm) ^{3} × 100 and Gonado Somatic Index was calculated by GSI = gonad weight (g) / (body weight (g) – gonad weight (g)) × 100 BARICHE *et al.* (2003).

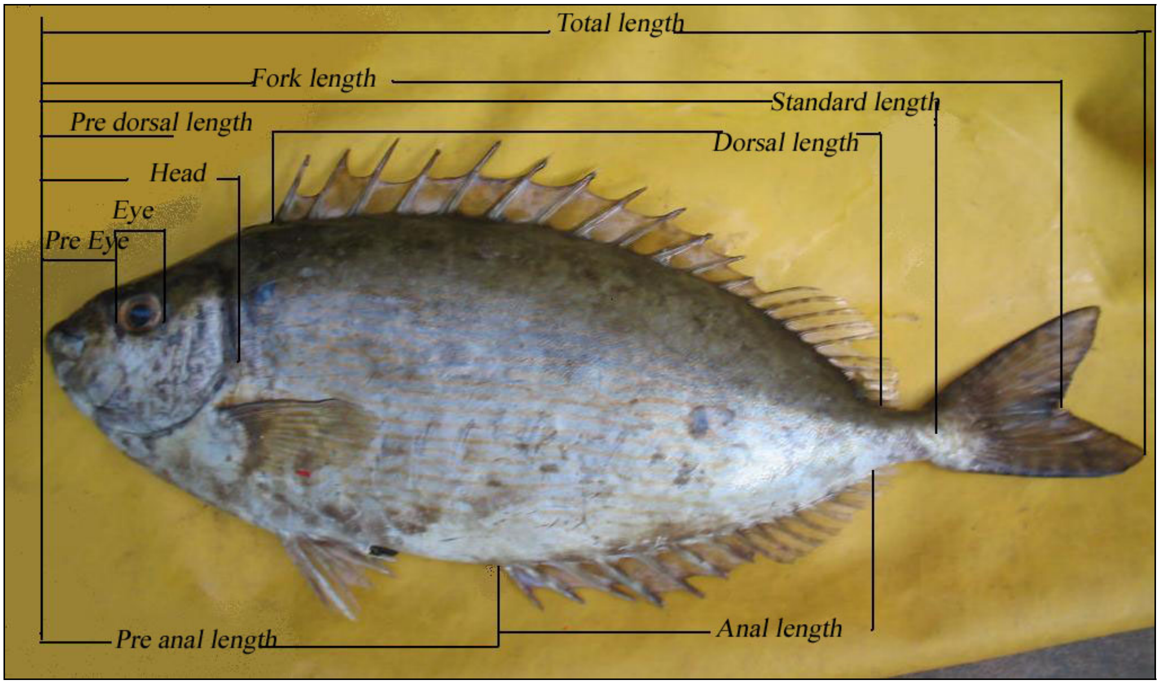

Fig. 3. Morphometric measurements for *Siganus rivulatus* and *S. luridus*

2.4 Reproduction and spawning period of *Siganus rivulatus* and *S. luridus*

The monthly samples were collected by trammel nets (inner mesh 26 mm, outer mesh 120 mm) in coastal waters (1-30 m depth) for *S. rivulatus* from March 2005 to February 2006 and from March 2005 to March 2006 for *S. luridus*. Sea surface water temperatures (˚C) were recorded monthly at mid day (10-12h) and samples of surface water were taken seasonally to measure the Salinity according to STRICKLAND and PARSONS (1972). A total of 1,216 *S. rivulatus* specimens was collected and selected randomly from the eastern region (Tubruk and Benghazi) and the Gulf of Sirt (Musrata) (Fig. 1). And 1,229 of *S. luridus* specimens was collected monthly and selected randomly from the west region (Zwara and Tripoli) and the Sirt gulf region (Musrata) (Fig. 1). The samples were taken and transported immediately in an ice box to the laboratory for analysis. The total weight (W_T) was measured to the nearest 0.1g and total length (L_T) to the nearest mm. Fresh gonads were removed, weighed to the nearest 0.01 g and visually inspected for size, colour, vascularization and presence of milt and oocytes. The maturity stages were noted according to YELDAN and AVSAR (2000).

The total fecundity (F_T) was calculated according to Yeldan and Avsar (2000). Twenty matured ovaries in June and July 2005 of *S. rivulatus* and sixty matured ovaries of *S. luridus* in May, June and July 2005 were removed and weighed to the nearest 0.001g. Three sub-samples from the ovary (anterior, middle, posterior) were weighed and counted under the microscope; only ripe oocytes were counted. Each sub-sample was placed on a slide, which was divided into 3 mm squares, and a drop of glycerine was added. Five squares were then observed under the microscope, to count oocytes. The total number of oocytes in the sub-sample was counted. The total fecundity (F_T) was estimated using the following equation: F= (gonad weight (g) × number of oocytes in the sub-sample / sub-sample weight (g)) (YELDAN and AVSAR 2000).

The same procedure was then repeated with the other two sub-samples. The values obtained from three sub-samples were then averaged to determine accurately the number of oocytes. The monthly Gonadosomatic index (GSI) was calculated using the following formula:

GSI = gonad weight (g) / (body weight (g) – gonad weight (g)) × 100 (BARICHE *et al.* 2003). The total length at first maturity (L_{T50}) was calculated for females and males according to KING (1995) by fitting a logistic function to the proportion of sexually mature individuals by length: P= $\{1 + e[-r (L_T - L_T 50)]\}^{-1}$, where (P) is the proportion of mature fish and (r) the slope. A Chi-square (χ^2) test was used to compare the sex ratio within the size group at each sampling, and Multivariance (ANOVA) was also used to compare the gonado weight dependence on the total length (L_T) between females and males in the spawning period.

2.5 Food and feeding habits of *Siganus rivulatus* and *S. luridus*

This study was carried out along the Libyan coast from March 2005 to February 2006 for *S. rivulatus* and from March 2005 to March 2006 for *S. luridus*. Monthly samples were collected by trammel nets (inner mesh 26 mm, outer mesh 120 mm) in coastal waters of 1 to 30 m depth. A total of 261 specimens of *S. rivulatus* were collected from the eastern region (Tubruk and Benghazi) and 394 specimens of *S. luridus* were collected from the western region (Zwara and Tripoli) and Sirt gulf (Musrata) (Fig.1, Table 1). The samples were stored cool and were transported immediately to the laboratory for analysis. The total weight (W_T) was measured to the nearest 0.1g and total length (L_T) to the nearest mm, and gut (W_G) were removed and weighted to the nearest 0.01g. Stomach samples were removed, weighed and preserved in a 4% formaldehyde-seawater solution. The stomachs were opened in a petri dish and food items were carefully grouped in different categories and identified to the lowest taxonomic level possible.

Several parameters were used in the analysis of feeding behaviour. The Feeding Index (FI) and Gastro-Somatic index (GSI) were calculated as follows:

Feeding Index (FI): $FI = NF / NE \times 100$, where NF is the number of fishes with food in the stomach, NE is the number of fishes examined (SURESH *et al*. 2006).

Gastro-Somatic Index (GSI): GSI = (Gut weight (g) / Body weight (g)) × 100 (SURESH *et al*. 2006).

The Occurrence Frequency (F%) was calculated as $F\% = n \times 100 / N$, where n is number of stomachs in which a particular food item is observed and N is the number of full stomachs (HYSLOP 1980, BOWEN 1983, LIMA-JUNIOR and GOITEIN 2001).

While the seasonal F% is based on the number of stomachs per season (Tables 18 and 19, Figs. 42 and 43), the overall F% is based on the total number of stomachs (Fig. 44). If F% is less than 10% the occurrence of that particular food item is regarded as being by chance, if F% is between 10% and 50% the food item is regarded as being moderately preferable, and if F% is greater than 50 % the item is regarded as preferable (SABOUR 2004). A one-way ANOVA was used to compare the FI and GSI, between the two species in different months.

Table 1. Seasonal number of samples of *S. rivulatus* and *S. luridus* with their total length (L_T)

Season	***S. rivulatus***		***S. luridus***	
	Number	**Total length (cm)**	**Number**	**Total length (cm)**
Spring	86	13.3-27.4	77	13-23.8
Summer	69	10.4-23.8	68	13.3-24.6
Autumn	16	15.8-22.2	121	11.2-23.8
Winter	90	10.8-25.3	128	13.4-24.3
Total	261	10.4-27.4	394	11.2-24.6

2.6 Ectoparasite

Biological studies on rabbitfishes have been made in the south central Mediterranean, along the Libyan coast (Fig. 1). *Siganus rivulatus* and *S. luridus* were both collected from three different localities (Tripoli, Musrata and Tubruk) using trammel nets (inner mesh 26 mm, outer mesh 120 mm) (Fig. 1). While processing, all fishes were investigated for the possible presence of ectoparasites. All collected cymothoids were preserved in 70% alcohol and deposited at the Zoological Collection of the University of Rostock (ZSRO, ISO 001 to ISO 008), Germany.

2.7 Genetic study of *Siganus rivulatus* and *S. luridus*

2.7.1 Samples collections:

The samples were collected by trammel nets from the south Mediterranean, Egyptian coast (Alexandria), Libyan coast (six regions) and Egyptian red sea (Hurghada) for *S. rivulatus* while samples for *S. luridus* were collected from the Libyan coast (Six regions) and Tunisian coast (Gabe's gulf; Fig. 4). After sample collection, white tissue samples were immediately placed in 95% ethanol and stored at ambient temperature in the field and then at 4 ° C in the lab. The sampling sites and their denomination are presented in Table 20.

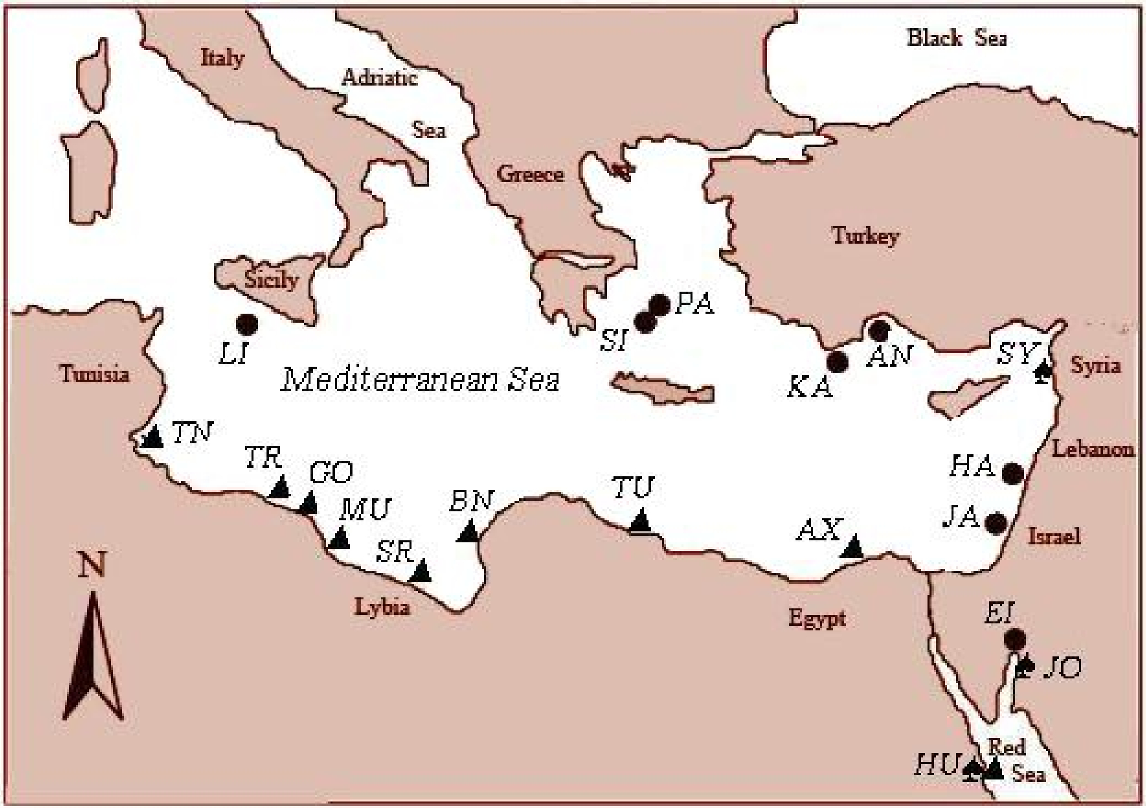

Fig. 4. The map representing samples collection from different geographic locations of the Red and Mediterranean Seas (TN: Tunisia, TR: Tripoli, GO: Al Gomas, MU: Musrata, SR: Sirt, BN: Benghazi, TU: Tubruk, AX: Alexandria, HU: Hurghada, JO: Jordan, EI: Elat, JA: Jaffa, HA: Haifa, SY: Syria, AN: Antalya, KA: Kastellorizon, PA: Paros, SI: Sifnos, LI: Linosa), (▲: present study, ♠,●: GenBank)

2.7.2 DNA extraction, amplification and sequencing:

Tissue was placed in 500 µl of 5 % Chelex® 100 sterile water and incubated at 56° C for one hour after brief vortexing. Extracts were incubated at 94°C form 7 to 8 hours and then stored at -20°C. Before use, extracts were centrifuged at 13,000 rpm for 5 min; the supernatants were directly used in PCR. Amplification of mitochondrial control region was conducted using the primers CR-A and CR-E (LEE *et al*. 1995). While mitochondrial Cytochrome b was amplified using modified universal primers L14841 (5' – GCT TCC ATC CAA CAT CTC AGC ATG ATG – 3') and H15149 (5' – CTG CAG CCC CTC AGA ATG ATA TTT GTC – 3') (KOCHER *et al*. 1989). All amplifications (30µl) contained 3µl from dNTPs, each primer CRA, CRE for control region and 15149, 14841 for Cytochrome b and PCR buffer, 11.445 µl Distilled water, 0.255 µl Taq DNA polymerase (5U/µl), 0.3 µl MgCl2 and 6 µl DNA sample and used a cycling profile 30 s at 94 ° C, 30 s at 50 ° C, 1 min for 72 ° C, for 35 cycles. PCR products were electrophoresed through a 2% agarose gel in TAE buffer to verify amplification.

For purification, the PCR products were extracted from agarose gels according to the protocol of the NucleoSpin® Extract Kit (Macherey-Nagel).

All PCR products were sequenced (cyt b: 258bp; CR: 383-384bp) using the CEQ Dye Terminator cycle sequencing quick start kit (Beckman Coulter) according to the manufacturer's protocol and electrophoresed on an automated DNA sequencer (CEQ 8000; Beckman Coulter). The control region and cytochrome b fragments were sequenced bi-directionally using the PCR primers

2.7.3 Alignments, datasets, phylogenetic analyses

Additionally, sequences of control region for *S. luridus* and *S. rivulatus* of the north Mediterranean Sea and Red sea (Elat gulf) were taken from GenBank (Accession numbers see Tables 22, 23), also sequences of cytochrome b. for both species of the north Mediterranean (Syria) and Red sea (Jordan, Hurghada) were taken from GenBank (Table 21). The sequences were automatically analysed using the software CEQ8000XL (Beckman Coulter), visually controlled and finally aligned using the BioEdit software (HALL 1999). Nucleotide (π), haplotype diversity (H; NEI 1987), F_{ST} and Nm [$F_{ST} = 1 / (1 + 2\ Nm)$] were calculated with DnaSP 4.1 (ROZAS *et al*. 2003).

2.7.4 Sequence analysis

Phylogenetic analysis was performed by applying the neighbour-joining method without distance correction with MEGA4 (TAMURA *et al*. 2007).

Additionally, a median-joining (MJ) network analysis was performed. The MJ networks were calculated with the NETWORK software (BANDELT *et al*. 1999; www.fluxus-engineering.com) using default parameters.

3 Results

3.1 Distribution and characterization of lessepsian fish species

A total of sixteen Lessepsian fish species were found (Table 2). Four of them are recorded for the first time on the Libyan coast: *Herklotsichthys punctatus* (Rüppell, 1837), *Liza carinata* (Valenciennes, 1836), *Hemiramphus far* (Forsskål, 1775) and *Pempheris vanicolensis* Cuvier, 1821. Their morphological and meristic characters are given (Table 3). The species *Sphyraena obtusata* and *S. pinguis* are named according to revision of DOIUCHIAND and NAKABO (2005).

Table 2. List of Lessepsian fish species of the Libyan coast

Scientific name	English name	Libyan name	Family
Siganus luridus	dusky spinefoot	Batata Khahlla , Shifsha	Siganidae
Siganus rivulatus	marbled spinefoot	Batata beda	Siganidae
Sphyraena obtusata	obtuse barracuda	Moshta , Maghzil Asfar	Sphyraenidae
Sphyraena pinguis	red barracuda	Moshta , Maghzil Magrgab	Sphyraenidae
Herklotsichthys punctatus	spotback herring	Sridna	Clupeidae
Saurida undosquamis	brushtooth lizardfish	Makarona	Synodontidae
Hemiramphus far	blackbarred halfbeak	Abo-meshfa	Hemiramphidae
Fistularia commersonii	bluespotted cornetfish	Gaeta	Fistulariidae
Atherinomorus lacunosus	hardyhead silverside (silverside fish)	Namousa , Owzaf	Atherinidae
Alepes djedaba	shrimp scad	Saurou Asfar	Carangidae
Upeneus pori	Por' s goatfish	Treellya Khadra	Mullidae
Crenidens crenidens	karenteen seabream (porgie)	Sparus Masrry	Sparidae
Pempheris vanicolensis	Vanikoro sweeper (sweeper fish)	Samk deal , Gasaetlla	Pempheridae
Liza carinata	keeled mullet (roving grey mullet)	Buri	Mugilidae
Scomberomorus commerson	narrow-barred Spanish mackerel	Balameta Yamania	Scombridae
Stephanolepis diaspros	reticulated leatherjacket (filefish)	Halof boresha , Halof Abo shuka	Monacanthidae

Table 3. Morphological and meristic characters for *Herklotsichthys punctatus*, *Liza carinata*, *Pempheris vanicolensis* and *Hemiramphus far*, N: Number

Scientific name	Coordinate	(N)	Total length (cm)	Meristic	Habitat	Average Temperature (˚C)	Depth (m)
H. punctatus	32°03' 50 "N 23°59 ' 02"E	1	7.2	D15, A17, P16, V8.	Pelagic	15	1–3
L. carinata	32°04' 43 "N 23°58 ' 50"E	2	16.3–23.3	D1, IV, D2 1+8, A III + 9P 15, V I + 5	Pelagic	17	5–7
H. far	32°03' 50 "N 23°59 ' 02"E	72	17.9-24.5	D 12-14, A 10-12, P 11-12, V 6	Pelagic	18.1	4-6
P. vanicolensis	-	1	14.9	D: V+9, A: III + 37, P: I + 16, VL: 1 + 5, P: 16, LL: 53	Rocky	22	4

As regards the abundance, 56.25% representing most of the Lessepsian fish species are rare (<1% of the total Lessepsian fish collected), but seven species (43.75%) are common. The habitat occupation was 12.5% on vegetation, 43.75% pelagic, 31.25% sandy and 12.5% rocky. According to size, 75% of the Lessepsian species were categorized as medium, followed by small (6.25%) and large (18.75%). More than one-third, 37.5%, were species of commercial value whilst 62.5% were species of no commercial value (Fig. 5). The distribution was 50% along the entire Libyan coast, 37.5% in the east part, and 12.5% in the east and middle (Fig. 6).

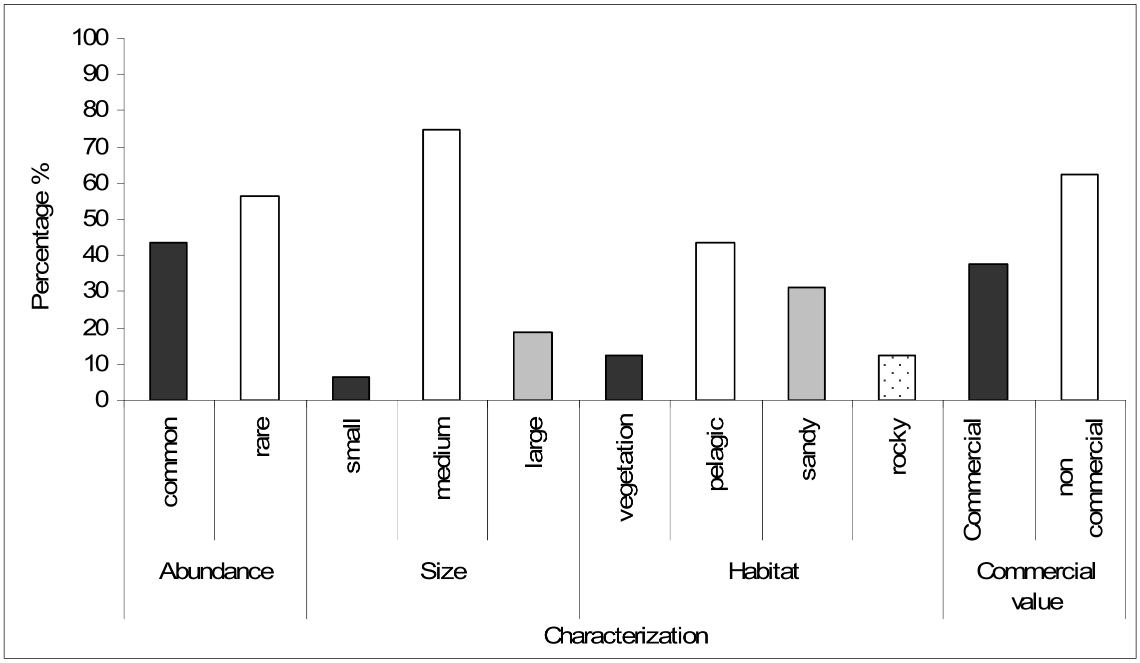

Fig. 5. Characterization of Lessepsian fish species along the Libyan coast

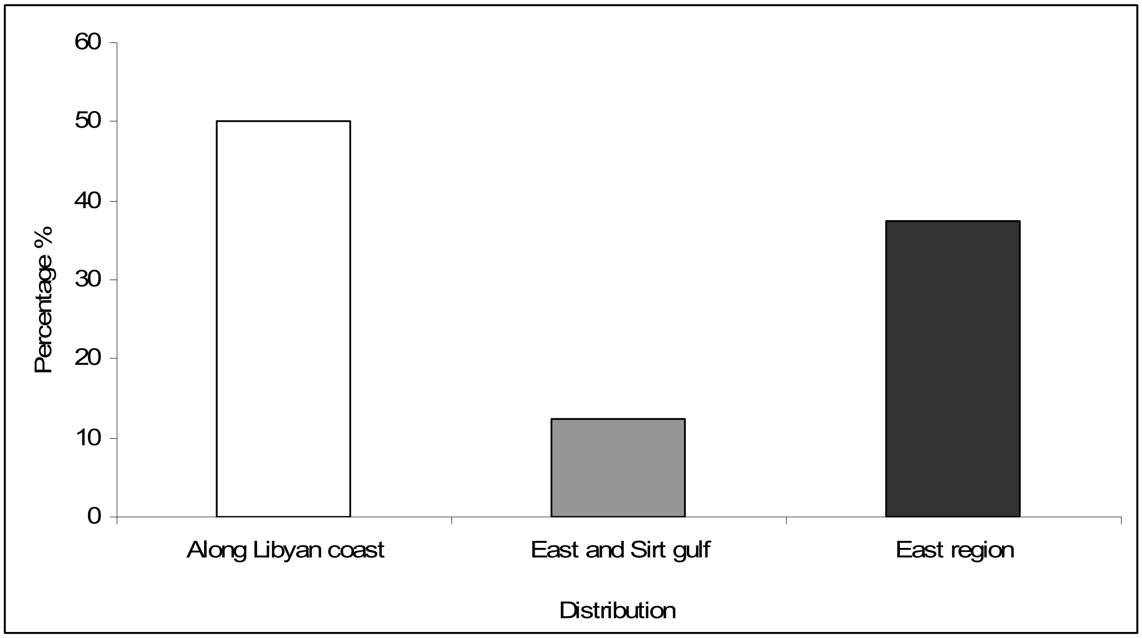

Fig. 6. Distribution of Lessepsian fish species along the Libyan coast

The abundance and habitat occupation of the species in each of the main regions are presented in Table 4. The commercial value, size and distribution of the species in each of the main regions are presented in Table 5. Fig. 7 illustrates the distribution of each species along the Libyan coast.

Table 4. Abundance and habitat occupation for each lessepsian fish species according to the main regions along the Libyan coast

Species	**Habitat**	**Regions**					
		West Region		**Sirt Region**		**East Region**	
		%	**Abundance**	**%**	**Abundance**	**%**	**Abundance**
S. luridus	Vegetation	87.74	Common	81.27	Common	6.52	Common
S. rivulatus	Vegetation	9.91	Common	11.46	Common	75.18	Common
S. obtusata	Pelagic	0.21	Rare	0.77	Rare	2.43	Common
S. pinguis	Pelagic	0.36	Rare	3.41	Common	7.82	Common
H. punctatus	Pelagic	×	×	×	×	0.04	Rare
S. undosquamis	Sandy	×	×	0.31	Rare	0.99	Rare
H. far	Pelagic	×	×	×	×	3.24	Common
F. commersonii	Sandy	0.07	Rare	0.15	Rare	0.04	Rare
A. lacunosus	Sandy	×	×	0.46	Rare	0.76	Rare
A. djedaba	Pelagic	0.36	Rare	0.62	Rare	1.62	Common
U. pori	Sandy	×	×	×	×	0.09	Rare
C. crenidens	Sandy	×	×	×	×	0.09	Rare
P. vanicolensis	Rocky	×	×	×	×	0.09	Rare
L. carinata	Pelagic	×	×	×	×	0.09	Rare
S. commerson	Pelagic	1.07	Common	1.08	Common	0.54	Rare
S. diaspros	Rocky	0.29	Rare	0.46	Rare	0.45	Rare
Total		100		100		100	

(× Species Absent)

Table 5. The Size, commercial value and distribution of each lessepsian fish species according to the main regions along the Libyan coast

Species	**Regions**						
	Size	**West Region**		**Sirt Region**		**East Region**	
		Distribution	**Commercial value**	**Distribution**	**Commercial value**	**Distribution**	**Commercial value**
S. luridus	Medium	/	Commercial	/	Commercial	/	Commercial
S. rivulatus	Medium	/	None	/	Commercial	/	Commercial
S. obtusata	Large	/	None	/	None	/	None
S. pinguis	Medium	/	None	/	None	/	Commercial
H. punctatus	Small	×	×	×	×	/	None
S. undosquamis	Medium	×	×	/	None	/	None
H. far	Medium	×	×	×	×	/	Commercial
F. commersonii	Large	/	None	/	None	/	None
A. lacunosus	Medium	×	×	/	None	/	None
A. djedaba	Medium	/	None	/	None	/	Commercial
U. pori	Medium	×	×	×	×	/	None
C. crenidens	Medium	×	×	×	×	/	None
P. vanicolensis	Medium	×	×	×	×	/	None
L. carinata	Medium	×	×	×	×	/	None
S. commerson	Large	/	Commercial	/	Commercial	/	Commercial
S. diaspros	Medium	/	None	/	None	/	None

(/ = Present, × = Absent)

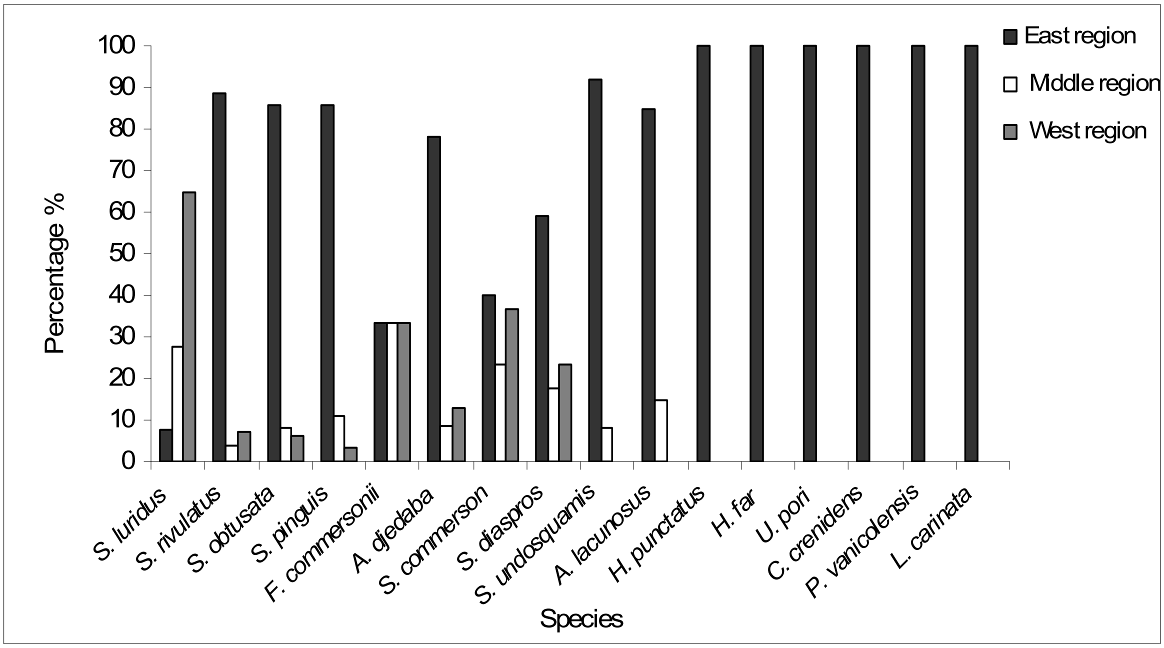

Fig. 7. Distribution in percentage of each Lessepsian fish species along the Libyan coast

3.1.1 Discussion

Sixteen Lessepsian fish species were found, four of them are additions to the Libyan fish fauna and are also additions to the list of Lessepsian fish migrants in Libya: *H. punctatus* (Rüppell, 1837), *L. carinata* (Valenciennes, 1836), *H. far* (Forsskål, 1775) and *P. vanicolensis* Cuvier, 1821 (Tables 2, 3). These species have been recorded in many areas of the eastern Mediterranean Sea by EL-SAYED (1994), KOSSWIG (1956), MOUNEIMNÉ (1977) and WHITEHEAD *et al.* (1984–1986). When a species is found to be rare or as single specimen only, this is considered to be the first step in establishing a successful population, as expressed by an increase in the population (GOLANI and BEN-TUVIA 1989). Three species have also been recorded from Libya by other authors: *Parexocoetus mento* (Valenciennes, 1846) (BEN-TUVIA 1966), *Sargocentron rubrum* (Forsskål, 1775), and *Upeneus moluccensis* (Bleeker, 1855) (STIRN 1970), but they were not found during the present study.

The abundance indicates that seven species can be considered as common, namely *Siganus luridus*; *S. rivulatus*; *Sphyraena obtusata* Cuvier, 1829; *Alepes djedaba* (Forsskål 1775); *Hemiramphus far* (Forsskål 1775); *Sphyraena pinguis*; *Scomberomorus commerson* (Lacepède, 1800) (43.75%), while most of the Lessepsian fish species were rare, such as *Fistularia commersonii*; *Stephanolepis diaspros* Fraser-Brunner, 1940;

Herklotsichthys punctatus (Rüppell, 1837); *Upeneus pori* Ben-Tuvia and Golani, 1989; *Crenidens crenidens* (Forsskål 1775); *Pempheris vanicolensis* Cuvier, 1821; *Liza carinata* (Valenciennes, 1836); *Saurida undosquamis* (Richardson, 1848); and *Atherinomorus lacunosus* (Forster, 1801) (56.25%) (Fig. 5). The abundance of these species differs between the main regions (Table 4), which may be due to a relation between the species' early arrival and the species abundance. GOLANI (1998a) showed that there is a correlation between species that arrived earlier in the Mediterranean and their greater abundance. This can be explained by (a) the longer they are in the Mediterranean, the greater the opportunity for them to build up their populations, or (b) the greater research effort, which was much less intense in the past (GOLANI 2002). On the Turkish coast, the abundance of the Lessepsian fish has the following proportions: 5 species (15%) are categorized as rare and the remaining 28 species (84.8%) as common (BILECENOGLU and TASKAVAK 2002). The proportions are different in the presently study.

Regarding habitat occupation, the majority of the Lessepsian migrant fish species were found in the coastal area and usually at depths of 1–50 m (Fig. 5, Table 4), while only two species were found in the vegetation habitat, namely *S. rivulatus* and *S. luridus* (12.5%). *S. rivulatus* was found in several different overgrown habitats (rocks with algae, sand with algae, and grass with algae) whereas *S. luridus* was found in one specific vegetation habitat (rocks with algae). Both *Siganus* species are considered to be strictly herbivorous, and in the Mediterranean only two fish species belong to a similar trophic guild - *Sarpa salpa* (L.) (Sparidae) and *Sparisoma cretense* (L.) (Scaridae) - both in the eastern and central basins (AZZURRO and ANDALORO 2004). BARICHE *et al*. (2004) showed that *S. rivulatus* is able to settle on a large range of substrates and habitats, including rock pools, muddy harbours, and sea-grass beds. In the eastern Mediterranean, *S. rivulatus* has a wider settlement range than that of *S. luridus*, probably due that *S. rivulatus* has benefited from the low diversity of native herbivorous species (BARICHE *et al*. 2004). Five species were found in the sand habitat: *S. undosquamis*, *F. commersonii, A. lacunosus, U. Pori*, and *C. crenidens* (31.25%), and two species were on rocks: *P. vanicolensis* and *S. diaspros* (12.5%). The many potential rock habitat site-related species from the Red Sea would not succeed, or would only rarely succeed, in reaching that habitat in the Mediterranean, since they would need to cross the Suez Canal, the northern Gulf of Suez and the south-eastern Mediterranean, all of which lack a continuous rocky habitat (GOLANI 2002). The pelagic species are the largest category (seven species): *S. obtusata, S. pinguis, H. punctatus, H. far, A. djedaba, L. carinata,* and *S. commerson* (43.8%). The majority of these species tend to spread within a depth range of 20 to 40 m (POR 1978).

As regards of their size, twelve species (75%) were classified as medium, followed by three species considered large (18.75%) and one species small (6.25%) (Fig. 5, Table 5). This result is similar to the results in the Turkish seas, where 78.8% of species were medium-sized, followed by large (12.5%) and small (9.1%) (BILECENOGLU and TASKAVAK 2002). However, these Figs differ from the results in the eastern Mediterranean where more than half of the Lessepsian migrants were of medium size; small- and large species were more or less equal in number (13 and 12, respectively) (GOLANI 2002).

As far as their commercial value is concerned, six species (37.5%) have become commercially valuable on the Libyan coast, and ten species (62.5%) are characterized as having no commercial value (Fig. 5). Of these six, three (*S. pinguis*, *H. far*, and *A. djedaba*) were found in the east part of the Libyan coast, two (*S. luridus*, *S. commerson*) all along the Libyan coast, and one (*S. rivulatus*) in the east part and the Sirt Gulf only (Table 5). These species are now found regularly in the Libyan catches; most of them have been recorded as commercially valuable in many areas in the eastern and central-south Mediterranean Sea (TORCU and MATER 2000, BILECENOGLU and TASKAVAK 2002, GOLANI 2002, SHAKMAN and KINZELBACH 2006).

The distribution observed, implies that half of the species (50%) are present all along the Libyan coast (Fig. 6). There is a different concentration for the different species: *S. luridus* is concentrated more in the west part and the Sirt Gulf rather than in the east part of the Libyan coast, whilst *S. rivulatus* is concentrated in the east part and decreases in the Sirt Gulf and the west part (Fig. 7). There may be competition between *S. luridus* and *S. rivulatus* in the east region, as these species together are less concentrated in the area from Zwara up to the Tunisian border, although there is an appropriate habitat for herbivorous species in this area especially on the Farwah coast. Two species are distributed in the east part and Sirt Gulf (*S. undosquamis*, *A. lacunosus*) and six species are distributed only in the east part (*H. punctatus*, *H. far*, *U. pori*, *C. crenidens*, *P. vanicolensis*, *L. carinata*) (Fig. 7). For a better understanding of Lessepsian immigration, additional taxonomic and biological investigations are required (BEN-TUVIA 1978). It is expected that in some cases the exchange of fauna and flora may have taken place before the opening of the Suez Canal, as a result of the elevation of sea levels and undulations of the Isthmus during the Pleistocene (BEN-TUVIA 1978).

The presently study has shown that some of the Lessepsian migrants have successfully adapted to the different topography and environments of Libyan coast and four fish species are also recorded for the first time. Many species have become widespread along this coast, which means that they are contributing to the commercial fish catch in Libya.

3.2 Commercial fishery

3.2.1 Fishing vessels

The number of boats found in this study was 1,511; of them 64.3% were “flouka”, 24.1% were “mator”, 6.9% were “lampara” and 4.8% were “batah” (Fig. 8). Most of them were concentrated in the western part of the Libyan coast (Table 6). In the coastal area the fishing vessel used most was flouka. Lampara, used to catch small pelagic fish, were concentrated in the western part and with a few in the Gulf of Sirt, especially in Musrata. Batah, on the other hand, were concentrated in the shallow water of the western region (Farwah site), only a small number of them was found in the eastern region (Attimimi and Ainghazala) (Fig. 9).

Table 6. Number and percentage of fishing vessels along the Libyan coast

Region	**East region**	**Middle region**	**West region**	**Total**
Number	308	317	886	1511
Percentage	20.4%	20.98%	58.6%	100

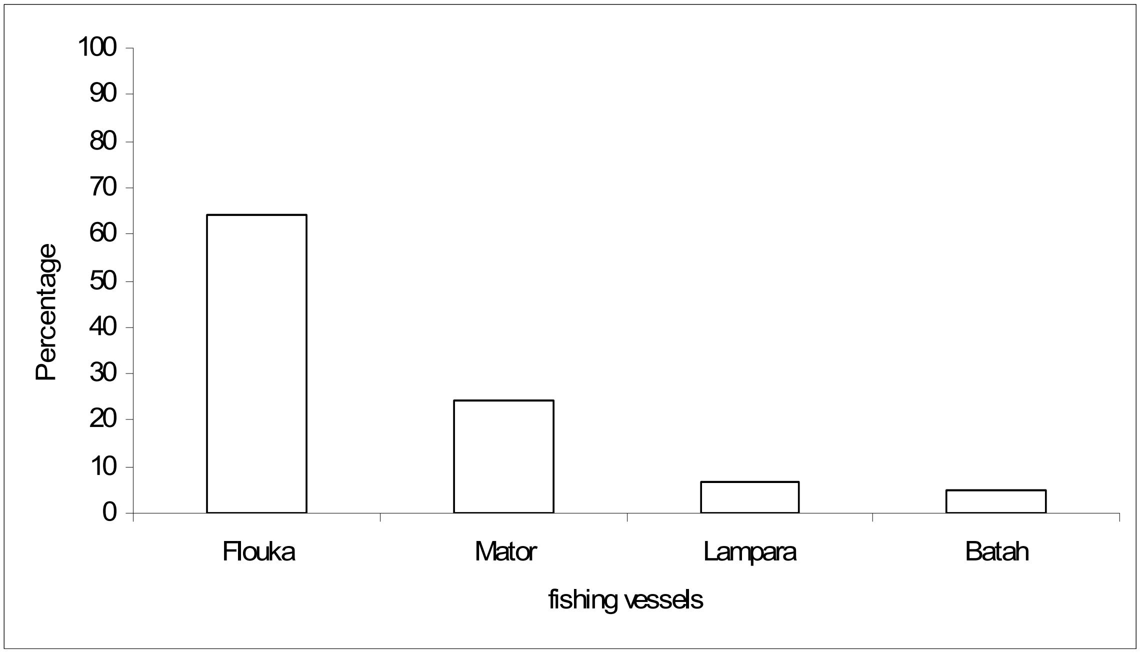

Fig. 8. Percentage of fishing vessels used in the coastal area along the coast of Libya in 2005

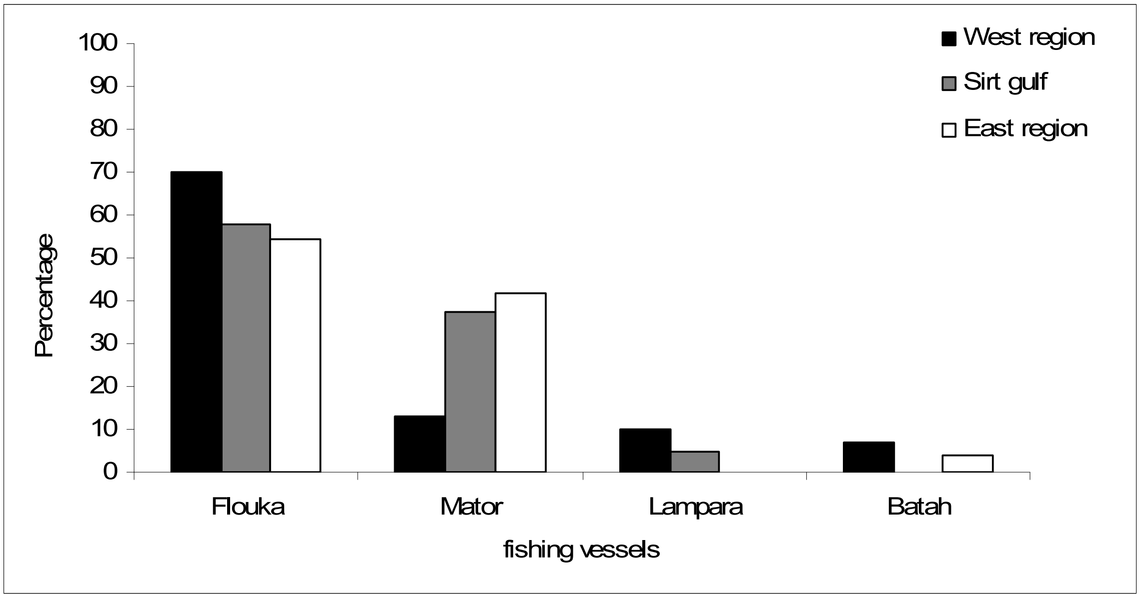

Fig. 9. Percentage of fishing vessels in the coastal area and their distribution along the coast of Libya in 2005

The most important fishing gear used in the coastal area was trammel nets. They are used by flouka in depths of one meter to fifty meters, and are operated by mator in more than thirty meters. They are also used by batah in depths of up to 5 meters (Fig. 10). Flouka also use other fishing gear for example (long line, gill nets etc.); depending on the season and size of different target fish species caught along the Libyan coast (Fig. 11).

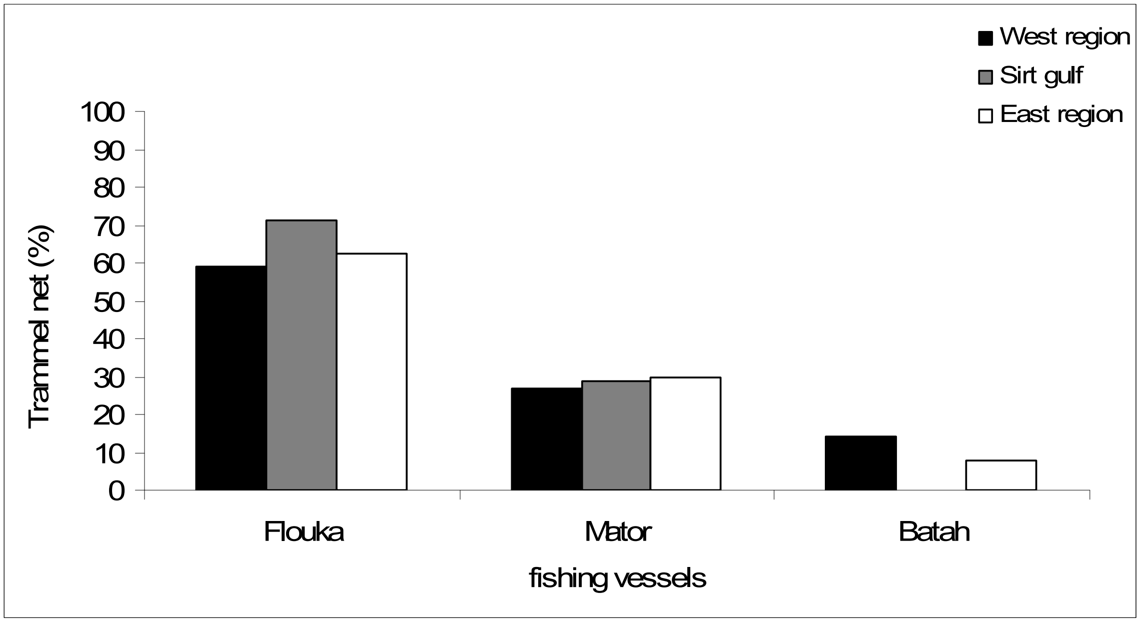

Fig. 10. Percentage fishing vessels that used the trammel net in the coastal area along Libyan coast in 2005

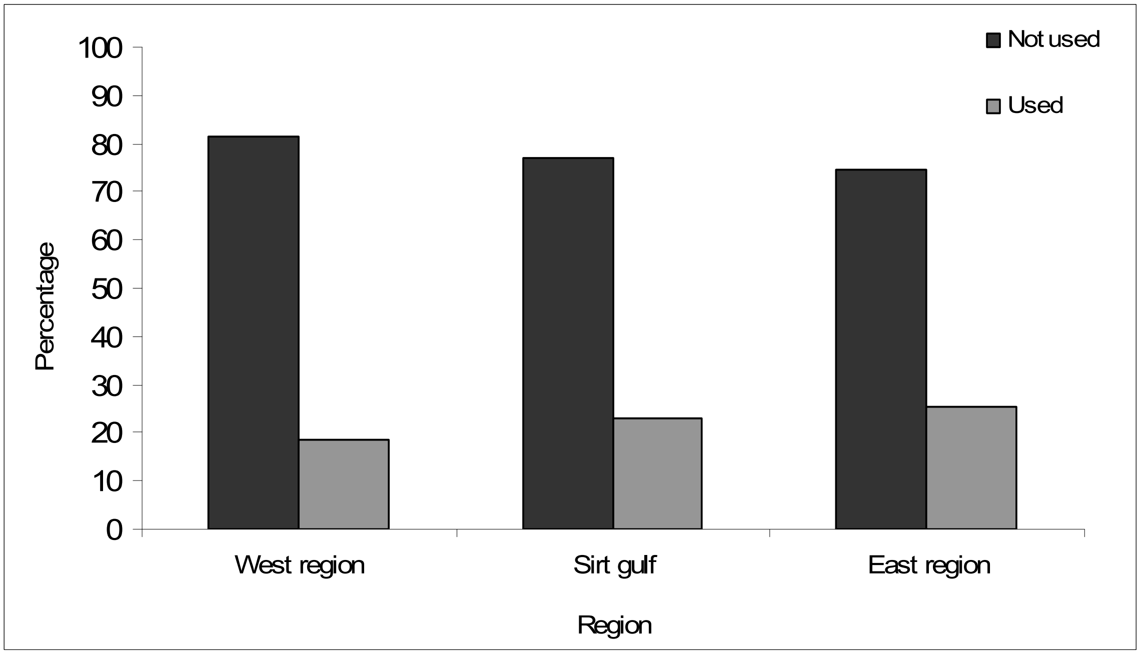

Fig. 11. Percentage of the (Flouka) that used the trammel net and not used along the Libyan coast in 2005

3.2.2 Species composition

In this study, the highest fish species diversity in the coastal area was in the eastern region (45.65%) while in the Gulf of Sirt and western regions the Fig. was 23.91% and 30.43% respectively (Fig. 12). The percentage of native fish species was higher than exotic fish species in the eastern region (61.90%), in the Gulf of Sirt region the percentage of native fish species was 54.55%, while 71.43% of fish were native fish species in the western region (Fig. 13).

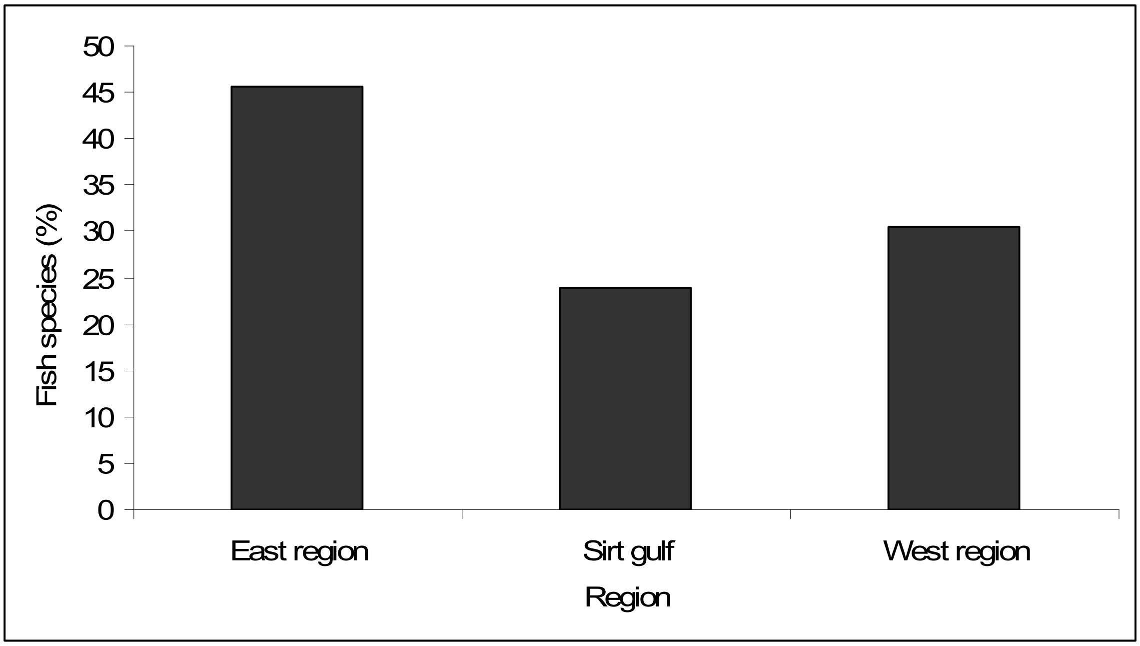

Fig. 12. Number percentage of fish species along the coastal area in the Libyan coast in 2005

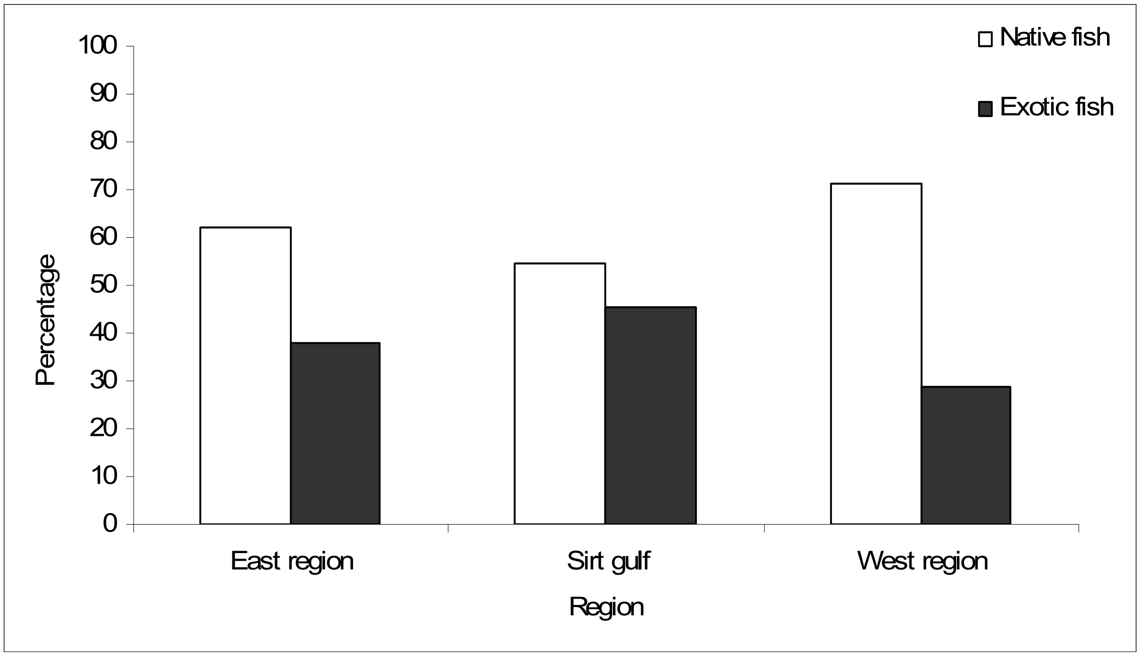

Fig. 13. Relationship between the number of exotic fish species and native fish species in the coastal water of Libya in 2005

In the eastern region of the Libyan coast, forty two fish species were found (Table 7). The highest percentage for the native species was Annular Seabream *D. annularis* (Sparidae) 7.74% and the lowest percentage was Shi Drum *Ubbrina cirrosa* (Sciaenidae) 0.10% of total catch; the highest percentage for exotic fish species was Marbled Spine-foot *S. rivulatus* (Siganidae) with 41.20% and the lowest percentage was Blue-spotted Cornetfish *F. commersonii* (Fistularidae) with 0.02% and Spotback Herring *Herklotsichthys punctatus* (Clupeidae) with 0.02% of total catch.

Table 7. Species composition of number and weight percentage that collected from the coastal by trammel net of eastern part of Libya (March 2005-March 2006) (* Cephalopod)

Libyan name	Common name	Scientific name	family	N%	W%
Kahlla	Saddledbream	*Oblada melanura*	Sparidae	0.67	1.15
Treellya	Striped red mullet	*Mullus surmuletus*	Mullidae	3.01	4.31
Garagous mausham	Banded seabream	*Diplodus vulgaris*	Sparidae	1.48	1.37
Garagous	White sea bream	*Diplodus sargus*	Sparidae	4.16	4.79
Brakash	Painted comber	*Serranus scriba*	Serranidae	0.30	0.22
Sbarus	Annular seabream	*Diplodus annularis*	Sparidae	7.74	4.29
Shkorfo	Scorpionfish	*Scorpaena* spp	Scorpaenidae	2.12	1.90
Buri	Box lip mullet	*Oedalechilus labeo*	Mugilidae	3.18	5.10
Mankos	Striped sea bream	*Lithoganthus mormyrus*	Sparidae	2.71	2.59
Zemrina	Mediterranean moray	*Muraena helena*	Muraenidae	0.27	0.38
Ghazla	Parrotfish	*Sparisoma cretense*	Scaridae	6.31	11.1
Abokather	Ballan wrasse	*Labrus bergylata*	Labridae	1.31	1.93
Dout	Dusky grouper	*Epinephelus guaza*	Serranidae	0.81	1.62
Morjan	Common sea bream	*Pagrus pagrus*	Sparidae	0.89	0.84
Baghllah	Shi drum	*Ubbrina cirrosa*	Sciaenidae	0.10	0.41
Grab	Brown meagre	*Sciaena umbra*	Sciaenidae	0.76	1.21
Pullem	Stargazer	*Uranoscopus scaber*	Uranoscopidae	0.27	0.39
Halof	Grey trigger fish	*Balistes carolinensis*	Balistidae	0.30	0.40
Homrayah	Common dentex	*Dentex dentex*	Sparidae	0.22	0.11
Dendashie	Common dentex	*Dentex dentex*	Sparidae	0.30	0.33
Shelpa	Salema	*Sarpa salpa*	Sparidae	1.11	0.97
Tannut	Black seabream	*Spondyliosoma cantharus*	Sparidae	0.22	0.39
Mdas	Common Sole	*Solea spp*	Soleidae	0.15	0.09
Mugazl	Barracuda	*Sphyraena spp*	Sphyraenidae	0.12	0.23
Strelia	Leerfish	*Lichia amia*	Carangidae	0.02	0.29
Sardine	Madeiran Sardinella	*Sardinella maderensis*	Clupeidae	5.05	6.18
Moshta , Maghzil Asfar	Obtuse barracuda	*Sphyraena obtusata*	Sphyraenidae	1.33	2.61
Moshta,MaghzilMagrgab	Red barracuda	*Sphyraena pinguis*	Sphyraenidae	4.29	5.60
Sridna	Spotback herring	*Herklotsichthys punctatus*	Clupeidae	0.02	0.01
Makarona	Brushtooth lizardfish	*Saurida undosquamis*	Synodontidae	0.54	0.66
Abo- meshfa	Halfbeak	*Hemiramphus far*	Hemiramphidae	1.77	0.75
Gaeta	Bluespotted Cornetfish	*Fistularia commersonii*	Fistularidae	0.02	0.09
Namousa , Owzaf	Silverside fish	*Atherinomorus lacunosus*	Atherinidae	0.42	0.06
SaurouAsfar,,Saurou Imperially	Shrimp scad	*Alepes djedaba*	Carangidae	0.89	0.56
Treellya Khadra	Goatfish	*Upeneus pori*	Mullidae	0.05	0.04
Sparus Masrry	Porgie	*Crenidens crenidens*	Sparidae	0.05	0.03
Samk deal , Gasaetlla	Sweeper fish	*Pempheris vanicolensis*	Pempheridae	0.05	0.02
Buri	Roving grey mullet	*Liza carinata*	Mugilidae	0.05	0.05
Balameta Yamania	Spanish Mackerel	*Scomberomorus commerson*	Scombridae	0.30	4.41
Halofboresha,Halof Aboshuka	Filefish	*Stephanolepis diaspros*	Monacanthidae	0.25	0.13
Batata Khahlla ,Shifsha	Dusky spine-foot	*Siganus luridus*	Siganidae	3.57	3.36
Batata beda	Marbled spine-foot	*Siganus rivulatus*	Siganidae	41.2	25.8
*Garneat	Octopus, Cuttlefish	*Octopus* sp., *Eledone* sp.	Octopodidae	0.17	0.70
*Sepei	Inkfish	*Sepia offlcinalis*	Sepeiidae	1.45	2.51

Twenty one fish species were found in the Gulf of Sirt region of the Libyan coast (Table 8). The highest percentage of native fish species was Annular Seabream *D. annularis* (Sparidae) with 17.11 % and the lowest percentage was Saddled Bream *Oblada melanura* (Sparidae) with 4.56% of total catch; the highest percentage of exotic fish species was Dusky Spine-foot *S. luridus* (Siganidae) with 36.82% and the lowest percentage was Blue-spotted Cornetfish *F. commersonii* (Fistularidae) with 0.07% of the total catch.

Table 8. Species composition of number and weight percentage that collected from the coastal by trammel net of Sirt gulf of Libya (March 2005-March 2006) (* Cephalopod)

Libyan name	**Common name**	**Scientific name**	**family**	**N%**	**W%**
Treellya	Striped red mullet	*Mullus surmuletus*	Mullidae	2.88	3.24
shkorfo	Scorpionfish	*Scorpaena* sp	Scorpaenidae	9.26	5.47
Kahlla	Saddledbream	*Oblada melanura*	Sparidae	4.56	4.32
Sbarus	Annular seabream	*Diplodus annularis*	Sparidae	17.1	10.1
Grab	Brown meagre	*Sciaena umbra*	Sciaenidae	1.26	3.31
Garagous	White sea bream	*Diplodus sargus*	Sparidae	3.86	3.02
Shelpa	Salema	*Sarpa salpa*	Sparidae	2.31	2.00
Dout	Dusky grouper	*Epinephelus guaza*	Serranidae	0.98	2.06
Ghazla	Parrotfish	*Sparisoma cretense*	Scaridae	2.88	4.63
Abokathear	Ballan wrasse	*Labrus bergylate*	Labridae	4.42	8.05
Mankos	Striped sea bream	*Lithoganthus mormyrus*	Sparidae	3.65	2.06
Moshta , Maghzil Asfar	Obtuse barracuda	*Sphyraena obtusata*	Sphyraenidae	0.35	0.50
Moshta,MaghzilMagrgab	Red barracuda	*Sphyraena pinguis*	Sphyraenidae	1.54	1.54
Makarona	Brushtooth lizardfish	*Saurida undosquamis*	Synodontidae	0.14	0.15
Gaeta	Bluespotted Cornetfish	*Fistularia commersonii*	Fistularidae	0.07	0.11
Namousa ,Owzaf	Silverside fish	*Atherinomorus lacunosus*	Atherinidae	0.21	0.09
Saurou Asfar ,Saurou Imperially	Shrimp scad	*Alepes djedaba*	Carangidae	0.28	0.36
Balameta Yamania	Spanish Mackerel	*Scomberomorus commerson*	Scombridae	0.49	5.44
Halof boresha ,Halof Abo shuka	Filefish	*Stephanolepis diaspros*	Monacanthidae	0.21	0.20
Batata Khahlla , Shifsha	Dusky spine-foot	*Siganus luridus*	Siganidae	36.8	37.2
Batata beda	Marbled spine-foot	*Siganus rivulatus*	Siganidae	5.19	5.31
* Sepia	Inkfish	*Sepia offlcinalis*	Sepiidae	1.54	0.91

Twenty eight fish species were found in the western region of Libya (Table 9). The highest percentage for native fish species was Annular Seabream *Diplodus annularis* (Sparidae) with 10.74% and the lowest was Red Sea Bream *Pagellus bogaraveo* (Sparidae) with 0.16% of the total catch; the highest percentage of exotic fish species was Dusky Spine-foot *S. luridus* (Siganidae) with 40.06% and the lowest was for Blue-spotted Cornetfish *Fistularia commersonii* (Fistularidae) with 0.03% of total catch.

Table 9. Species composition of number and weight percentage that collected from the coastal by trammel net of west part of Libya (March 2005-March 2006) (* Cephalopod)

Libyan name	Common name	Scientific name	family	N%	W%
Treellya	Striped red mullet	*Mullus surmuletus*	Mullidae	3.25	2.57
Shkorfo	Scorpionfish	*Scorpaena* spp	Scorpaenidae	7.03	7.08
Dendashie	Common dentex	*Dentex dentex*	Sparidae	0.20	0.67
Sbarus	Annular seabream	*Diplodus annularis*	Sparidae	10.7	6.23
Grab	Brown meagre	*Sciaena umbra*	Sciaenidae	3.97	4.11
Morgan abo ain	Large-eyed dentex	*Dentex macrophthalmus*	Sparidae	1.07	0.83
Kahlla	Saddledbream	*Oblada melanura*	Sparidae	1.37	1.56
Tanot	Black sea bream	*Spondyliosoma cantharus*	Sparidae	0.81	1.70
Garagous	White sea bream	*Diplodus sargus*	Sparidae	4.88	3.68
Garagose mausham	Banded seabream	*Diplodus vulgaris*	Sparidae	2.34	0.53
Abokathear	Ballan wrasse	*Labrus bergylate*	Labridae	5.43	5.25
Djaja	Tub gurnard	*Trigla lucerna*	Triglidae	0.98	1.47
Dout	Dusky grouper	*Epinephelus guaza*	Serranidae	1.11	2.16
Brakash	Painted comber	*Serranus scriba*	Serranidae	0.33	0.25
Ghazla	Parrotfish	*Sparisoma cretense*	Scaridae	2.73	3.98
Mankos	Striped sea bream	*Lithoganthus mormyrus*	Sparidae	1.69	1.64
Shelpa	Salema	*Sarpa salpa*	Sparidae	3.12	0.48
Morjan	Common sea bream	*Pagrus pagrus*	Sparidae	2.60	0.28
Hamreia	Red sea bream	*Pagellus bogaraveo*	Sparidae	0.16	0.18
Strelia	Leerfish	*Lichia amia*	Carangidae	0.10	0.15
Moshta,Maghzil Asfar	Obtuse barracuda	*Sphyraena obtusata*	Sphyraenidae	0.10	0.16
Moshta,MaghzilMagrgab	Red barracuda	*Sphyraena pinguis*	Sphyraenidae	0.16	0.18
Gaeta	Bluespotted Cornetfish	*Fistularia commersonii*	Fistularidae	0.03	0.06
SaurouAsfar,Saurou Imperially	Shrimp scad	*Alepes djedaba*	Carangidae	0.16	0.37
Balameta Yamania	Spanish Mackerel	*Scomberomorus commerson*	Scombridae	0.49	3.91
Halofboresha,Halof,Abo shuka	Filefish	*Stephanolepis diaspros*	Monacanthidae	0.13	0.15
Batata Khahlla , Shifsha	Dusky spine-foot	*Siganus luridus*	Siganidae	40.1	45.3
Batata beda	Marbled spine-foot	*Siganus rivulatus*	Siganidae	4.52	4.47
* Sepia	Inkfish	*Sepia offlcinalis*	Sepiidae	0.42	0.64

3.2.3 Herbivorous fish species

The abundance of *S. rivulatus* (more than *S. luridus* and native fish species *S. salpa* and *S. cretense*) was in the eastern region of the Libyan coast. In the Gulf of Sirt region the exotic herbivore *S. luridus* was more abundant than *S. rivulatus* and the native fish species *S. salpa* and *S. cretense*; in the western region the highest percentage was for *S. luridus*, more abundant than *S. rivulatus* and the native *S. salpa* and *S. cretense* (Fig. 14).

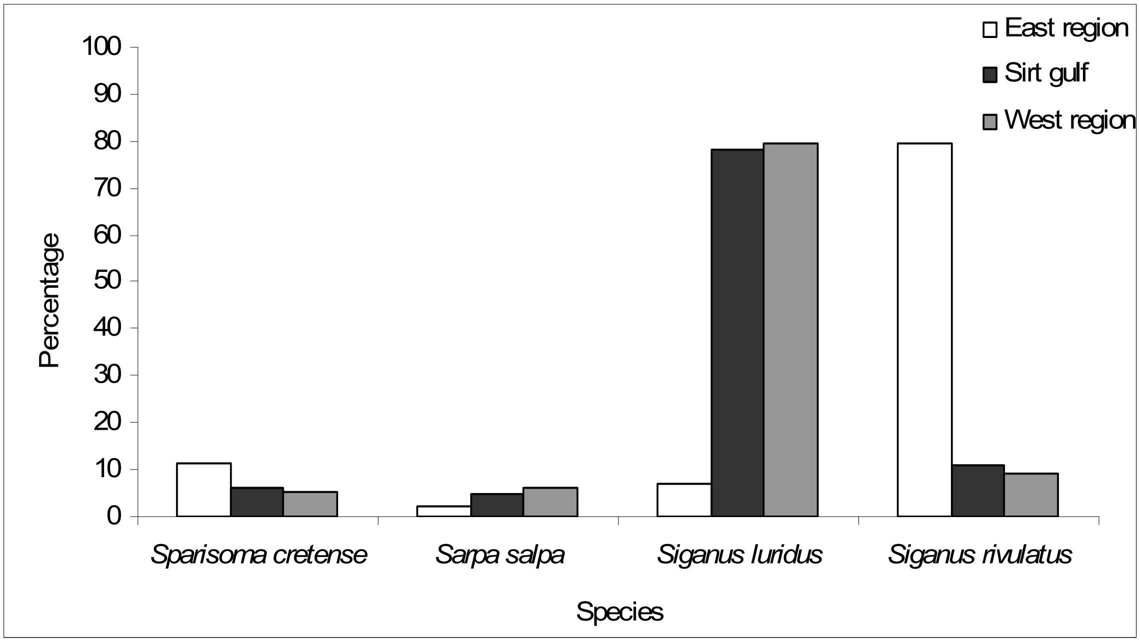

Fig. 14. Relationship between Lessepsian herbivorous fish species and native fish species in the main regions of the Libyan coast (March 2005-March 2006)

3.2.4 Discussion

The ichthyocoenosis of the Mediterranean Sea consists primarily of Atlanto-Mediterranean species (62%) from the adjacent Atlantic biogeographic provinces beyond the Straits of Gibraltar (Lusitanian Sea). Many Mediterranean species are endemic (20%) while others are cosmopolitan or circumtropical (13%) or Indo-Pacific (5%). These proportions differ for different major taxonomic groups and also for different parts of the Mediterranean Sea, but the pattern remains essentially the same (KETCHUM 1983).

At the time of this study, a total of 1,511 boats were being used in the coastal area of Libya. The percentages of different fishing craft were: 64.26% flouka, 24.09% mator, 6.88% lampara and 4.77% batah (Fig. 9). Most of them were concentrated in the western part of Libya (58.64%) (Table 6). The lampara was found predominantly in the western part, with a few exceptions in the Gulf of Sirt. The lampara is used to catch small pelagic fish species (Sardine, Mackerel etc.). The flouka and the mator were found right along the Libyan coast, while the batah, which is used in shallow water (Fig. 10), was found in the Farwah Lagoon, with a few boats of this type in the Attimimi and Ainghazala regions. The flouka was used in regions where the water was between one and fifty meters deep, while the mator was used for depths of more than thirty meters; the batah was used in depths of up to 5 meters.

In 2000 the country's entire fishing fleet numbered 1,866 boats; of these 1,266 boats were operated along the Libyan coast. Around 55% of the total number of boats was found in the western region, while 23% and 22% were found in the Gulf of Sirt region and in the eastern part of Libya respectively. The results of this study are almost identical to the framework survey of 135 landing sites in 2000, in which 61% of the fleet were flouka, 28% were mator, 7% were lampara used to catch small pelagic fish, while the batah represented only a small fraction of the total number of boats (4%) (LAMBOEUF 2000). However, two major differences distinguish this study from the one conducted in 2000, namely: a) in the present study only 76 active sites were considered because some of the landing sites investigated in the year 2000 were only seasonally, b) in the year 2000 all the craft were counted (operational (68%), non-operational (8%), under repair (22%) and unknown (2%)) whereas in this study only operational craft were counted.

As mentioned earlier, the percentage of exotic fish species relative to native fish species decreases from east to west along the Libyan coast. This means that there is a correlation between early arrival and greater abundance which can be explained (a) because the longer a species is in the Mediterranean, the greater the opportunity to build up its population, or (b) by the greater research effort, which was much less intense in the past (GOLANI 2002). This also means that there are many Lessepsian fish species included in the Libyan ichthyofauna which are of commercial value (SHAKMAN and KINZELBACH 2007a). The exotic fish species are still spreading in the various parts of the Mediterranean Sea (GOLANI *et al*. 2002, GOLANI *et al*. 2004), and some of these species have become established, become commercially important, and become regular catch species in many different parts of the Mediterranean Sea (EL-SAYED 1994, TORCU and MATER 2000, PAPACONSTANTINOU 1990a, BARICHE *et al*. 2004, SHAKMAN and KINZELBACH 2007a). There is a difference in the distribution of native and exotic fish species along the Libyan coast, with the diversity of fish species in the eastern region being high in comparison with the middle and the western parts of Libya. The most abundant native fish species along the Libyan coast was Annular Seabream *Diplodus annularis* (Sparidae), which made up 7.74% of the total in the eastern part, 17.11% in the middle region and 10.74% in the western part; the least abundant were the two Indo-Pacific fish species Spotback Herring *Herklotsichthys punctatus* (Clupeidae) at 0.02%

and Blue-spotted Cornetfish *Fistularia commersonii* (Fistulariidae) at 0.02% in the eastern part, and the Blue-spotted Cornetfish *F. commersonii* (Fistulariidae) at 0.07% in the middle region and 0.03% in the western part of Libya. In the present study, the results do not mean that these fish species are only established in this area, for the simple reason that different fish species are caught using different types of fishing gear, whereas this study only investigates the trammel nets used throughout the year along the Libyan coast. It is illogical to assume that the whole body of the Mediterranean Sea has the same species composition; regional speciation is evident in the Mediterranean Sea (WHITEHEAD *et al.* 1984-1986). Many surveys have been carried out along the Libyan coast in order to study species composition in different parts of Libya. In 1972 sixty two fish species were listed (GORGY *et al.* 1972). Some other surveys concentrated on trawler fishing and found 131 fish species (SOGREAH 1977), while 185 bony fish are listed by CONTRANSIMEX (1977). The highest diversity of fish species was found in a specific area of the Benghazi region (201 species). This Fig. was based on the catch captured by different types of commercial fishing gear (HASSAN and SILINI 1999).

The low diversity of herbivorous fish in the Mediterranean Sea includes only two herbivorous fish *S. salpa* (L., 1758) (Sparidae) and *S. cretense* (L., 1758) (Scaridae) (BAUCHOT and HUREAU 1986, QUIGNARD and PRAS 1986). In the present study the most abundant herbivorous fish were the Indo-Pacific fish species *S. rivulatus* and *S. luridus*, which are more numerous than the native fish species *S. cretense* and *S. salpa* along the Libyan coast. The concentration of these Indo-Pacific fish species varied along the coast, with *S. rivulatus* being concentrated in the eastern part of the Libyan coast, while *S. luridus* was concentrated in the middle region and western part of Libya (Fig. 14). It might be that there is competition between Indo-Pacific herbivorous fish species and native herbivorous fish species; On the other hand *S. rivulatus* was more abundant (79.47%) than *S. luridus* (6.89%) and the herbivorous native fish species *S. salpa* (2.14%) and *S. cretense* (11.50%) in the eastern region of Libyan coast, and when this result is compared with results from the eastern Mediterranean (Lebanon coast), the abundance of these species is quite similar: *S. rivulatus* was the most abundant at 72 % and *S. luridus* numbered 8 %, with the native species *S. cretense* at 20 % and the least abundant *S. salpa* (<1 %) (BARICHE *et al.* 2004). Furthermore DIAMANT *et al.* (1986) reported comparable relative abundance results from the eastern Mediterranean (Israelian coast) namely, 84% Siganids, 11% Scarids and 5% Sparids. In the Gulf of Aqaba, the dominant herbivores were the Acanthuridae (63%) and the Scaridae (35%) (BOUCHON-NAVARO and HARMELIN-VIVIEN 1981). *S. rivulatus* has an ability to adapt to most habitats, as it was found in different herbivorous habitats (rock with algae, sand with algae and grass with algae), whereas *S. luridus* was found in one specific habitat (rock with algae); it might be that *S. rivulatus* has benefited from a reduction of competition pressure due to the low diversity and abundance of native herbivorous fish species (BARICHE *et al*. 2004). GEORGE and ATHANASSIOU (1967) suggested that as *S. salpa* and *S. rivulatus* present similarities in body shape and habits, they might be in close competition for the same resources (BARICHE *et al*. 2004). Furthermore, this indicates that the population of the native fish species *S. salpa* has declined dramatically in the last seventy years (BARICHE *et al*. 2004). To conclude, the main fishing vessel used in the coastal area was the flouka, the most commonly used fishing gear in the coastal area were trammel nets, the fish species diversity in the coastal area was higher in the eastern part of Libya than in the middle and western parts, the abundance of exotic herbivorous fish species was higher than that of native herbivorous fish species with different concentrations on the coast, *S. rivulatus* is more abundant and has the ability to adapt to different habitats while *S. luridus* was found in one specific habitat.

3. 3 Biological characteristics of *Siganus luridus* and *S. rivulatus*

3.3.1 The total length frequency distribution

Length frequencies of pooled data (by sex, area and month) of *S. rivulatus* and *S. luridus* are given in Figs. 15 and 16 because the length frequencies of both sexes did not significantly differ ($p > 0.05$). The dominant total length in the Libyan catch was 15 cm for *S. luridus* and 18 cm for *S. rivulatus*. The range of total length, total weight and the mean and standard deviation are given by species in Table 10.

Table 10. Total length and total weight for *Siganus rivulatus* and *S. luridus* in the Libyan coast (Min: minimum, Max: maximum, SD: standard deviation and ANOVA (p- value))

Parameter	***Siganus rivulatus***						
	Female		**Male**			**Pooled fish**	
	Min-Max	**Mean±SD**	**Min-Max**	**Mean±SD**	**P-value**	**Min-Max**	**Mean±SD**
L_T (cm)	6.2 - 27	18.98±2.9	6.3 -26.5	18.8±2.7	>0.05	6.2 -27.4	18.78±2.8
W_T (g)	6.6-268.8	101.02±33.9	3.1-258.1	97.22±38.2	>0.05	3.1 - 268.8	96.16±39.7
	Siganus luridus						
L_T (cm)	11.5 -25.5	17.9 ± 3.12	10.2- 25.3	17.78±3.12	>0.05	10.2 - 25.5	17.75±3.0
W_T (g)	29.3 - 406	127.22±75.1	25 - 326.4	122.7±66.5	>0.05	25 -406	122.4±69.4

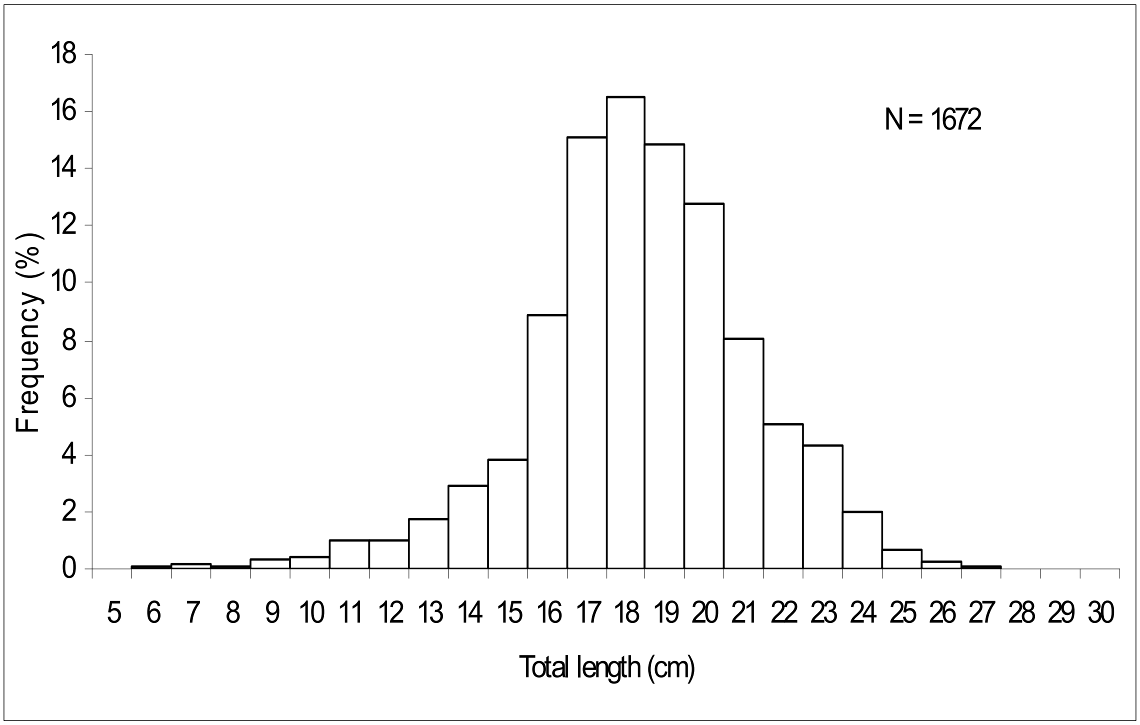

Fig. 15. Length frequency distribution of *Siganus rivulatus* collected from March 2005 to February 2006 from the eastern part of the Libyan coast. (N: number of specimens)

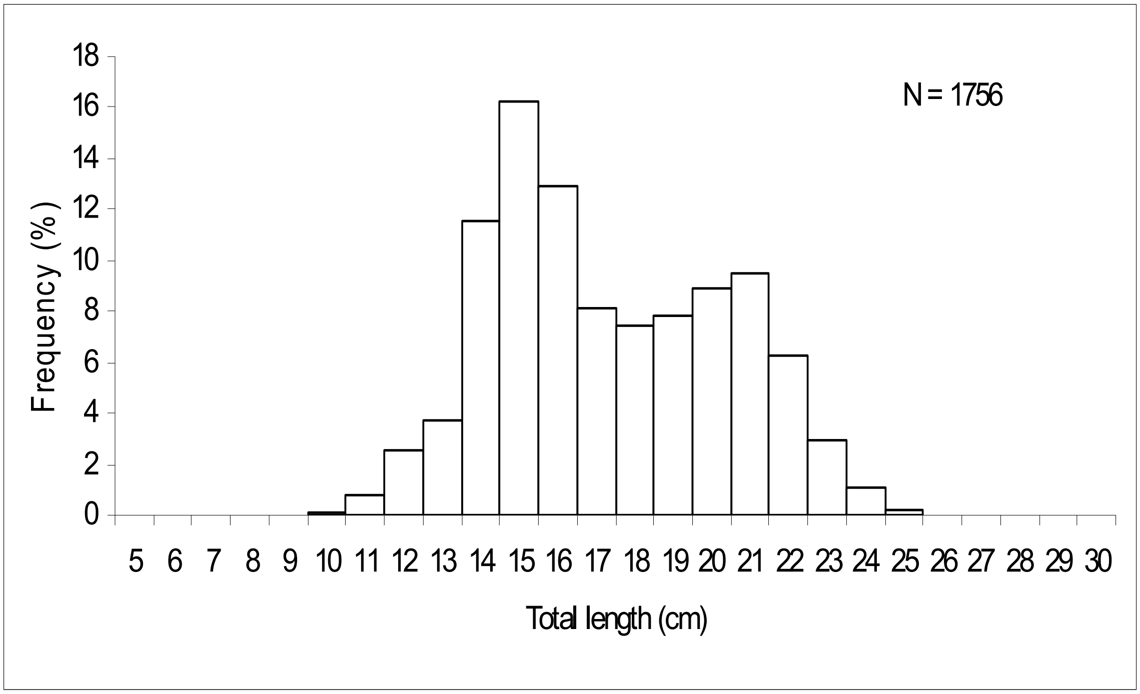

Fig. 16. Length frequency distribution of *Siganus luridus* collected from March 2005 to March 2006 from the Sirt gulf and western part of the Libyan coast. (N: number of specimens)

3.3.2 Relations of morphometric and meristic parameter

Generalized linear models were used to evaluate whether the categorical parameters of sex, area and month significantly influence the relations between the different parameters. It was shown that data from all samples can be pooled together for describing the relations, because the effects of sex, area and month were not significant ($p > 0.05$). The linear regression model was the most appropriate model for describing the relation between the different parameters. The regression parameters intercept (a) and slope (b) of the different relations morphometric, parameter = a + b * L_T are given by species in Table 11.

Table 11. Parameters intercept (a) and slope (b) of the linear regression, coefficient of determination (R²) and standard error (SE) for different morphometric measurements of *Siganus rivulatus* and *S. luridus* in relation to total length L_T and some meristic counts from the Libyan coast (March 2005 and March 2006) (N: number of specimens), * is average

Siganus rivulatus **(N = 509)**				
Parameter (cm)	a	b	R^2	SE
Standard length	0.530	0.738	0.98	0.308
Fork length	0.528	0.904	0.99	0.238
Body width	-0.388	0.288	0.90	0.269
Dorsal fin length	-0.014	0.552	0.95	0.336
Anal fin length	0.524	0.302	0.88	0.229
Head length	0.637	0.151	0.79	0.121
Eye diameter	0.472	8.567	0.44	0.094
Vertebras column	21 to 22 Vertebras			
Meristic counts*	D, XIV + 10; A, VII + 8 – 10; V, I + 3 + I			
Siganus luridus **(N = 593)**				
Standard length	0.092	0.776	0.96	0.454
Body width	-0.767	0.382	0.93	0.307
Dorsal fin length	0.068	0.583	0.96	0.356
Anal fin length	0.596	0.322	0.90	0.322
Head length	0.428	0.167	0.87	0.195
Eye diameter	0.127	13.40	0.72	0.082
Vertebras column	22 Vertebras			
Meristic counts*	D, XIV + 10; A, VII + 8 – 9; V, I + 3 + I			

3.3.3 The total length-weight relationships

The relation between length and weight was described by multiplicative regression models. Sex did not significantly influence the regression models ($p > 0.05$) which are given by species in Figs 17 and 18 (data and regression function). In addition, the parameter of the regression model together with the number of datasets (N), the coefficient of determination R² and the standard error SE are given.

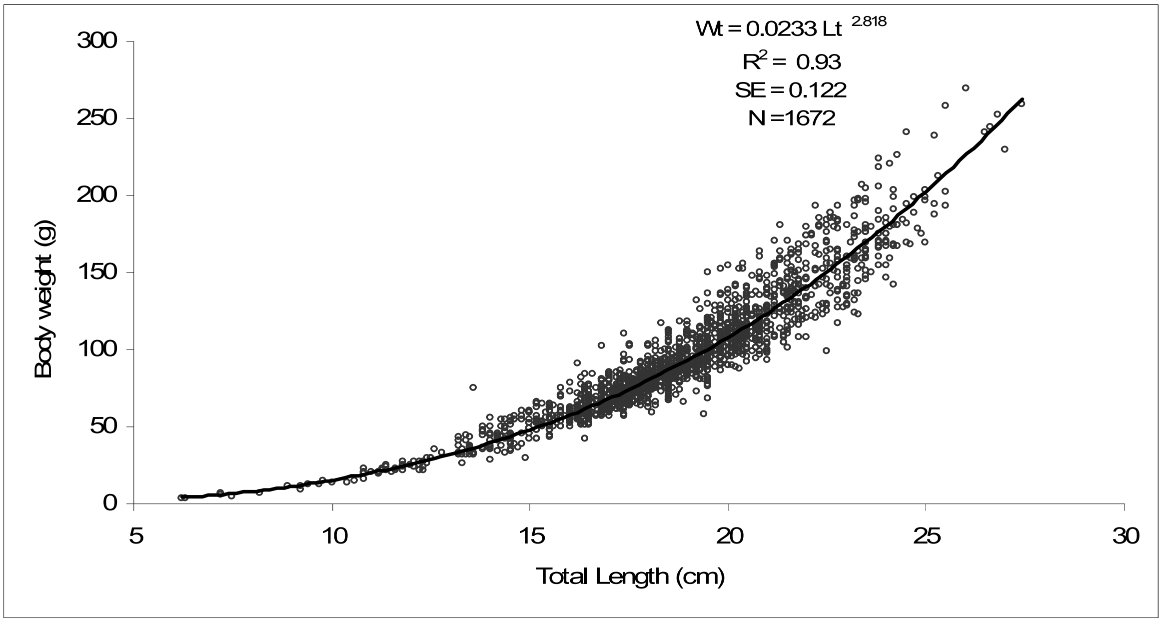

Fig.17. Length-weight relationship for *Siganus rivulatus* (N – number of samples, R^2 - coefficient of determination, SE - standard error) (March 2005 and February 2006)

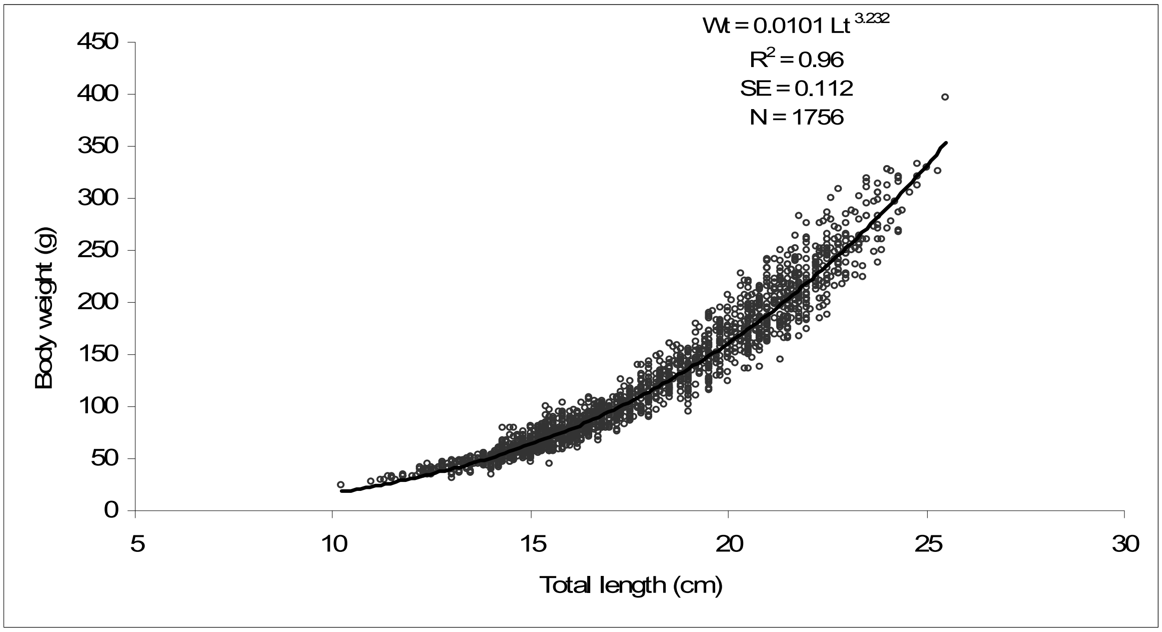

Fig. 18. Length-weight relationship for *Siganus luridus* (N – number of samples, R^2 - coefficient of determination, SE - standard error) (March 2005 and March 2006)

3.3.4 The age composition and growth

The age distribution of samples ranged from I to VI years for *S. rivulatus* and from I to VII years for *S. luridus*, based on the results of otolith reading (Fig. 19). The age group IV was dominant (29.8%) for *S. rivulatus*, followed by age groups II (20.2%), III

(17.9%), V (16.7), I (8.3) and VI (7.1%). Age group III was dominant (28.2%) for *S. luridus*, followed by age groups II (25.9%), V (21.2%), IV (11.8%), VI (9.4%), VII (2.4) and I (1.2%). Individuals of age group 0 of both species were not found in any samples. The growth of both species was described by the Bertalanffy model based on the back-calculated length at age data (Figs 20, 21). The estimated growth functions were:

$$L_T = 35.0 \text{ cm } (1 - e^{-0.16\,(t+1.04)}) \text{ for } \textit{S. rivulatus} \text{ and}$$

$$L_T = 30.0 \text{ cm } (1 - e^{-0.213\,(t+0.78)}) \text{ for } \textit{S. luridus.}$$

Growth in both species is similar with (K= 0.16 for *S. rivulatus* and K= 0.21 for *S. luridus*) and a maximum theoretical length of 35.0 cm and 30.0 cm for *S. rivulatus* and *S. luridus*, respectively. The results based on the weight were:

$$W_T = 424.3 \text{ (g) } (1 - e^{-0.10\,(t+1.18)}) \text{ for } \textit{S. rivulatus}$$

$$W_T = 525.9 \text{ (g) } (1 - e^{-0.13\,(t+1.44)}) \text{ for } \textit{S. luridus}$$

Growth of both species is similar (K= 0.10 for *S. rivulatus* and K= 0.13 for *S. luridus*) and a maximum theoretical weight of 424.3g *S. rivulatus* and 525.9g for *S. luridus*.

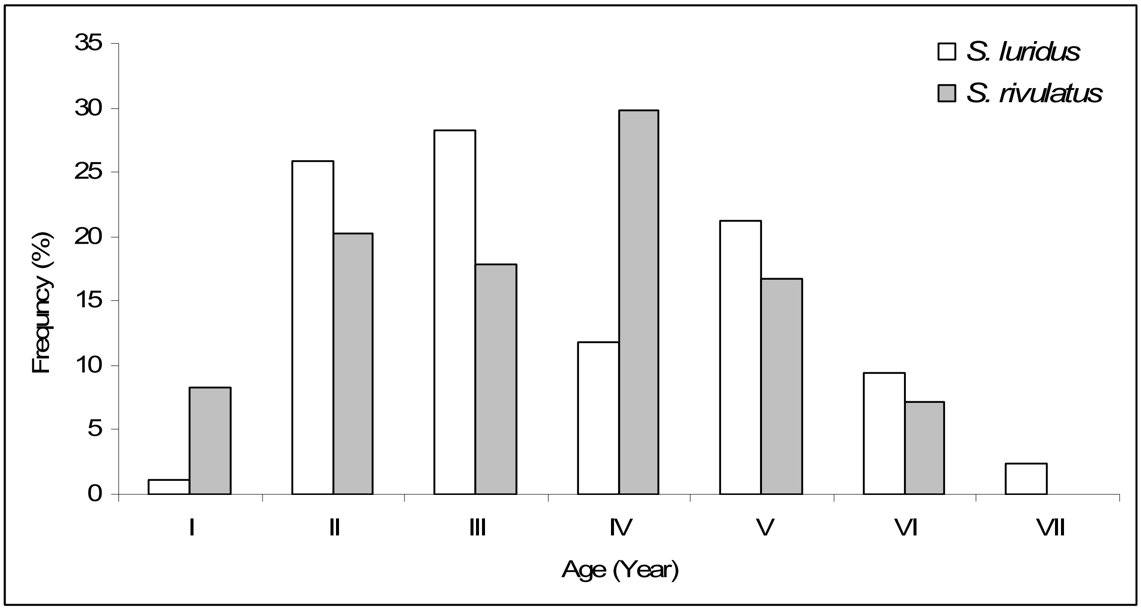

Fig. 19. Age composition for *Siganus rivulatus* and *Siganus luridus* in the Libyan coast (March 2005 to march 2006)

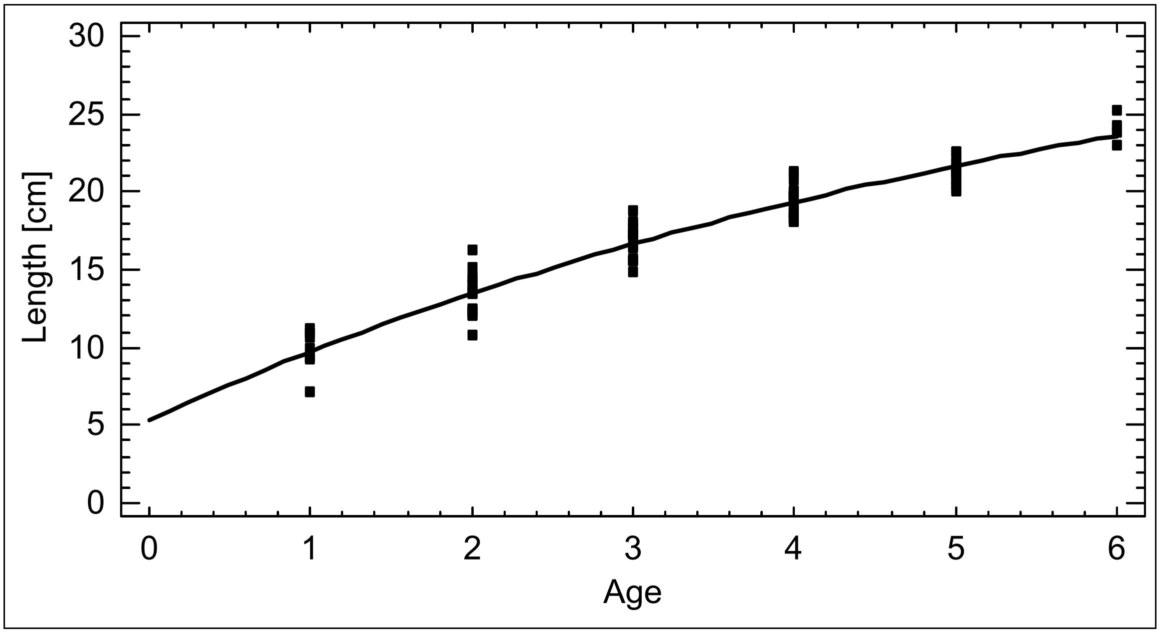

Fig. 20. Von Bertalanffy growth curve for *Siganus rivulatus* in the Libyan coast (March 2005 to February 2006)

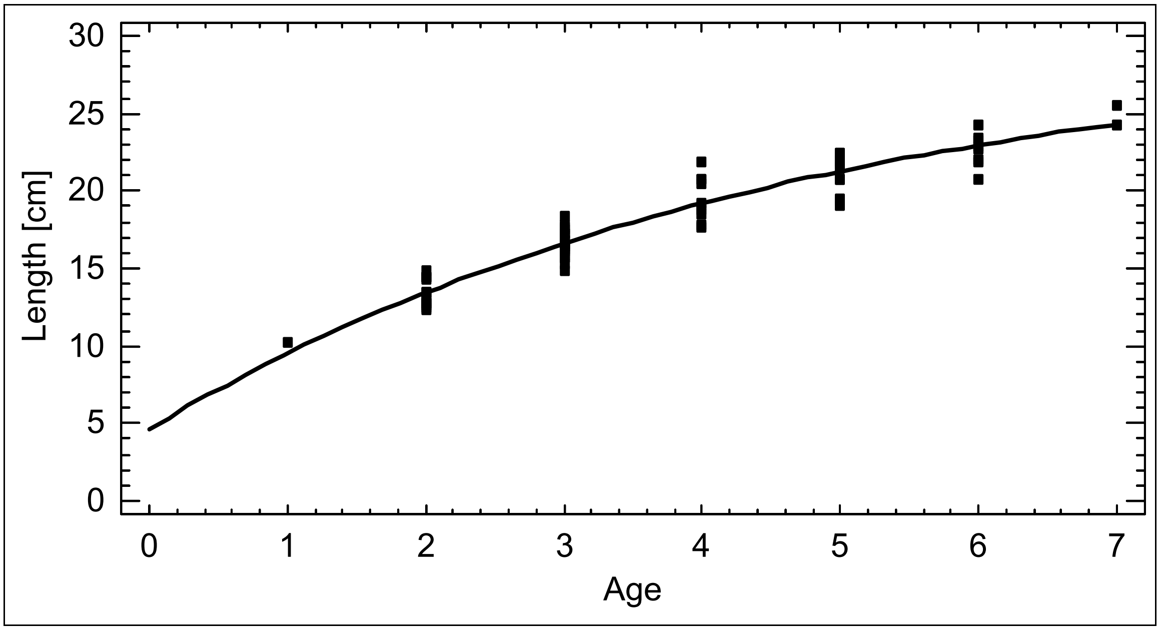

Fig. 21. Von Bertalanffy growth curve for *Siganus luridus* in the Libyan coast (March 2005 and March 2006)

3.3.5 The relation between Fulton's factor, HSI and GSI

Fulton's factor and HSI decreased during the spawning season, and increased again after spawning for both species (Figs. 22, 23). HSI for *S. rivulatus* ranged from 0.15 to 6.45, with a mean and standard deviation of 1.70 ± 0.68, while for *S. luridus* it ranged from 0.16 to 4.62, with a mean and standard deviation of 1.69 ± 0.65.

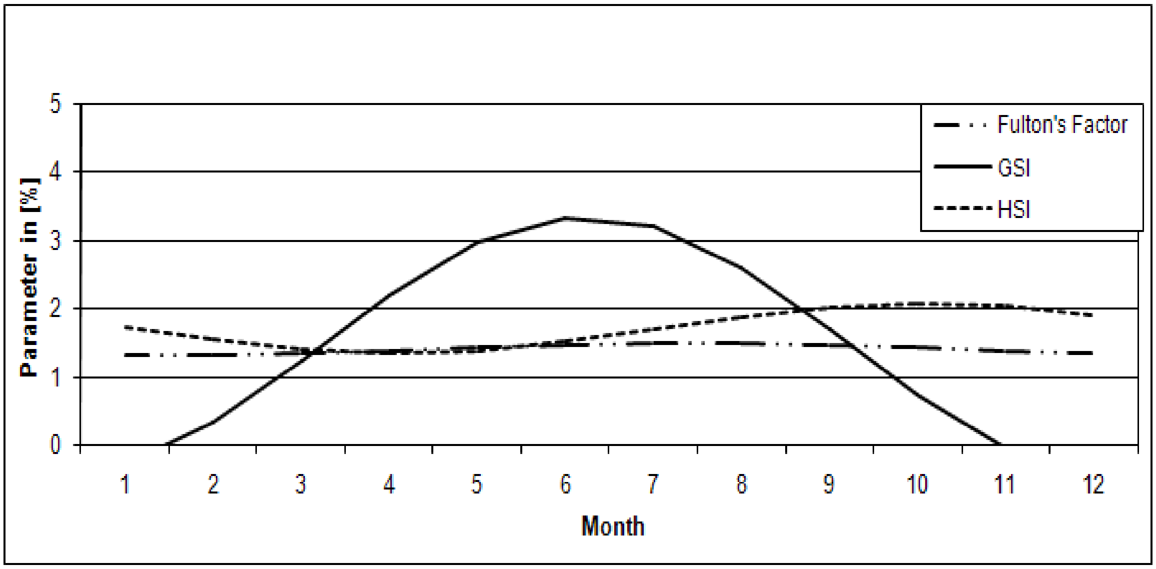

Fig. 22. Monthly development of average Fulton's factor, GSI and HSI for *Siganus rivulatus* of the Libyan coast (GSI: Gonado Somatic Index, HSI: Hepato Somatic Index) (spawning time two months June and July) (March 2005 and February 2006)

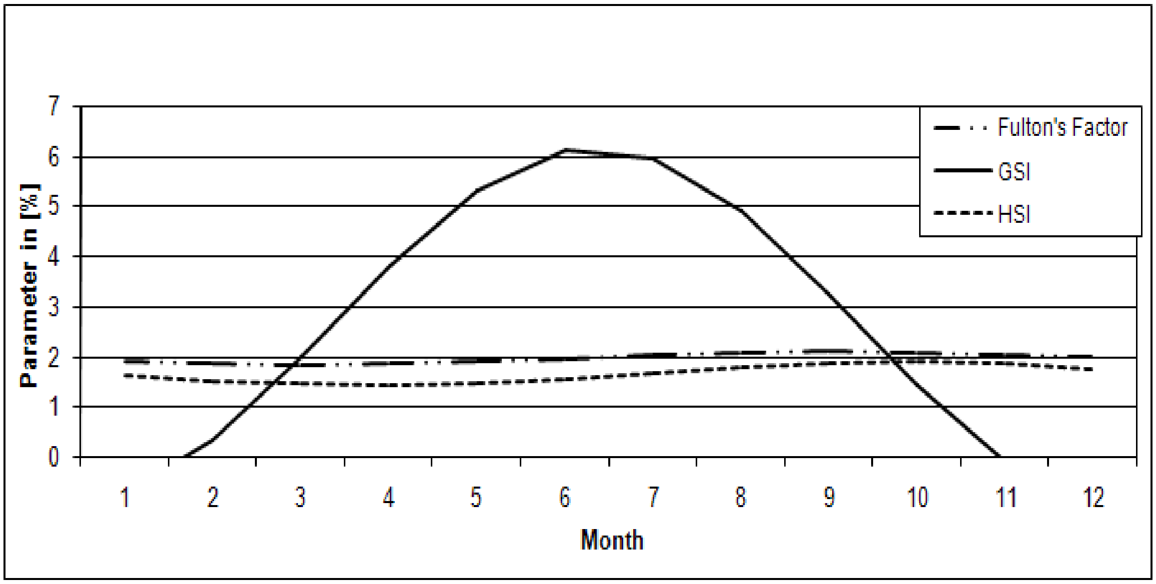

Fig. 23. Monthly development of average Fulton's factor, GSI and HSI for *Siganus luridus* of the Libyan coast (GSI: Gonado Somatic Index, HSI: Hepato Somatic Index) (spawning time three months May, June and July) (March 2005 and March 2006)

3.3.6 Monthly development of gutted weight

Gutted weight which is expressed by $W - W_D - W_G - W_L$ of both *Siganus* spp. decreased in summer and autumn and increased again during winter season (Figs. 24, 25). The mean gutted weight of both species ranged from about 60 % to 93 % with large variability between individuals.

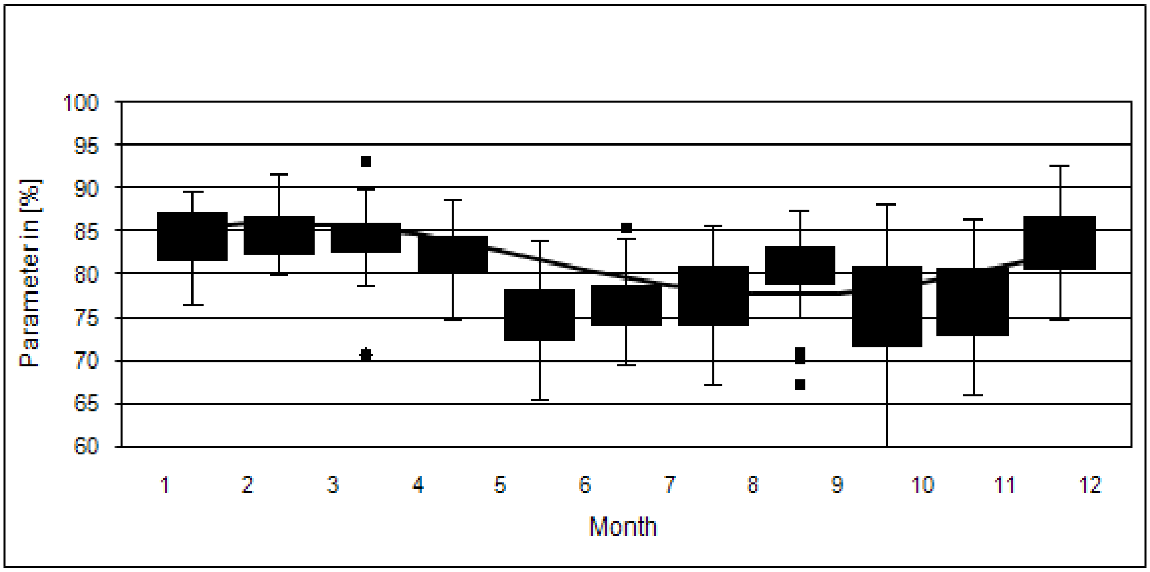

Fig. 24. Development of gutted weight in months for *Siganus rivulatus* of the Libyan coast (March 2005 and February 2006)

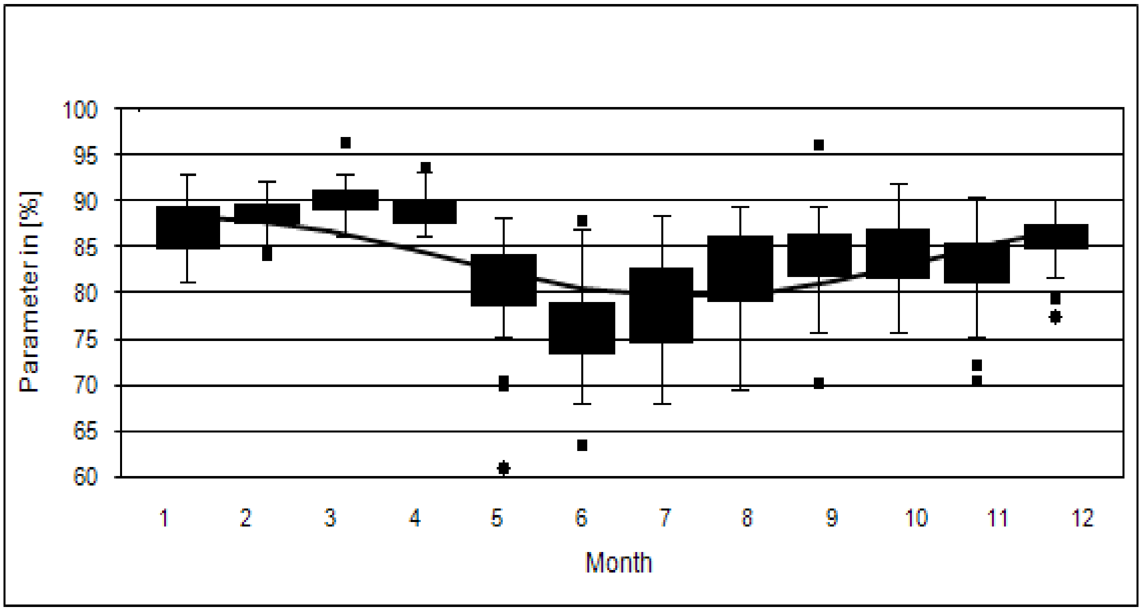

Fig. 25. Development of gutted weight in months for *Siganus luridus* of the Libyan coast (March 2005 and February 2006)

3.3.7 Discussion

The opening of the Suez Canal in 1869, connecting the Mediterranean Sea to the Red Sea, Indian Ocean and the Pacific Ocean, was one of the most important bio-geographical and bio-ecological events worldwide. This pathway made the Lessepsian migration possible (POR 1978).

In the present study, the most abundant size class (18 cm *S. rivulatus*, 15 cm *S. luridus*), is composed of fishes that have reproduced. The effects of sex, area and month were not significant ($p > 0.05$), and the relationship between morphometric measurements and total length were positive for both species (Table 11); that is usually the case for most species like them, also there is no significance in the meristic counts of individuals of different size within the same species. GOLANI (1990) reports that the change in meristic counts between Red Sea and Mediterranean populations is a combination of shifting and/or shortening of the spawning seasons and the different temperature regimes in the two seas. The length–weight relations can be used for predicting the potential yield and for determining the optimum size of capture to obtain optimum yield. These management parameters are directly related to the weight of the fish (SURESH *et al*. 2006). The exponent of the multiplicative regression model (b value) of *S. rivulatus* was 2.8 which shows that the growth is lightly allometry (RICKER 1975). Similar results were found for the Red Sea population and in the southeastern Mediterranean (Egyptian coast), and slightly different results were observed in the Red Sea and other parts of the Mediterranean (Table 12). This difference is certainly due to different physiological and environmental conditions, which vary with geographical locations (BARICHE 2005). Also different food preferences for these species might be considered. The b value of *S. luridus* was 3.2 which describe a slightly positive allometry in growth, which is similar to results from the south eastern and eastern Mediterranean Sea (ABDALLAH 2002, BARICHE 2005).

Table 12. Length-weight relationships and size range of sampled individuals from the present study and the literature for *Siganus rivulatus* and *S. luridus*; a and b parameters are estimated by relationship $W_T = a\ L_T\ ^b$. R^2 is coefficients of correlation and N. is number of specimens. M: males, F: females, P: pooled females and males. Unit of size range in (cm) and weight in (gm)

Area	Species	Sex	a	b	R^2	N	Size
Red Sea							
Ghardaqa (Egypt) El-Gammal (1988)	*S. rivulatus*	M	12.33×10^{-3}	2.84	0.99	114	×
		F	11.32×10^{-3}	2.84	0.99	137	×
Jeddah (Saudi Arabia) Hashem (1983)	*S. rivulatus*	P	10.86×10^{-3}	3.07	×	898	11-30
Mediterranean Sea							
Batrun (Lebanon) Bariche (2005)	*S. rivulatus*	M	2×10^{-6}	3.32	0.95	98	12.7-13.2
		F	1×10^{-5}	3.01	0.96	93	12.6-26.7
		P	1×10^{-5}	3.04	0.99	781	2.48-26.7
	S. luridus	M	7×10^{-6}	3.18	0.96	198	12.5-22.6
		F	6×10^{-6}	3.19	0.97	213	13.5-24.5
		P	6×10^{-6}	3.2	0.97	434	8.1-24.5
Alexandria (Egypt) Abdallah (2002)	*S. rivulatus*	P	22×10^{-3}	2.82	0.93	112	5.5-27.6
	S. luridus	P	11×10^{-3}	3.04	0.91	144	3.8-17
Antalya (Turkey) Bilecenoglu and Kaya (2002)	*S. rivulatus*	M	7.94×10^{-3}	3.14	0.95	229	7.1-20.6
		F	6.43×10^{-3}	3.22	0.95	292	7-21.5
		P	7.13×10^{-5}	3.18	0.95	521	7-21.5
Junieh (Lebanon) Mouneimné (1978)	*S. rivulatus*	P	0.71×10^{-5}	3.14	×	458	5-25.2
	S. luridus	P	0.67×10^{-5}	3.18	×	634	10.5-21.4
Present study (Libya)							
East part	*S. rivulatus*	P	23.3×10^{-3}	2.82	0.93	1672	6.2-27.4
West part and Sirt	*S. luridus*	P	1.01×10^{-3}	3.23	0.96	1756	10.2-25.5

Age is a parameter which is necessary to assess the population dynamics and the state of exploited resources (Allain and Lorance 2000). The maximum age of *S. rivulatus* was 6 years and for *S. luridus* 7 years (Fig. 19). Different results were found in the Red Sea and Mediterranean Sea which partly used different method of ageing. Bariche (2005) reports a maximum age of 6 years for both Siganid species, based on annual ring counting which were similar to the presented results of *S. rivulatus* and one year less for *S. luridus*, probably due to different maximum total length of this species. Bilecenoglu and Kaya (2002) reported a maximum age of 8 years for individuals of *S. rivulatus* with a total length of 20 cm captured along the Turkish coast. They used scales for ageing. This different method can explain the different age structure and support the hypothesis that scales are not an adequate method for the determination of age of Siganid species, which is also supported by the considerable overlapping of the length distributions of age groups (BARICHE 2005). EL-GAMMAL (1988) estimated the age of *S. rivulatus* by otolithometry and found the maximum age of 4-5 years in the Red Sea (El-Ghardaqa) and HASHEM (1983) reported a maximum of 6 years for the same species in Saudi Arabia (Jeddah) using the Petersen method. These results were similar to studies of MOUNEIMNÉ (1978) along the Lebanese coast using the same method but were different from studies in the Al-Ghardaqa region (Red Sea), probably due to differences in the maximum length and the use of different methods for ageing.

The presented maximum theoretical length is slightly higher than the results from comparable studies in the Mediterranean Sea; and similar to results from Red Sea population of *S. rivulatus* (EL-GAMMAL 1988); In the Red Sea, *S. rivulatus* grows faster due to the rich offer of green algae which constitutes the main food of Siganids and therefore ensures a sufficient and permanent food base for this species. The high growth rate virtually affects the sexual maturation and the high water temperature influences the spawning season (AMIN 1985b). The highest growth rate of *S. luridus* was observed along the Lebanon coast with K > 0.33 (BARICHE 2005) whilst the growth rate of *S. rivulatus* was highest (K > 0.4) in the Red Sea (EL-GAMMAL 1988). These estimates differ from the present results (k = 0.16 for *S. rivulatus* and k = 0.21 for *S. luridus*). POPPER and GUNDERMANN (1975) also showed that *S. luridus* grows faster than *S. rivulatus* based on preliminary experiments. The growth rate k of *S. luridus* varied between 0.049 along the Lebanon coast (MOUNEIMNÉ 1978) and 0.33 in the same area (BARICHE 2005), whereas the growth rate of *S. rivulatus* varied between 0.04 along the Lebanese coast (MOUNEIMNÉ 1978) and 0.50 in the Red Sea (Al-Ghardaqa) coast (EL-GAMMAL 1988). The reason for different growth rates might be the different habitats and the variability of food of these species where the samples were collected. POPPER and GUNDERMANN (1975) report that the main reason for different growth of populations of the same species in different areas seems to be food habitats, difference of available algae and length of breeding period, which might be different due to temperature differences between the Mediterranean and Red Sea. The maximum theoretical weight was different: 525.9g for *S. luridus* and 424.3g for *S. rivulatus*; this difference might be due to the different habitats of these species and the fishes' condition. It is difficult to compare these results with other locations since they are dependent on different factors such as fish condition, freshness of the samples and even stomach fullness (BARICHE 2005).

The Fulton's factor and HSI of both species decreased during the spawning season (summer) and increased after this season. The high value of HSI may be related to the big amount of deposited fat in winter before the spawning season (AMIN 1985a). The estimated average HSI of *S. rivulatus* ranged from 0.15 to 6.45 whereas the same parameter for *S. luridus* varied between 0.16 and 4.62. AMIN (1985b) reported an average HSI of male *S. rivulatus* as being from 0.96 to 2.79. SCHMIDT-NIELSEN (1975) stated that the value of HSI of Osteichthyes usually varied between 1.0 and 2.0, while OGURI (1978) showed that it can vary from 1.0 to 5.65 due to correlations between Fulton's condition factor and changes in the food elements deposited in the muscle tissues of fish (YELDAN and AVSAR 2000) which were used to determine the breeding times of bony fishes by HTUN-HAN (1978) and AVSAR and BINGEL (1994). In the present study, the differences in the Fulton's condition factor were low in the different seasons this result is different from the results in the northeastern Mediterranean, where higher differences in Fulton's condition factor were estimated for early spring, autumn and especially for winter. These results emphasize that the period when this population is fattest and in best condition is from the end of autumn until the breeding of spring for *S. rivulatus* (YELDAN and AVSAR 2000).

The variation in the development of gutted weight by month seems to be similar for both species. The highest values were observed before and after spawning period. The reason for this development might be the behaviour of these species during the spawning season or the variability of food which is available in this area. As a working hypothesis it is suggested that these parameters of both Siganid species have adapted to the different topography and habitats of different locations in the new habitat (Mediterranean) compared to the original habitats in the Red Sea.

3.4 Reproduction and spawning period

3.4.1 *S. rivulatus*

3.4.1.1 Maturity stages

Maturity stages were determined monthly (Figs 26, 27). For both sexes, stage I was found in most months except September. Stage II was absent from June to October. Stage III was found in April and May. Stage IV appeared in June and July; Stage V was noted from August to November.

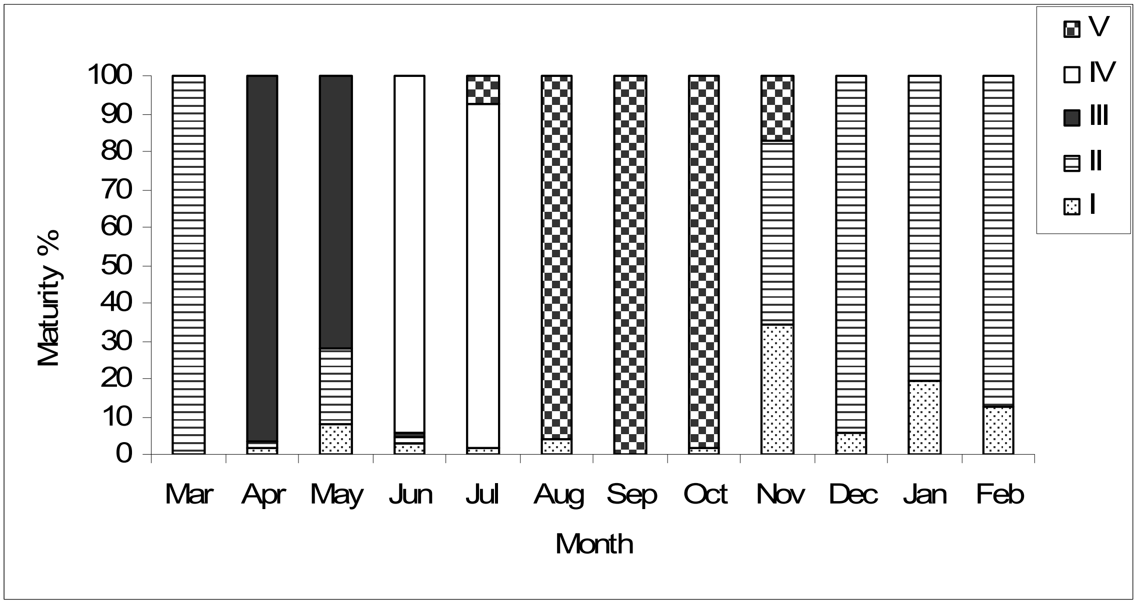

Fig. 26. Monthly percentage in the maturity stages of *Siganus rivulatus* (Female) in the Libyan coast (March 2005 to February 2006) (I – V: gonad stages)

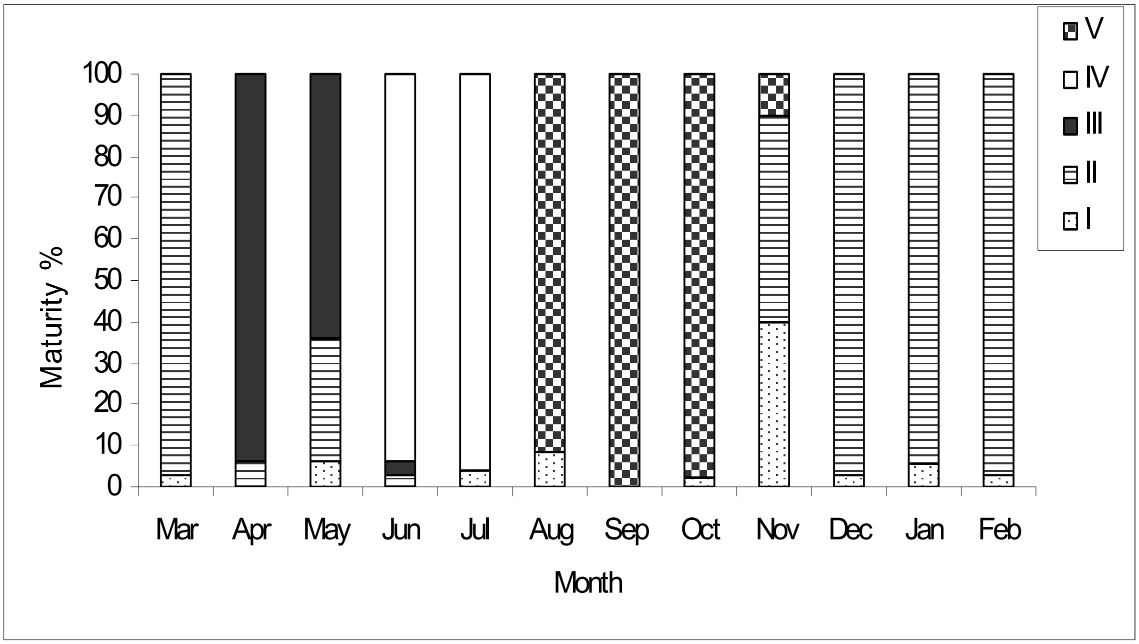

Fig. 27. Monthly percentage in the maturity stages of *Siganus rivulatus* (Male) in the Libyan coast (March 2005 to February 2006) (I – V: gonad stages)

3.4.1.2 Sex ratio

Table 13 shows a total of 1,216 *S. rivulatus*, consisting of 684 females and 532 males were used in the reproductive biology study. The overall female to male sex ratio was 1.3: 1 and was significant difference ($P < 0.05$). The monthly determined sex ratio indicated that there was significant difference between females and males ($P < 0.05$) in the spawning period Females more than males. And was no significant difference ($P > 0.05$) in the other months, before and after spawning season.

Table 13. Chi-square (χ 2) test for *Siganus rivulatus* sex ratio comparisons by months in the Libyan coast (March 2005 to February 2006), (F: female, M: male)

Month	**Total**	**Female**	**Male**	**Female/Male**	χ^2
March	81	48	33	1.5:1	2.78
April	195	116	79	1.5:1	7.02*
May	111	61	50	1.2:1	1.09
June	101	68	33	2.1:1	12.13*
July	79	54	25	2.2:1	10.65*
August	62	26	36	0.7:1	1.61
September	81	49	32	1.5:1	3.57
October	104	55	49	1.1:1	0.35
November	59	29	30	1.0:1	0.02
December	72	35	37	1.0:1	0.06
January	110	57	53	1.0:1	0.15
February	161	86	75	1.2:1	0.75
Total	1216	684	532	1.3:1	19*

3.4.1.3 Spawning period

The spawning was limited to June and July. The average GSI began to increase in April and decreased in August with a peak in June and July (stage IV) for females and males (Fig. 28), correlated with average surface temperatures of 20 to 23˚C (Fig. 29). This is indicated by the presence of gonads at stage IV during these months only (Figs 26, 27). The mean GSI did not differ between females and males (ANOVA, P. 0.836). The average surface salinity ranged from 37.8 to 39.3 ‰ in the coastal area in the eastern region and Gulf of Sirt at the spawning period.

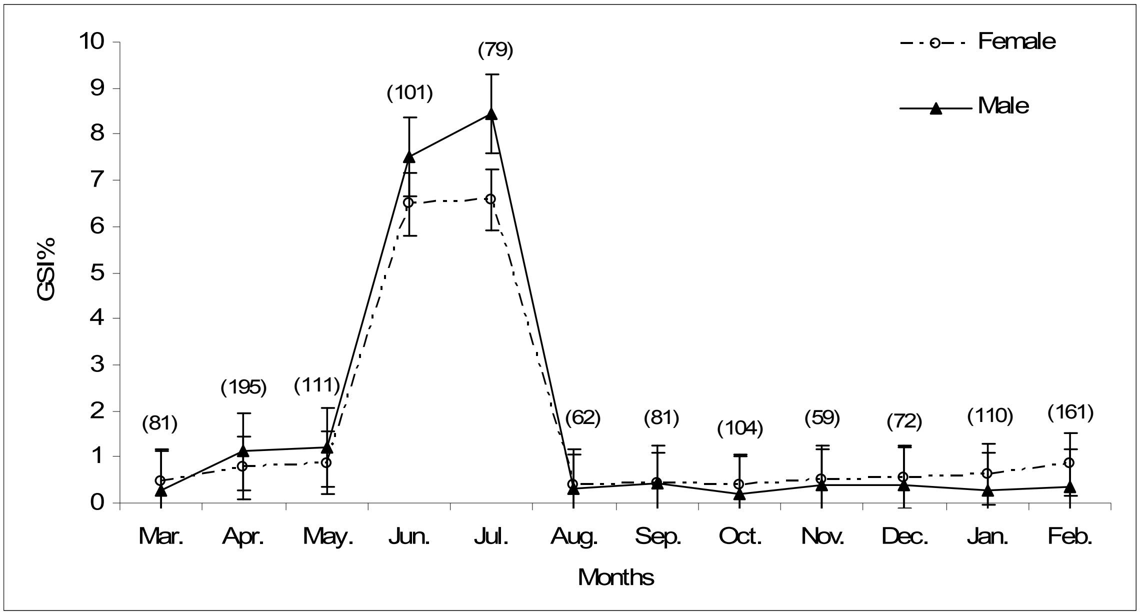

Fig. 28. GSI percentage (average + standard error) for *Siganus luridus* females and males in the Libyan coast (March 2005 to March 2006), the corresponding number of fish (female and male) is given in brackets above each bar

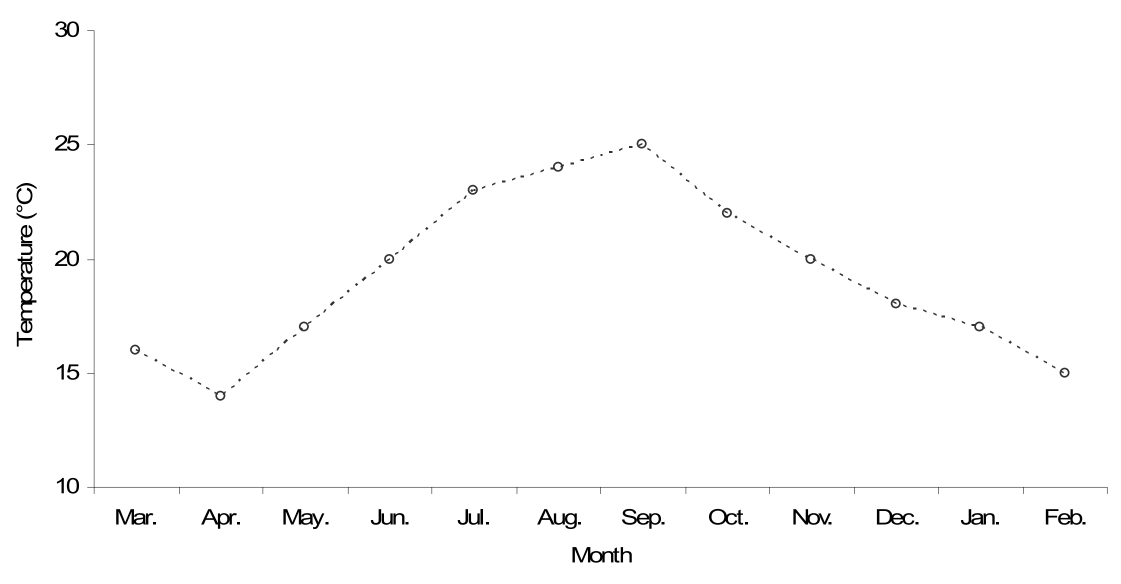

Fig. 29. Average sea surface temperature at the sampling station in the eastern part of the Libyan coast (March 2005 to February 2006)

3.4.1.4 Size at Maturity

The females ranged in size from 7.2 to 32 cm L_T and the males from 6.3 to 26.5 cm L_T. the smallest reproducing female was 13.5 cm L_T and male 12.6 cm L_T. the length at first

50% maturity was calculated in 1 cm total length intervals, the sizes at first maturity are given by the following equations:

Female: $P = \{1 + e^{[-1.36885 (L_T -14.0793)]}\}^{-1}$, $r^2 = 0.998$, S.E. (L_{T50}) = 1.64 and

Male: $P = \{1 + e^{[-1.03202 (L_T -13.4803)]}\}^{-1}$, $r^2 = 0.999$, S.E. (L_{T50}) = 1.12. The estimated L_{T50} was 14.1 cm for females and 13.5 for males (Fig. 30).

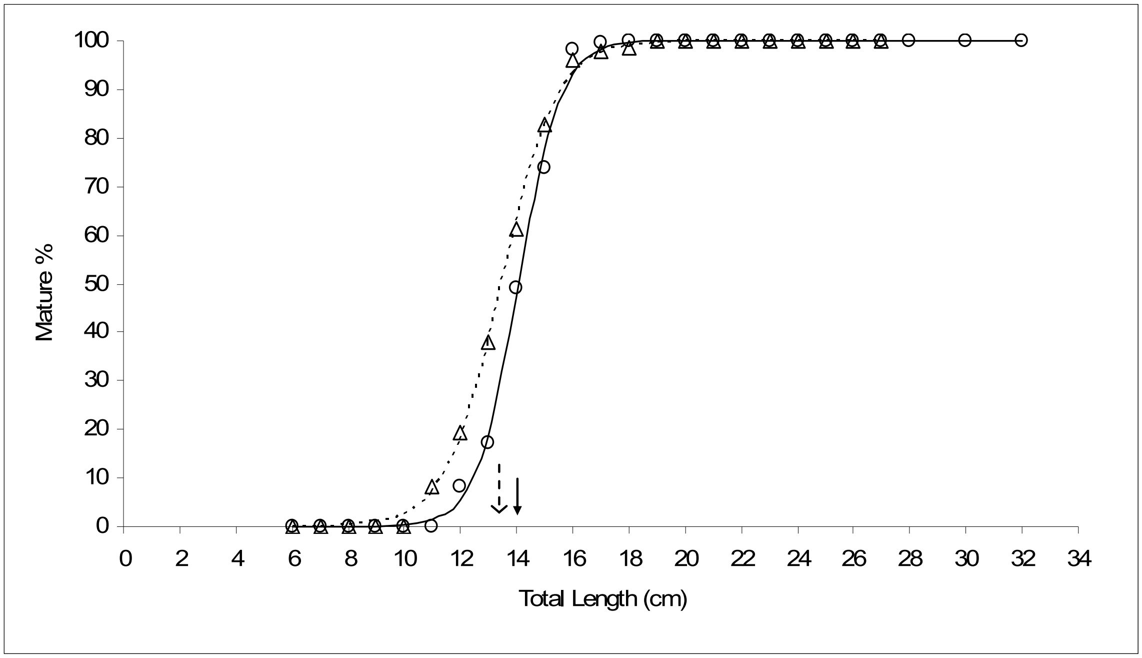

Fig. 30. Percent of mature female (○) and male (Δ) at increasing (L_T) of fish, lines have been plotted for female (—) and male (---).↓⇣, L_T50 for *Siganus rivulatus* in the Libyan coast (March 2005 to February 2006)

3.4.1.5 Fecundity

The total fecundity in number of oocytes was between 94,259 and 490,898 with mean and standard deviation of 226,289±123,189. The L_T of individuals used to determine fecundity was 16.4 to 32 cm. The relationship between L_T and fecundity and W_T and fecundity were estimated (Figs. 31, 32) and the relations indicated that there was positive correlation between number of oocytes and total length and body weight.

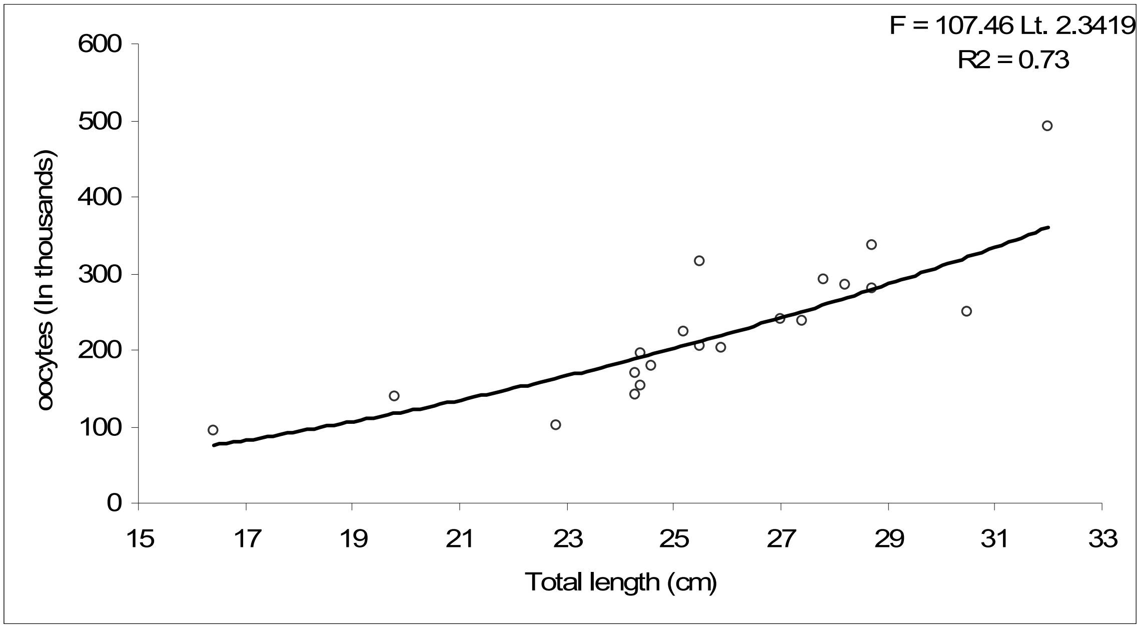

Fig. 31. Relationship between total length and oocytes for *Siganus rivulatus* in the Libyan coast (March 2005 to February 2006). (R^2: coefficient of correlation)

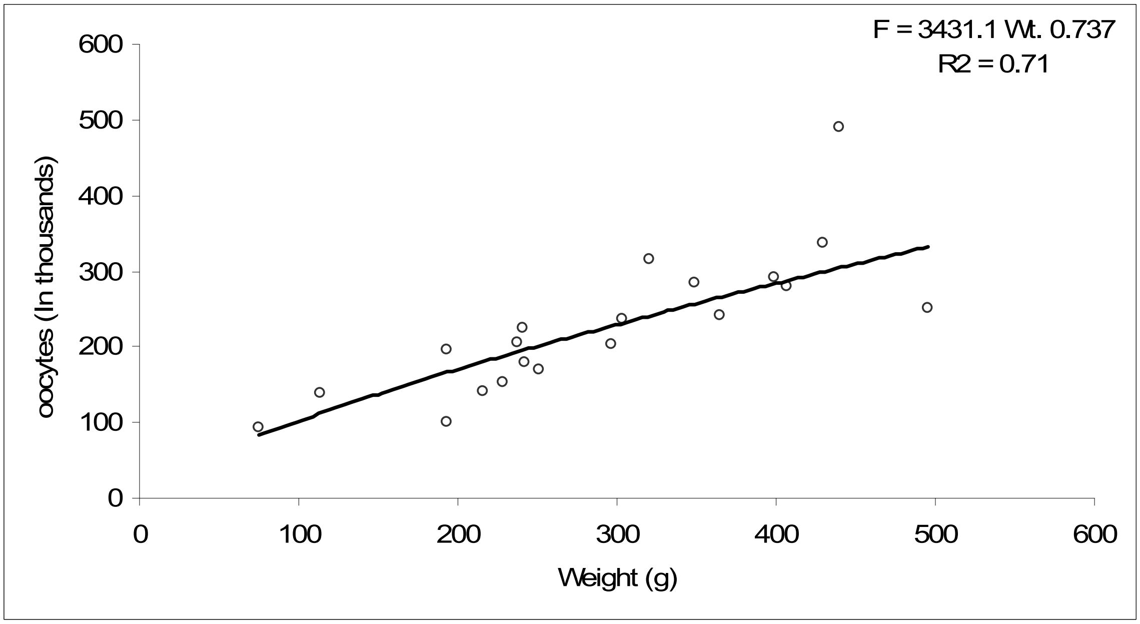

Fig. 32. Relationship between body weight and oocytes for *Siganus rivulatus* in the Libyan coast (March 2005 to February 2006). (R^2: coefficient of correlation)

3.4.1.6 Discussion

In the present study, although there was no significant difference in sex ratio during most of the months before and after spawning period, the sex ratio was significantly different in the spawning period ($P < 0.05$, Table 13). These differences could be due to different feeding and spawning migrations of the two sexes in the course of a year (KAUNDA-ARARA and NTIBA 1997, YELDAN and AVSAR 2000). An alternative explanation is a shift in habitat preference in one sex during spawning season. ISMEN (2006) reports that the seasonal variations in the sex ratio may be due to the difference between the sexes in length at sexual maturity, and different length classes show a distribution in relation to depth. The results of the present study show a different pattern, with the results in the Turkish coast and that mentioned the sex ratio did not differ significantly from 1:1 in the spawning time for this species (YELDAN and AVSAR 2000). In contrast, the sex ratio of *S. rivulatus* did not deviate significantly from 1:1 in Lebanese waters, neither during the spawning period nor between size classes BARICHE *et al.* (2003). HASHEM (1983) observed an overall ratio (March and April) of females to males of 1.3:1 in Red Sea populations.

There is a difference in the spawning duration for this species in the Red Sea and the Mediterranean (Table 14), which might be due to different climatic conditions or a difference in available resources. The spawning time in the Red Sea is from May to August (GOLANI 1990, POPPER and GUNDERMANN 1975), The difference in meristic counts between Red Sea and Mediterranean populations is a combination of both shifting and shortening of the spawning season as a result of the different temperature regimes in the two seas (GOLANI 1990). The observed timing and duration of sexual reproduction in the Mediterranean differs greatly between authors. In the present study, the spawning season lasted only two months (June – July), when average surface water temperatures ranged from 20 to 23˚C (Fig. 29). Surprisingly, no spawning took place during the period with the warmest water temperatures (24-25˚C). In Lebanese waters *S. rivulatus* spawned within a temperature range of 24-29˚C, while during the warmest period (30-31˚C) no fish ripening was observed (BARICHE *et al.* 2003). GEORGE (1972) noted that spawning of *S. rivulatus* occurred when water temperature reached 27˚C in the Lebanese coast, and also suggested that there might be a second spawning event in September for this species. Other reports claim that the spawning season extends to November (MOUNEIMNÉ 1978).

Table 14. Spawning period reported in the literature for *Siganus rivulatus* according to different geographical locations

Area	**Spawning period**	**Authors**
Central south Mediterranean	June and July	Present study
Eastern Mediterranean	June and possible in September to October	GEORGE (1972)
Eastern Mediterranean	May to July	POPPER and GUNDERMANN (1975)
Eastern Mediterranean	June to August and possible in August to November	MOUNEIMNÉ (1978)
South-eastern Mediterranean	June to September	HUSSEIN (1986)
Eastern Mediterranean	May to August	GOLANI (1990)
North-eastern Mediterranean	July to August	YELDAN and AVSAR (2000)
Eastern Mediterranean	July	SAAD and SABOUR (2001)
Eastern Mediterranean	June	BARICHE *et al.* (2003)
Red Sea	March to September	AMIN (1985 a, b)
Red Sea	May to August	GOLANI (1990)
Red Sea	May to August	POPPER and GUNDERMANN (1975)

These strongly differing observations indicate that other factors than temperature are the triggers for the start and length of the reproductive period. Although this is an introduced species, it became established as a fish of commercial value, especially in the eastern part of the Libyan coast and the Gulf of Sirt (SHAKMAN and KINZELBACH 2007a). To maintain a sustainable fishery of a fish stock, effective management is necessary (SPARRE and VENEMA 1992), and therefore it is suggested that *S. rivulatus* fisheries in Libya should stop during the spawning period (June and July).

Also with regards to literature reports on the average size at maturity (L_{T50}) there is no clear pattern. In the present study the L_{T50} for females was 14.1 cm and 13.5 cm for males. BARICHE *et al.* (2003) found the L_{T50} for this species to be 13.3 cm for males and 13.7 cm for females. However, the L_{T50} was 17.2 cm for females and 17.9 cm for males on the Syrian coast (SAAD and SABOUR 2001), these values are higher than our values because of being converted from standard length (L_S.) using the regression equation of BILECENOGLU and KAYA (2002). The smallest sexually mature female values are 14.8 cm for Lebanese waters (MOUNEIMNÉ 1978), 15 cm for Egyptian waters (HUSSEIN 1986), and 13 cm for the original habitats in the Red Sea (HASHEM 1983) and in this study was 13.5 cm L_T.

When comparing the total fecundity in number of oocytes and L_T with results from other parts of the Mediterranean and the Red Sea, the results obtained in the present study is higher (Table 15). The reason might be the different L_T measurement approach used in other studies: according to HUSSEIN (1986) this difference results partly from varying techniques used for counting and estimation of the oocytes and partly from different food resources available in the Red Sea and the Mediterranean. Also FAGADE *et al*. (1984) suggested that variation in fecundity may be due to dietary differences. In this study, some differences were found in the number of oocytes in equal sized individuals which might be caused by variable egg sizes and different stages of maturity, this kind of variation is common in other fishes too (DOHA and HYA 1970, HUSSAIN *et al*. 2003).

Table 15. Oocytes number reported in the literature for *Siganus rivulatus* according to different geographical locations (* Average)

Area	Oocytes number (In thousands)	Total length (cm)	Authors
Central south Mediterranean	94,259 – 490,898	16.4 – 32	Present study
South-eastern Mediterranean	103,200 – 396,600	15 – 28	HUSSEIN (1986)
North-eastern Mediterranean	434,761 *	15.5 – 22	YELDAN AND AVSAR (2000)
Red Sea	40,000 – 300,000	15 – 17	HASHEM (1983)

It is concluded that the spawning period for *S. rivulatus* on the central Mediterranean (Libya) occurs during June and July at depths of 1-30 m. The spawning season occurs at lower temperatures and is reduced by two months in comparison with Red Sea populations (May to August). This indicates that *S. rivulatus* has acclimatised and is successfully breeding on the Libyan coast, where environmental conditions are different from its native range. Although the spawning time is shortened in length, *S. rivulatus* established self-sustaining populations in the invaded region and continues to spread.

3.4.2 *S. luridus*

3.4.2.1 Maturity stages

Maturity stages were described and determined monthly for this species (Figs. 33, 34). Stage I appeared in most months but did not appear in August or from January to March 2006. Stage II did not appear from June to September. Stage III appeared from March to June and also in September. Stage IV appeared in three months: May, June and July (spawning period). Stage V appeared from June up to November.

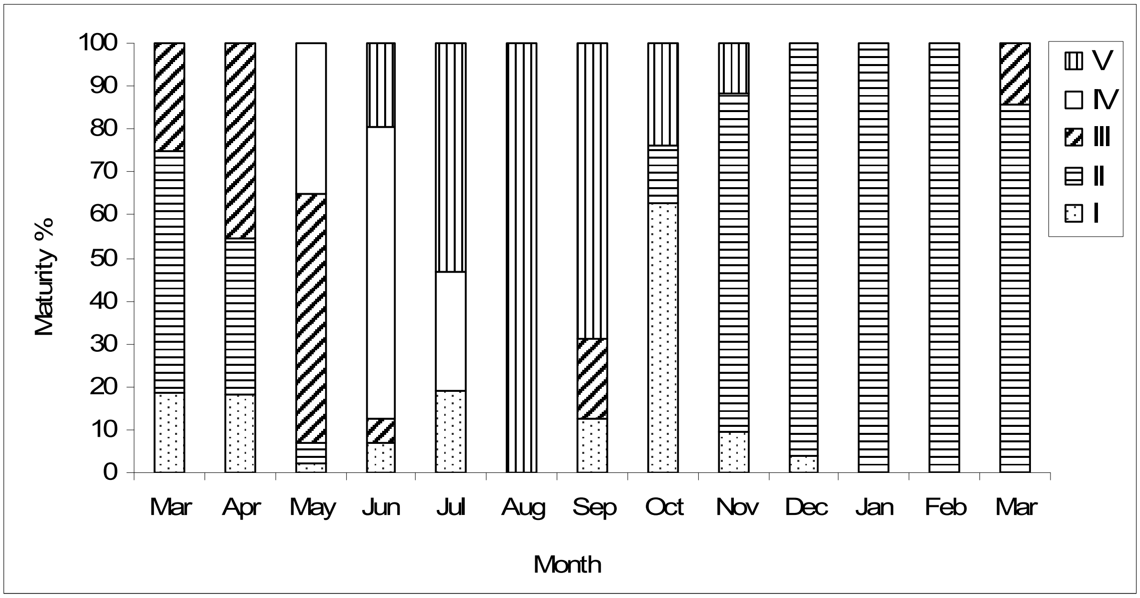

Fig. 33. Variation in the distribution of gonad maturity stages for *Siganus luridus* (Female) in the Libyan coast (March 2005 to March 2006), (I – V: gonad stages)

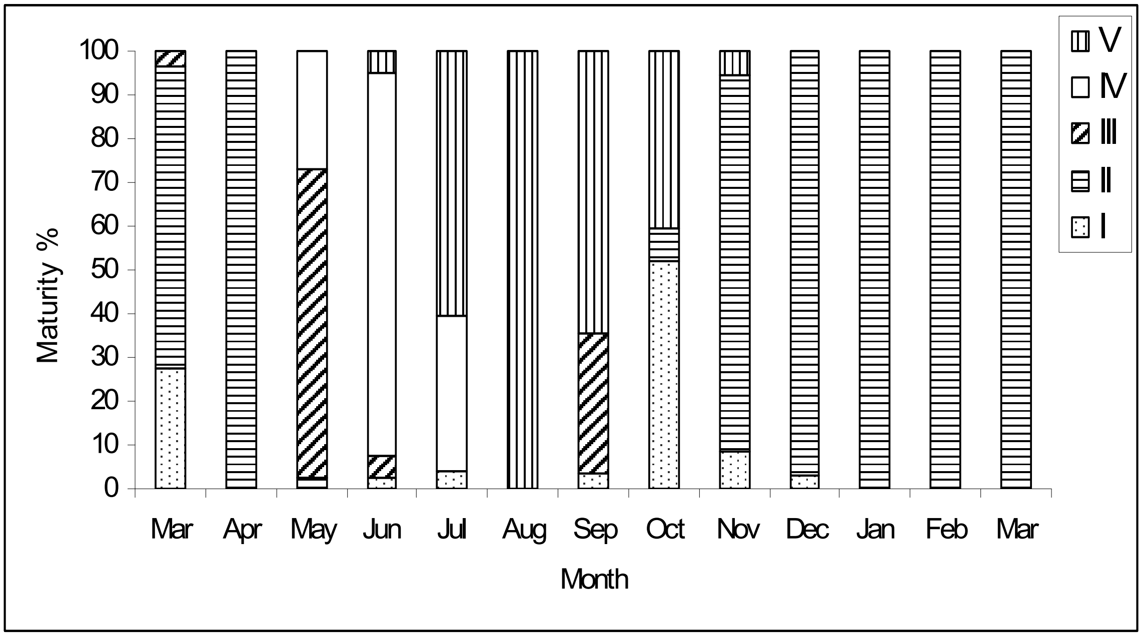

Fig. 34. Variation in the distribution of gonad maturity stages for *Siganus luridus* (Male) in the Libyan coast (March 2005 to March 2006), (I – V: gonad stages)

3.4.2.2 Sex ratio

Table 16 shows a total of 1,229 *S. luridus*, consisting of 720 females and 509 males were used in the reproductive biology study, the overall female to male sex ratio was 1.4: 1 and the difference was significant ($P < 0.05$). The monthly determined sex ratio indicated that there was significant difference between females and males ($P < 0.05$) in different month's females more than males. And was no significant difference ($P > 0.05$) in May and July (Spawning period), September and from January to March 2006.

Table 16. Chi – square (χ 2) test for *Siganus luridus* sex ratio comparisons by months in the Libyan coast (March 2005 to March 2006), (* Significance difference $P < 0.05$)

Month	Total	Female	Male	Female/Male	χ^2
March	77	48	29	1.7:1	4.69*
April	30	22	8	2.8 :1	6.53*
May	80	43	37	1.2 :1	0.45
June	112	72	40	1.8 :1	10.37*
July	126	73	53	1.4 :1	3.17
August	71	47	24	2 :1	7.45*
September	107	48	59	0.8 :1	1.13
October	163	67	96	0.7 :1	5.16*
November	140	104	36	2.9 :1	33.03*
December	109	77	32	2.4 :1	18.58*
January	75	37	38	1 :1	0.013
February	68	40	28	1.4 :1	2.12
March	71	42	29	1.5 :1	2.38
Total		720	509	1.4 :1	36.23*

3.4.2.3 Spawning time

The spawning extended over three months, from May to July, in the coastal area; Stage III also was observed in September after the spawning period (Figs 33, 34). The average GSI began to increase in April, decreased in August, and after that increased again in September (Stage III). With a peak in May, June and July stage IV correlated with average surface temperatures of 19 to 23˚C (Figs 35, 36) and the average surface salinity was in the range of 37.80 to 41.30‰ in the western coastal region and Gulf of Sirt at the spawning period. The Multivariance showed that the gonado weight depended on total length was significant difference between females and males (ANOVA, $P < 0.05$) in the spawning period.

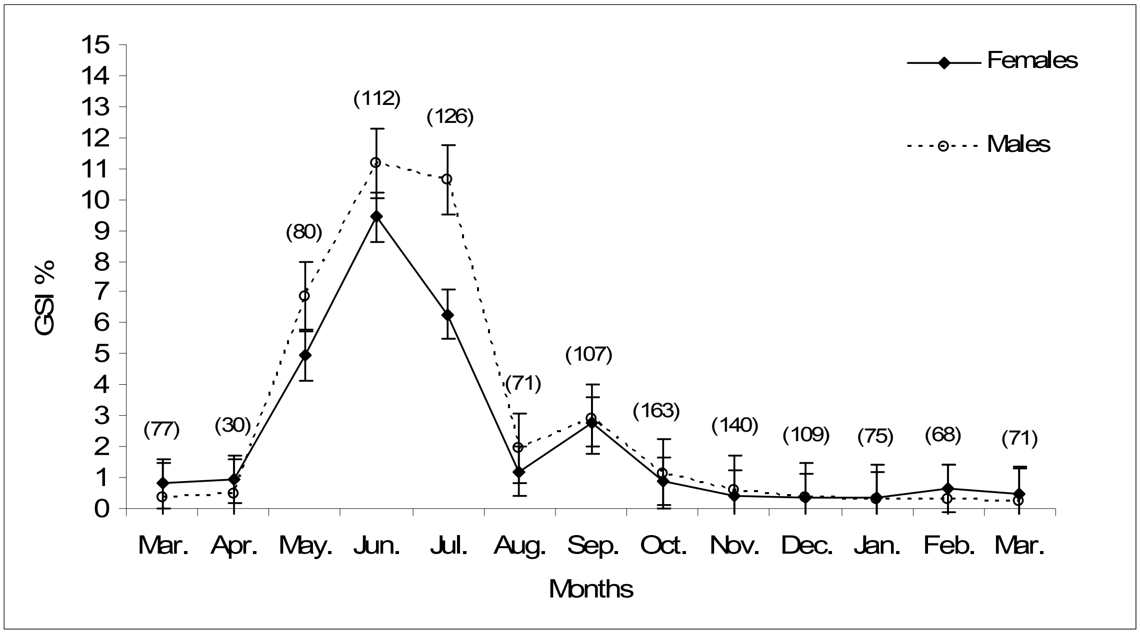

Fig. 35. GSI percentage (average + standard error) for *Siganus luridus* females and males in the Libyan coast (March 2005 to March 2006), the corresponding number of fish (female and male) is given in brackets above each bar

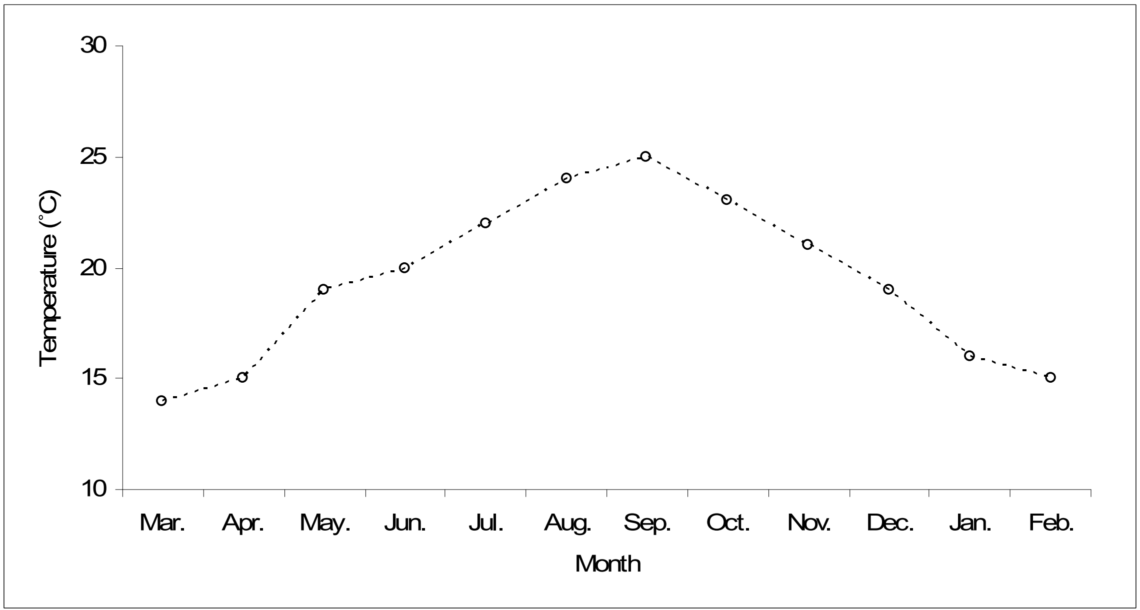

Fig. 36. Average sea surface temperature and standard error at the sampling station in the western part of the Libyan coast (March 2005 to February 2006)

3.4.2.4 Fecundity

The total fecundity (F_T) in number of oocytes was between 66,000 and 301,482 with a mean and standard deviation of (148,449 ± 70,727), the total length of individuals used to determine fecundity was 16.50 to 26.00 cm, the middle portion of the ovary was broader than the anterior and posterior regions. The relationships between L_T and fecundity and W_T and fecundity were obtained (Figs 37, 38); and the relations indicated that there was positive correlation between number of oocytes and total length and body weight.

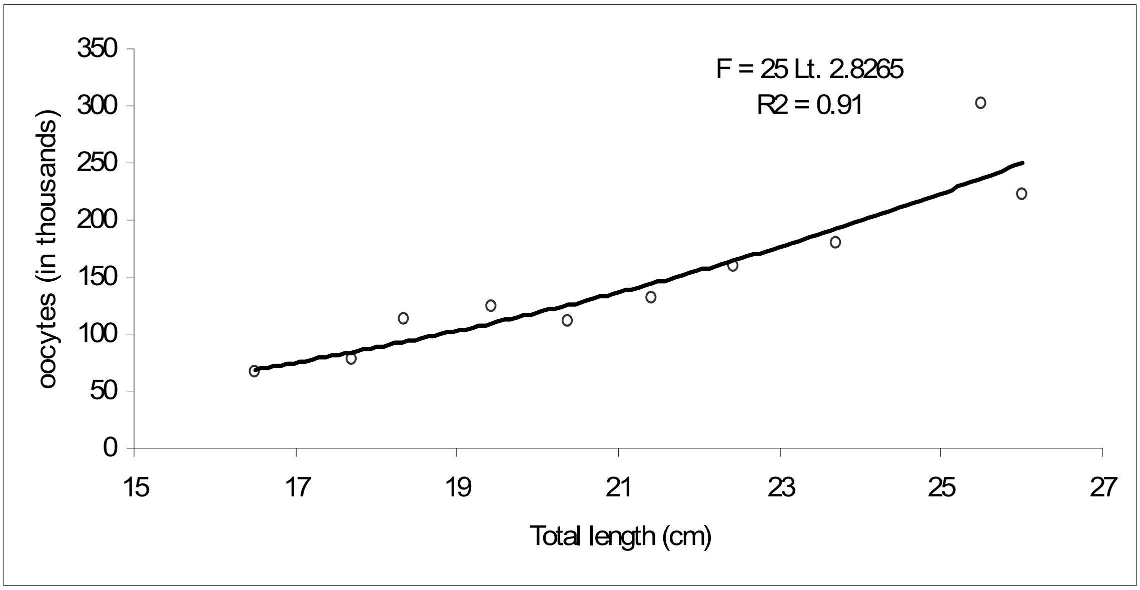

Fig. 37. Relationship between total length and oocytes for *Siganus luridus* in the Libyan coast (March 2005 to March 2006). (R^2: coefficient of determination)

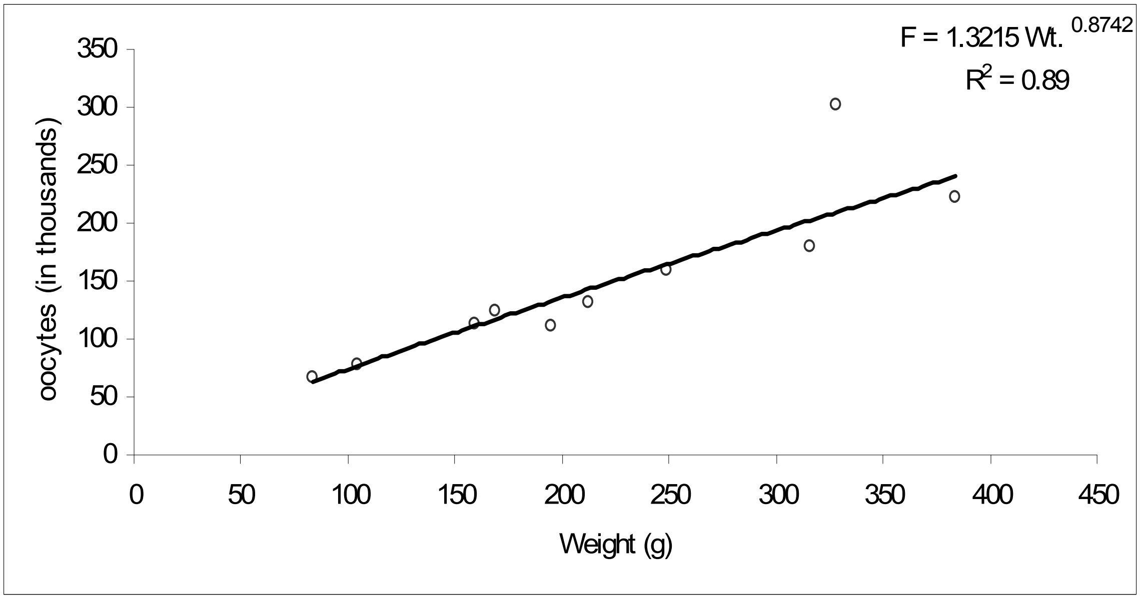

Fig. 38. Relationship between body weight and oocytes for *Siganus luridus* in the Libyan coast (March 2005 to February 2006). (R^2: coefficient of determination)

3.4.2.5 Size at Maturity

The females ranged in size from 11.4 to 26.00 cm (L_T), and the males from 10.2 to 25.3 cm (L_T). The smallest reproducing female was 11.5 cm (L_T) and the smallest male 11.8 cm (L_T) long. The length at first 50% maturity was calculated in 1 cm length intervals. The sizes at first maturity are given by the following equations:

Female: $P = \{1 + e^{[-1.2371 (L_T -12.86)]}\}^{-1}$, $r^2 = 0.998$, S.E. (L_{T50}) = 1.74

Male: $P = \{1 + e^{[-1.2826 (L_T -12.76)]}\}^{-1}$, $r^2 = 0.994$, S.E. (L_{T50}) = 2.77. The estimated L_{T50} was 12.9 cm for females and 12.8 cm for males (Fig. 39).

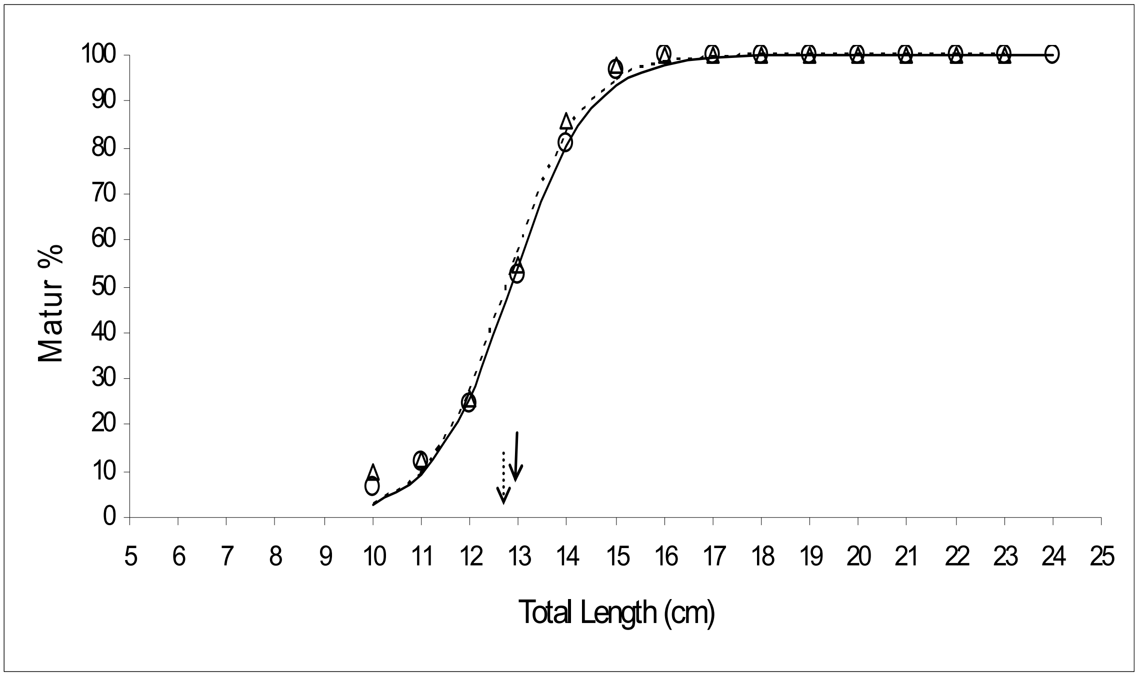

Fig. 39. Percent of mature female (○) and male (Δ) at increasing (L_T) of fish, lines have been plotted for female (—) and male (---).↓⇣, L_T50, for *Siganus luridus* in the Libyan coast (March 2005 to March 2006)

3.4.2.6 Discussion

The overall sex ratio of *S. luridus* in the Libyan coast showed the significant difference (Chi-square = 36.23, d.f 1; $P < 0.05$) from the expected females: male's ratio of 1:1 (Table 16). In contrast, monthly sex ratios were difference, in particular, before and after spawning period females more than males, but during the spawning season, the difference in the sex ratio was not significant in May and July ($P > 0.05$) but was significant in June, females more than males. The fluctuation in the sex ratio of females to males is most probably due to spawning and feeding migrations (YELDAN and AVSAR 2000); ISMEN (2006) reports that the seasonal variations in the sex ratio may possibly be due to the difference in the length (or age) of sexual maturity and the difference in length distribution in relation to depth. In Lebanese waters, BARICHE *et al*. (2003) indicate that the sex ratio did not differ significantly from 1:1 for *S. luridus* between May and August and was 1: 0.93 during the spawning period. This result was quit the same as mine in the spawning period, although the number of samples was different. In the present study the number of samples studied is higher than that of BARICHE *et al*. (2003).

The spawning period for *S. luridus* lasted three months (May, June and July) (Fig. 35) in the coastal area (1-30 m depth) of the central Mediterranean (Libyan coast); this result agrees with the result on the Lebanese coast, with the same spawning period (BARICHE *et al*. 2003). Stage III also showed up in September (Figs 33, 34), without observed spawning in this month; it might be that it is extended to the spawning season, or if good environmental conditions are available the species may spawn again in the autumn (BARICHE *et al*. 2003). On the Lebanese coast BARICHE *et al*. (2003) observed fish with maturing gonads (Stage III) in October and November without any observed spawning, and relate such observations to an additional spawning event in autumn if the environmental conditions had been suitable. Although there is no difference in the spawning period (March to September) in the original habitats (Red Sea) (GOLANI 1990, POPPER and GUNDERMANN 1975) (Table 17), there are different periods in the spawning season for this species in the new habitat (Mediterranean Sea); the spawning duration was shorter than in the Red Sea, perhaps because environmental conditions are different for example temperature and salinity are higher in the Red Sea than in the Mediterranean (BEN-TUVIA 1966).

Table 17. Spawning period for *Siganus luridus* according to the literatures

Area	**Spawning period**	**Authors**
Central south Mediterranean	May to July	Present study
Eastern Mediterranean	June to August, possible August to November	MOUNEIMNÉ (1978)
Eastern Mediterranean	March to August	GOLANI (1990)
Eastern Mediterranean	May to July	BARICHE *et al*. (2003)
Red Sea	March to September	GOLANI (1990)
Red Sea	March to September	POPPER and GUNDERMANN (1975)

Previous reproductive and biological studies of Siganid species have shown that water temperature is an important factor for determining the time and duration of the spawning season. In the present study, this species spawned within an average temperature range of 19 to 23 ˚C (Fig. 36). Furthermore, no ripening fish were observed in the warmest period (24-25˚C). On the Lebanese coast *S. luridus* spawned within the temperature range of 24-29˚C, and during the warmest period (30-31˚C) no ripening fishes were observed and all had spawned (BARICHE *et al.* 2003). The high rate of growth virtually affects the sexual maturation, the high water temperature influences the spawning season (AMIN 1985b); whereas HUSSEIN (1986) reports that the different latitudes affect the onset of spawning in the different localities. To maintain a sustainable fishery of a fish stock, effective management is necessary (SPARRE and VENEMA 1992). Therefore, it may be necessary to reduce fishing pressure due to the selectivity of fishing gear, and it may in fact be necessary to stop fishing during certain period (YELDAN and AVSAR 2000), it can be sensible that *S. luridus* fisheries in Libya should stop during the spawning period (May, June and July). In the present study, the size at first maturity (L_{T50}) for this species was quit the same, 12.9 cm for females and 12.8 cm for males (Fig. 39). BARICHE *et al.* (2003) reported that reproducing females ranged in size from 13.5 to 23.8 cm and that the size at first maturity was 14.2 cm for female and 13.9 cm for males; these findings are quit different from the results obtained in the present study, variation might be due to the large size spawning females and males present in the Lebanese coasts. In addition, sample size used in both studies was different.

Regarding fecundity, there are only few studies on record on the fecundity of this species; some difference was found in the fecundity of the species in fish of the same size. Such differences might be due to variable egg size, stages of maturing and month of spawning. This type of variation is common in other fishes (DOHA and HYA 1970, HUSSAIN *et al.* 2003). In the present study, the total fecundity (F_T) was between 66,000 and 301,482 oocytes (16.5 to 26.0 cm (L_T)), with mean and standard deviation of (148,449 ± 70,727). On the Lebanese coast, the study reported the average fecundity for this species gave 250,000 oocytes (BARICHE 2003), this finding is different from my result; the reason might be the different total length that was used. FAGADE *et al.* (1984) suggested that variation in fecundity may be due to differential food. The fecundity increased with increase in total length and body weight of this species (Figs 37, 38); and that it was the same for *S. rivulatus* in northeastern Mediterranean coast (YELDAN and AVSAR 2000). It is concluded that the spawning time for *S. luridus* covered three months (May, June and July) in the Libyan coast (1-30 m), and that temperature appeared to be the limiting factor in gonadal development of this species. It has reduced its spawning season by four months; on the Red Sea, according to GOLANI (1990) and POPPER and GUNDERMANN (1975) the spawning season is seven months, from March to September. This indicates that *S. luridus* has adapted to the Libyan coast, where environmental conditions are different from its native habitat. Although the spawning time is shortened in length, *S. luridus* established self-sustaining populations in the invaded region and continues to spread.

3.5 Food and feeding habits

The total length (L_T) of individuals ranged from11.2 to 24.6 cm for *S. luridus* and from 10.4 to 27.4 cm for *S. rivulatus* (Table 1). The Feeding Index (FI) was slightly elevated in the spring for *S. luridus*, but did not change significantly between seasons; the percentage of full stomachs was between 75% and 85% in all seasons. *Siganus rivulatus* showed lower FI values than *S. luridus*: a decrease from ca. 70% in spring and summer to less than 50% in winter was observed (Fig. 40). A significant difference between two species (ANOVA, $p = 0.017$) was found.

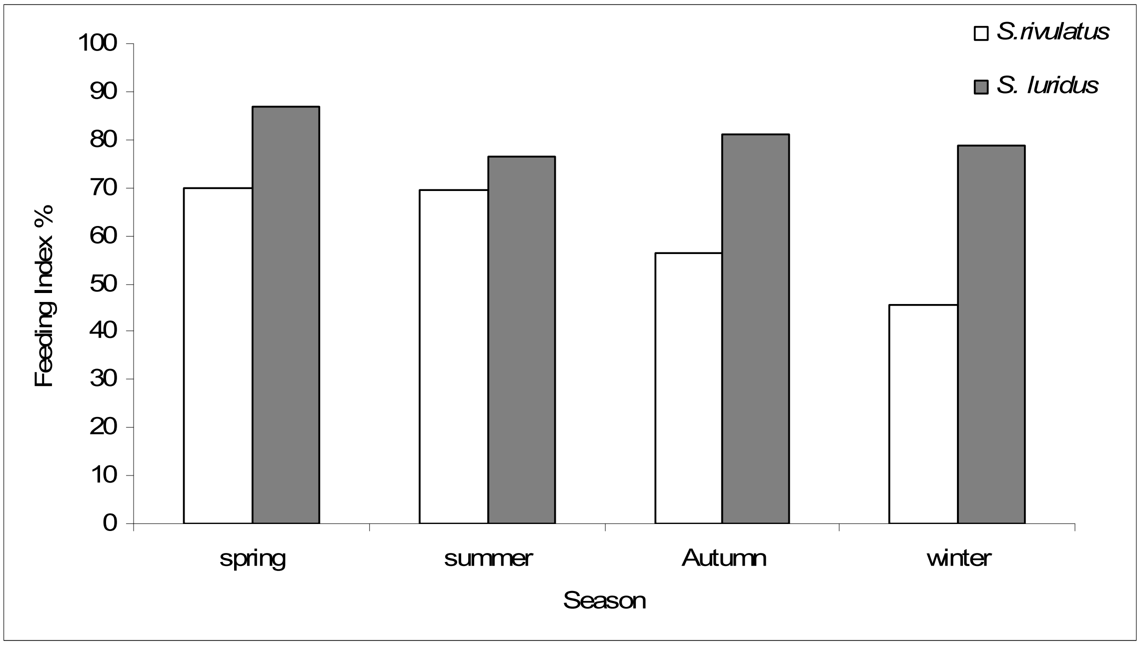

Fig. 40. Seasonal changes in the Feeding Index of *Siganus rivulatus* and *S. luridus*, differences between species are significant (one way ANOVA, p=0.017)

The mean GSI-values ranged from 6.1% to 14.5% for *S. luridus,* and from 9.1% to 21.3% for *S. rivulatus* (Fig. 41). The GSI started to increase in early spring with highest values in summer and autumn before dropping again in winter. The amplitude was lower for *S. luridus* than *S. rivulatus*. A small drop was observed in July for *S. rivulatus*, and in September for *S. luridus*. The differences in GSI between the two species are significant (ANOVA, p = 0.009).

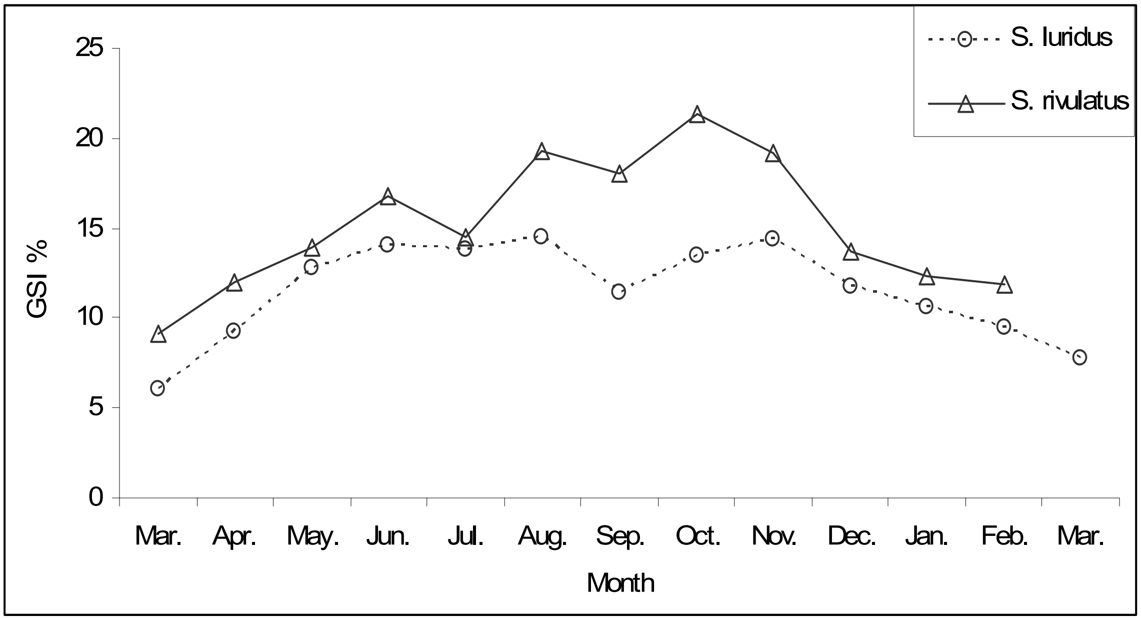

Fig. 41. Monthly changes in the mean Gastro-Somatic Index (GSI) of *Siganus rivulatus* and *S. luridus*. Differences between species are significant (one way ANOVA, p=0.009)

Macroalgae and seagrass (*Posidonia oceanica*) are the dominant constituents of the diet of both species (Figs. 42-44). The Occurrence Frequency illustrates that *S. luridus* feeds mainly on Phaeophyceae in spring and summer (85.1% and 63.5%, respectively), on Chlorophyta in autumn (84.7%), and mainly on Rhodophyta (97.0%) and Phaeophyceae (68.3%) in winter (Fig. 42). Rhodophyta are only an important part of the diet in winter, while seagrass consumption is important in all seasons and does not change much over the year. *Siganus rivulatus* feeds mostly on Chlorophyta in spring and summer (58.3% and 58.3%, respectively) and on Phaeophyceae in autumn and spring (55.6% and 50.0%, respectively), and on Rhodophyta (65.3%) in winter (Fig. 43).

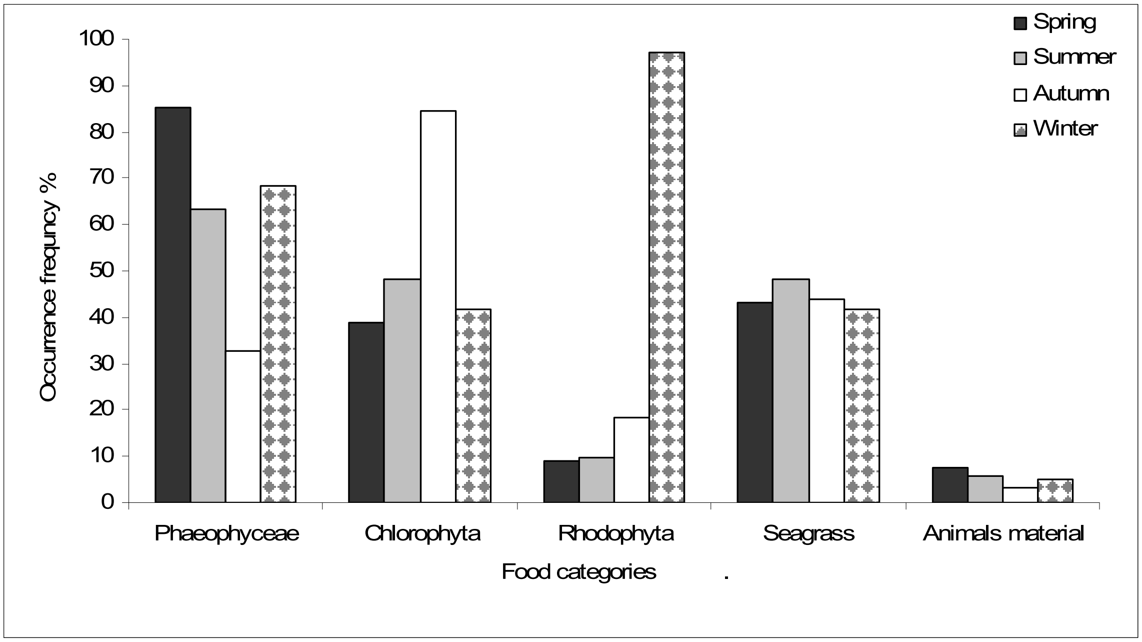

Fig. 42. Seasonal Occurrence Frequencies of different food categories for *Siganus luridus*

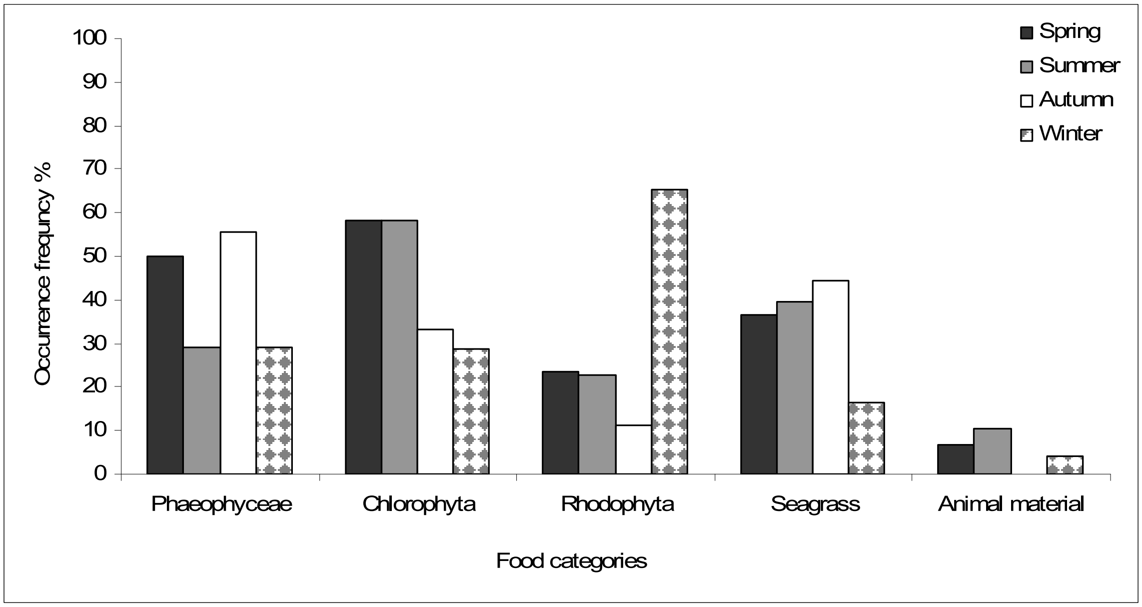

Fig. 43.Seasonal Occurrence Frequencies of different food categories for *Siganus rivulatus*

Preferred food categories, expressed as overall F% values (Fig. 44), of *S. luridus* are Phaeophyceae and Chlorophyta (60.1% and 55.3%, respectively), followed by seagrass (43.7%) and Rhodophyta (39.9%). Small amounts of animal material (5.0%) were also found, probably ingested by chance. The food preferences of *S. rivulatus* were quite similar, with Chlorophyta being the preferred food category (50.6%), followed by

Phaeophyceae (38.6%), Rhodophyta (36.7%) and seagrass (33.5%). Animal material represents only a small fraction of the diet again (6.3%). Both species show very similar overall preferences, with the only differences that *S. rivulatus* feeds less on Phaeophyceae and seagrass than *S. luridus*.

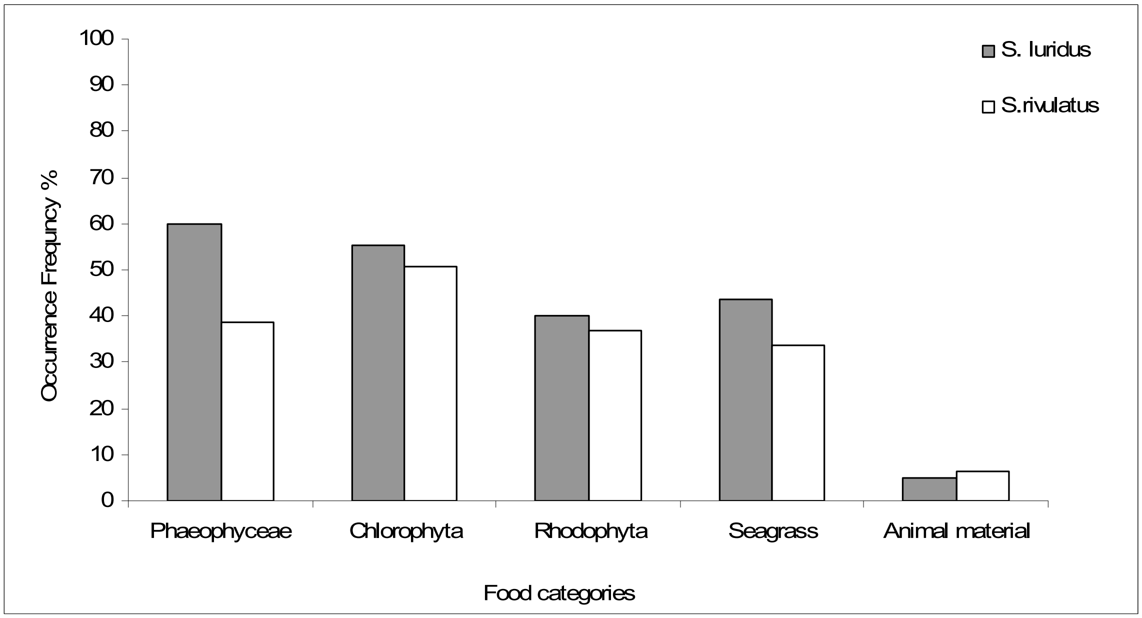

Fig. 44. Overall Occurrence Frequencies of different food categories for *Siganus rivulatus* and *S. luridus*

In the present study, 21 taxa have been identified to the level of classes or below for *S. luridus* (Table 18). Preferred taxa (F% > 50%) were members of the Dictyotales (Phaeophyceae) in spring and summer, *Ulva spp.* (Chlorophyta) in autumn and *Contarinia squamariae* (Rhodophyta) in winter (Table 18). Among the green algae, *Cladophora spp.* and *Ulva spp.* were an integral part of the diet in all seasons, while *Codium spp.* and *Dasycladus vermicularis* were only ingested in autumn and winter. As for the red algae, *Corallina officinalis* played an additional role in autumn and winter. Tough brown algae were an important food source during all seasons, mostly Dictyotales which were replaced by *Sargassum spec.* in autumn. Other moderately preferred brown algae were *Halopteris filicina* and *Stypocaulon scoparium* (Sphacelariales) in spring.

Table 18. Seasonal Occurrence Frequencies for identified taxa from the stomach contents of *Siganus luridus* X: absent

Taxa	**Order**	**Seasonal Occurrence Frequencies**			
Chlorophyta		Spring	Summer	Autumn	Winter
Caulerpa racemosa	Bryopsidales	X	1.9	1.0	1.0
Codium spp.	Bryopsidales	X	X	14.3	16.8
Cladophora spec.	Cladophorales	34.3	15.4	22.5	9.9
Dasycladus vermicularis	Dasycladales	X	X	12.2	10.9
Ulva spp.	Ulvales	32.8	44.2	52.0	29.7
Rhodophyta					
Asparagopsis armata	Bonnemaisoniales	X	X	X	9.0
Hypoglossum hypoglossoides	Ceramiales	X	X	X	3.0
Polysiphonia spp.	Ceramiales	X	X	X	5.0
Corallina officinalis	Corallinales	6.0	X	18.4	34.7
Contarinia squamariae	Gigartinales	6.0	9.6	9.2	60.4
Phaeophyceae					
Sauvageaugloia griffithsiana	Chordariales	X	X	X	3.0
Dictyota spp.	Dictyotales	28.4	5.8	9.2	37.6
Padina spec.	Dictyotales	3.0	5.8	X	1.0
Taoina/Spatoglossum	Dictyotales	58.2	53.9	X	21.8
Unidentified Dictyotales	Dictyotales	3.0	X	X	5.9
Unidentified Ectocarpales	Ectocarpales	1.5	X	8.2	X
Cystoseira spp.	Fucales	X	X	3.1	1.0
Sargassum spec.	Fucales	4.5	11.5	22.5	1.0
Halopteris filicina.	Sphacelariales	26.9	3.9	7.1	5.9
Sphacelaria spp.	Sphacelariales	6.0	1.9	X	X
Stypocaulon scoparium	Sphacelariales	17.9	1.9	X	7.9
seagrass					
Posidonia oceanica		43.3	48.1	43.9	41.6
animal material					
Polychaeta		4.5	1.9	X	5.0
Larvae		X	X	2.0	1.0
Mollusca		4.5	3.6	1.0	X

24 taxa have been identified to the level of classes or below for *S. rivulatus* (Table 19). The preferred food item was *Ulva* (Chlorophyta) in spring and summer, but *Sauvageaugloia griffithsiana* (Phaeophyceae) was also frequently found in spring. No strong preference for a particular group was observed in autumn, with *Stypocaulon scoparium* (Phaeophyceae) being most frequently ingested. *Rhodophyllis spec.* (Rhodophyta) was the preferred algal food source in winter. Other algae, classified as being moderately preferred (F% > 10%) were *Cladophora* spp. and *Ulva* spp. in all seasons but autumn, *Codium* spp. in all seasons but winter and a little *Dasycladus vermicularis* in summer for the green algae. Among the red algae, *Griffithsia cf. opuntioides* and *Jania rubens* were ingested in spring, *Corallina officinalis* and *Contarinia squamariae* in summer, and *Contarinia squamariae* and *Botryocladia* spec. in

autumn. Only in winter red algae were chosen as a food source more frequently, with *Corallina officinalis* and *Asparagopsis armata* being target species in addition to *Rhodophyllis* spec. Additional ingested brown algal taxa were *Dictyota* spp. and *Stypocaulon scoparium* in spring, some Dictyotales in summer and *Stypocaulon scoparium*, Ectocarpales, *Halopteris filicina* and cartilaginous species (cf. Fucales) in autumn. In winter, *Sauvageaugloia griffithsiana* was being moderately preferred. In all seasons, seagrass was an important food source, only found less frequently in winter.

Table 19. Seasonal Occurrence Frequencies for identified taxa from the stomach contents of *Siganus rivulatus*. X: absent

Items	**Order**	**Seasonal Occurrence Frequencies**			
Chlorophyta		Spring	Summer	Autumn	Winter
Codium spp.	Bryopsidales	15.0	29.2	33.3	X
Cladophora spec.	Cladophorales	21.7	16.7	X	29.3
Dasycladus vermicularis	Dasycladales	X	12.5	X	X
Ulva spp.	Ulvales	51.7	50.0	X	17.1
Rhodophyta					
Asparagopsis asparagoides	Bonnemaisoniales	X	X	X	12.2
Antithamnion spec.	Cermiales	X	X	X	4.9
Griffithsia cf. opuntioides	Cermiales	13.3	X	X	9.8
Heterosiphonia cf. crispella	Cermiales	3.3	6.3	X	9.8
Polysiphonia spp.	Cermiales	3.3	X	X	4.9
Corallina officinalis	Corallinales	1.7	16.7	X	29.3
Jania rubens	Corallinales	20.0	X	X	X
Contarinia squamariae	Gigartinales	X	12.5	11.1	9.8
Rhodophyllis spec.	Gigartinales	X	X	X	56.1
Botryocladia spec.	Rhodymeniales	X	X	11.1	4.9
Phaeophyceae					
Dictyota spp.	Dictyotales	26.7	4.2	X	7.3
Taoina/Spatoglossum	Dictyotales	X	16.7	X	X
Giffordia spec.	Ectocarpales	1.7	4.2	X	X
unidentified Ectocarpales	Ectocarpales	3.3	6.3	33.3	X
Sauvageaugloia griffithsiana	Chordariales	46.7	6.3	X	19.5
cartilaginous brown algae	Fucales	X	X	33.3	X
Sargassum spec.	Fucales	3.3	8.3	X	X
Halopteris filicina	Sphacelariales	X	X	22.2	9.8
Sphacelaria spp.	Sphacelariales	1.7	6.3	X	X
Stypocaulon scoparium	Sphacelariales	26.7	X	44.4	2.4
seagrass					
Posidonia oceanica		36.7	39.6	44.4	19.5
animal material					
Polychaeta		X	6.3	X	4.9
Larvae		3.3	4.2	X	X
Mollusca		5.0	4.2	X	X

3.5.1 Discussion

The seaweed flora of the tropical Red Sea is characterized by lower total numbers of macroalgal species, and by less brown algae and higher percentages of green and red algae than temperate zones (LÜNING 1990). Around 1000 species of macroalgae occur in the Mediterranean (LÜNING 1990), while ca. 500 species are known for the Red Sea (PAPENFUSS 1968). Apart from general floristic differences between different climate zones, a main factor governing the abundance of algae in coral reefs is the spatial competition with hard and soft corals (BENAYAHU and LOYA 1977), which restricts algae to particular areas of the reef. Macroalgae are mostly found in the shallow reef lagoons, in crevices and caves in the reef, and as epiphytes on mangroves and seagrasses. On average, only 10% of the substrate is covered by macroalgae in the shallow parts of the reef (LÜNING 1990). Still, the importance of grazing by herbivorous fish is much higher in the tropics (VERMEIJ 1978), with about 20% of the fish species being herbivorous (BAKUS 1969). The typical large canopy species in reef lagoons are the fleshy brown algal genera *Sargassum* and *Turbinaria* (Fucales). Other browns that are common and sometimes dominant are the foliose genera *Dictyota* and *Padina* (Dictyotales). Common chlorophytes are *Caulerpa*, *Codium* and *Halimeda* (Bryosidales), common rhodophytes are the genera *Gelidium*, *Halymenia*, *Gracilaria*, *Grateloupia*, *Laurencia* and coralline algae. While in the Mediterranean the highest abundance of macroalgae is found during summer, the highest algal biomass in the Red Sea is found in the cold season (MERGNER and SVOBODA 1977, ATEWEBERHAN 2004). Seasonal effects are more pronounced in the foliose and canopy algae than in turf communities and coralline algae.

Information about food preferences and feeding habits of *Siganus luridus* and *S. rivulatus* in the Mediterranean allows to investigate changes in the diet compared to the original habitats and to speculate about the fate of these species in their new environments. It has been claimed that both species have changed their diet in the Mediterranean compared to the populations in the Red Sea (e.g., LUNDBERG 1981a, 1989).

In the Red Sea *S. luridus* consumes mainly large tough brown algae (LUNDBERG and GOLANI 1995), such as *Lobophora variegata* (Dictyotales), *Cystoseira myrica* and *Sargassum spp*. (Fucales) (LUNDBERG and LIPKIN 1979). A study in the gulf of Elat has shown that even though brown algae are the preferred food source a broad range of algal and seagrass species (28 taxa) are utilised (LUNDBERG and GOLANI 1995).

In the Red Sea, red algae contribute more than half to the diet of *S. rivulatus* (LUNDBERG and LIPKIN 1979, LUNDBERG and GOLANI 1995), with fleshy and soft taxa such as *Laurencia* spp., *Hypnea* spp., *Champia irregularis* and *Digenea simplex* are selected most frequently. Phaeophyceae (esp. *Sargassum dentifolium*) and Chlorophyta (esp. *Caulerpa racemosa*) are also an important part of the diet (LUNDBERG and GOLANI 1995). The diet of *S. rivulatus* was found to be more diverse compared to *S. luridus*, 39 algal and seagrass taxa were found in stomach contents from the gulf of Elat (LUNDBERG and GOLANI 1995). Even though the data available for the Red Sea is not extensive and lacks information on seasonality, both species can be characterised to feed on a range of taxa from all three major algal groups. *Siganus luridus* shows a stronger preference for brown algae while *S. rivulatus* feeds on a broader range of species and green and red algae play a more pronounced role in the diet. This might be due to the specialised morphology of the alimentary tract which may provide *S. luridus* with a greater ability to utilize coarse brown algae (LUNDBERG and GOLANI 1995).

In the present study the Feeding Index shows that *S. luridus* fed slightly more during spring but changes between seasons are not significant, while *S. rivulatus* showed an increased feeding intensity in spring and summer before a drop in winter. In a study undertaken in the north-eastern Mediterranean the degree of stomach fullness was at a maximum in spring and at a minimum in summer for *S. luridus* (STERGIOU 1988). This agrees with the data presented here, while the Feeding Index was found to be high in the summer and spring and low in winter for both species along the Alexandria coast (Egypt) (HAMZA *et al*. 2000). Maybe *S. luridus* finds more available resources in the southern Mediterranean during winter compared to northern areas with a more pronounced seasonality, allowing for a high metabolism all year round. The stronger preference of *S. luridus* for perennial brown algae could be a factor explaining the observed differences in winter.

Apart from the availability of resources, changes in the life cycle affect parameters such as feeding intensity. The spawning time was found to be during the summer season for both species in Libyan waters, for *S. luridus* from May to July and for *S. rivulatus* from

June to July, and does not correlate with observed trends in feeding intensity. This result agrees with studies from the southeastern Mediterranean (Egypt) for *S. rivulatus*, but is quite different for *S. luridus* (MOHAMED 1991, HAMZA *et al*. 2000). It has been shown that the feeding activity declines significantly during the spawning period (PAPACONSTANTINOU *et al*. 1986), a trend not observed in the present study. However, a drop in the GSI occurred in July and subsequently increased again for *S. rivulatus* (Fig. 41), coinciding with the end of the spawning season and probably indicating a lower body weight after release of the spawn. The drop of the GSI for *S. luridus* in September occurs later than could be expected from the end of the spawning season.

For the eastern Mediterranean (Israelian coast), LUNDBERG and LIPKIN (1993) and LUNDBERG *et al.* (1999a) report that the two *Siganus* species are selective when macrophyte assemblages are diverse and abundant and will eat whatever is available during the unfavourable season (October-November), such as *Sargassum* spp., *Padina* spp. or *Sphacelaria* spp. It is common in nature that animals feed on species when abundant and ignore them when scarce; a behaviour termed “switching” (MURDOCH and OATEN 1975).

Previous reports on the composition of the diet of *S. luridus* in the eastern Mediterranean report between 25 and 32 algal and seagrass taxa (STERGIOU 1988, LUNDBERG and GOLANI 1995, respectively); these numbers are in the range of what has been found in the Red Sea, and also of the results presented here (22 taxa). A feeding preference of *S. luridus* for brown algae has been reported from the eastern Mediterranean, but green and red algae can make up large percentages of the diet (LUNDBERG and GOLANI 1995). In the present study, a similar trend was observed, with brown algae being generally preferred, especially in spring, but green algae are the most important food source in autumn and red algae in winter (Fig. 42). The same switch from brown to red and green algae in autumn and winter was observed in Greek waters (STERGIOU 1988). In Israelian waters brown algae were still the preferred food source in autumn (LUNDBERG *et al.* 2004). In contrast to the data from the Red Sea, only very little *Caulerpa racemosa* was consumed even though occurring on the Libyan coast (Table 18).

For *S. rivulatus*, 41 algal and seagrass species have been found in gut content analyses from the eastern Mediterranean (LUNDBERG and GOLANI 1995), a similar value to what has been found in the Red Sea (39 taxa). From the Libyan samples a somewhat less diverse diet was reconstructed, 25 taxa were identified (Table 19). Mediterranean populations of *S. rivulatus* have been found to feed mainly on fleshy red algae and *Ulva spp*. (Chlorophyta) (LUNDBERG and GOLANI 1995) or coarse brown algae (LUNDBERG *et al.* 1999b). Green algae contribute more than 60% to the diet of *S. rivulatus* in Israelian waters during spring, while brown algae are the preferred food source in autumn (89%) (LUNDBERG *et al.* 2004). In the present study, brown and green algae were the most frequently consumed algal groups. Green algal consumption was most pronounced in spring and summer (60%, Fig. 43), with *Ulva* as the main target genus (Table 19). Brown algae are the preferred food source in autumn, and a switch to red algae was observed in winter. Seasonal variation in the abundance and availability of the important food items of *Siganus* species could be a major factor leading to variations in the diet of these species; or variations could be a result of behavioural changes of the fish such as targeting different taxa in different seasons due to specific metabolic needs.

Even if the consumed algal and seagrass taxa differ on the species (and genus) level between the Red Sea and the eastern Mediterranean, and other authors have regarded the diet to be considerably different in the Mediterranean (LUNDBERG 1981a, 1989), the composition of the diet of the two *Siganus* species appears to be very similar in the Red Sea and the eastern Mediterranean according to most literature data and the results presented here. The results on the food preferences from the Libyan coast are in general agreement with basically all studies from other parts of the eastern Mediterranean (STERGIOU 1988, MOHAMED 1991, LUNDBERG and GOLANI 1995, LUNDBERG *et al.* 1999b, HAMZA *et al.* 2000, LUNDBERG *et al.* 2004). Most studies show that even though certain food sources are clearly preferred, members of all three major macroalgae groups are consumed at different times. Both species are able to utilise a broad range of food sources and can switch between preferred groups according to availability, e.g. between seasons. Most genera of macroalgae that *Siganus* species feed on occur in both the Red Sea and the Mediterranean, so the main difference they face their in their new environments with regards to their diet is different algal community structures and abundances, as well as different seasonality. One interesting difference is the consumption of calcified algae (Corallinales, Rhodophyta) in the Mediterranean (Tables

18 and 19), while for the Red Sea basically only fleshy algae are reported as being ingested (LUNDBERG 1980). Several studies have shown that seagrass as a food source plays a different role in the Red Sea and the Mediterranean (LUNDBERG and LIPKIN 1979, LUNDBERG and GOLANI 1995, LUNDBERG *et al.* 1999, HAMZA *et al*. 2000). *Posidonia oceanica* was an important part of the diet in all seasons for both species in Libyan waters, and is consumed in a higher proportion compared to the Red Sea. The differences in food preferences between the two species has also not changed considerably in the new environment, *S. luridus* shows a stronger preference for brown algae while *S. rivulatus* displays a broader range of targeted food items and red and green algae play a more pronounced role in the diet.

Species with a wide range of possible food sources are more restricted in their distribution into new environments by other factors, most importantly probably temperature (esp. with regards to reproduction). Herbivorous species are also exposed to much less competition in the Mediterranean compared to the Red Sea (BARICHE *et al.* 2004, SHAKMAN and KINZELBACH 2007b), so the pressure to make drastic adjustments to the diet is not very high as long as food resources similar to the original area of distribution are available. Since algal resources are similar throughout the Mediterranean, it can be expected that both species will become a permanent part of the Mediterranean fauna and will spread further westwards, unless a temperature boundary is encountered.

3.6 Ectoparasites

The two collected cymothoid species *Anilocra physodes* (LINNAEUS 1758) and *Nerocila bivittata* (RISSO 1816) belong to the subfamily Anilocrinae. Both species can be found throughout the Mediterranean with *A. physodes* having a wider distribution in the eastern Atlantic (TRILLES 1994). Information regarding the collected parasites and their hosts is summarized in (Table 20). Only one *A. physodes* individual was collected on *S. luridus*. In the Mediterranean, *A. physodes* is a ubiquitous species which has been recorded on several native fish species, mainly Sparidae (KÖRNER 1982, TRILLES 1994, BARICHE and TRILLES 2005). Seven individuals of *N. bivittata* were collected from both *S. luridus* and *S.* rivulatus (Table 20). This species usually occur on a wide range of native Mediterranean fish hosts but is typically collected on Labridae (TRILLES 1994, ÖKTENER and TRILLES 2004, BARICHE and TRILLES 2005, RAMDANE et al. 2007, ALAS ET AL. 2008).

Table 20. Cymothoids collected from the Libyan coast. L_T: total length (mm), W_D: body width (mm)

ZSRO	Cymothoid	Sex	L_T	W_D	Date	Host	Infected body part	Locality
ISO 001	*A. physodes*	♂	27.18	7.73	Nov. 2005	*S. luridus*	Body	Musrata
ISO 002	*N. bivittata*	♀	17.04	8.3	Aug. 2005	*S. luridus*	Caudal fin	Tripoli
ISO 003	*N. bivittata*	♀	23.05	11.92	Jul. 2005	*S. luridus*	Caudal fin	Musrata
ISO 004	*N. bivittata*	♀	27.32	15.5	May 2005	*S. luridus*	Pectoral fin	Tripoli
ISO 005	*N. bivittata*	♀	21.22	13.84	Mar. 2005	*S. luridus*	Caudal fin	Musrata
ISO 006	*N. bivittata*	♀	20.97	10.98	Mar. 2005	*S. luridus*	Caudal fin	Tubruk
ISO 007	*N. bivittata*	♀	???	???	Apr. 2005	*S. luridus*	Body	Tripoli
ISO 008	*N. bivittata*	♀	18.45	9.25	Feb. 2006	*S. rivulatus*	Pectoral fin	Tubruk

Both *A. physodes* and *N. bivittata* are the first records of cymothoids from the Libyan fauna, and more importantly neither of the common Lessepsian *Siganus luridus* or *S. rivulatus* have been previously reported as hosts for Mediterranean native cymothoids. Previously two specimens of an unidentified *Nerocila* spp. from the coast of Lebanon were collected in 1999 and constitute the only record (BARICHE and TRILLES, 2005). These might likely belong to a new species of a newly introduced cymothoid from the Indo-Pacific that would be a new Lessepsian Nerocila sp. but more investigation is needed. Native cymothoids were never collected from rabbitfishes along the coast of Lebanon despite the few thousands fish collected and processed between 1998 and 2000 and despite the large-scale survey (2003-2005) undergone on the cymothoid fauna of Lebanon (MB pers comm). The situation is probably similar elsewhere in the Levantine basin, where the two Lessepsian fish have established large populations. Howevere, the degree of infestation on rabbitfishes seems very low and might be regionally localized to the southern central Mediterranean. Due to some adverse environmental conditions, rabbitfishes would have acquired native Mediterranean cymothoids in the central Mediterranean and not along the Levantine coast, despite the presence of *A. physodes* and *N. bivittata* in the easternmost part of the Mediterranean (BARICHE and TRILLES 2005). Data regarding cymothoid infestation on rabbitfishes is very scarce in the Indo-West

Pacific. The only available record concerns *Nerocila sigani* BOWMAN ET TAREEN 1983 collected on *Siganus canaliculatus* (as *S. oramin*) from Kowait (BOWMAN and TAREEN, 1983). Although *S. canaliculatus* is not present in the Red Sea, it seems likely to suspect that the parasite could infest also *S. luridus* and/or *S. rivulatus* both found in the Indian Ocean (WOODLAND 1990). However, *N. sigani* was never collected from the Mediterranean which indicates that it might not have found an adequate environment or that the invading rabbitfishes have lost their parasite while moving to the new environment. Another explanation could be that the Lessepsian rabbitfishes are not potential hosts for *N. sigani* in the Indian Ocean or that *N. sigani* might be present in the Mediterranean but not yet collected. Interestingly, both *S. rivulatus* and *S. luridus* have acquired instead native Mediterranean cymothoids but only in the central Mediterranean, particularly the congeneric *N. bivittata*. It seems noteworthy to mention here that *N. bivittata* was collected in 1932 by Gruvel from an unknown fish in the Great Bitter Lake (Suez Canal), which is midway between the Mediterranean and the Red Sea (TRILLES 1975). Other introduced Lessepsian cymothoids from the Indo-Pacific have been recently recorded in the Mediterranean. *Cymothoa indica* and *Anilocra pilchardi* were collected from the eastern Mediterranean and were considered the first Lessepsian cymothoids known to the Mediterranean Sea (BARICHE and TRILLES 2006, TRILLES and BARICHE 2006). *C. indica* seemed to be restricted to the Lessepsian fish *Sphyraena chrysotaenia* which was the most common host and while *A. pilchardi* was found on various native Clupeidae as well as on some Sparidae and Engraulidae. With more and more Lessepsian species establishing populations in the eastern Mediterranean in recent decades, parasite-host associations might be affected in some native and introduced species which will result in new combinations and might result in negative effects on the ecology of the concerned species, or create potential threats to local fisheries and fish farming or impact the ecosystem as a whole.

3.7 Genetic study

Based on the cytochrome b data (258bp), the results showed higher haplotype diversity (Hd) (0.85) and lower nucleotide diversity (π) (0.0053) in the south Mediterranean and Red sea than in the north Mediterranean for *S. luridus* and also showed higher haplotype diversity and lower nucleotide diversity in the south Mediterranean than in the north Mediterranean and Red sea for *S. rivulatus* (Table 21).

The results based on the control region (383-384bp) showed higher haplotype diversity (Hd) as well as nucleotide diversity in the south Mediterranean and Red sea than in the north Mediterranean sea for *S. rivulatus* and *S. luridus* (Table 21).

Table 21. Specimens number of *Siganus rivulatus* and *S. luridus* that collected from Red sea and Mediterranean Sea, (Hn: number of haplotypes, Hd: haplotypes diversity, π: nucleotide diversity)

Population	**Sample size**	**Hn**	**Hd**	**π**
***Siganus rivulatus* (Cytochrome b)**				
Red sea	86	4	0.13379	0.00053
South Mediterranean	33	5	0.37689	0.00159
North Mediterranean	50	3	0.15265	0.00076
***Siganus luridus* (Cytochrome b)**				
Red sea	76	5	0.39158	0.00191
South Mediterranean	28	9	0.8466	0.00536
North Mediterranean	49	4	0.50255	0.00222
***Siganus rivulatus* (Control region)**				
Red sea	23	22	0.9961	0.01289
South Mediterranean	34	26	0.9483	0.01108
North Mediterranean	19	9	0.84795	0.00533
***Siganus luridus* (Control region)**				
Red sea	26	21	0.9785	0.00958
South Mediterranean	30	19	0.9586	0.00752
North Mediterranean	69	15	0.8755	0.00587

In general haplotype diversity was higher in control region than in cytochrome b in both species. A total of 10 different haplotypes was obtained in 10 *S. rivulatus* populations based on Cytochrome b, the common haplotype was SrCy-4 and a total of 13 different haplotypes was obtained in 10 *S. luridus* populations and the common haplotypes are SlCy-10 and SlCy-4 (Table 22).

Table 22. Haplotypes obtained of different population based on cytochrome b. of both species (* GenBank)

Haplotype	Accessions number	South-Mediterranean	North-Mediterranean	Red-Sea	Total
Siganus rivulatus					
SrCy-1	AY249542*	–	1	–	1
SrCy-2	AM949028	2	–	–	2
SrCy-3	AM949029	3	–	–	3
SrCy-4	AY249540*	26	46	80	152
SrCy-5	AM949030	1	–	–	1
SrCy-6	AY249547*	–	–	1	1
SrCy-7	AY249544*	–	–	4	4
SrCy-8	AM949031	1	–	–	1
SrCy-9	AY249543*	–	–	1	1
SrCy-10	AY249541*	–	3	–	3
Total		**33**	**50**	**86**	**169**
Siganus luridus					
SlCy-1	AY249555*	–	–	1	1
SlCy-2	AM949022	1	–	–	1
SlCy-3	AY249554*	–	–	3	3
SlCy-4	AY249550*	–	16	13	29
SlCy-5	AM949023	3	–	–	3
SlCy-6	AY249549*	–	1	1	2
SlCy-7	AM949024	2	–	–	2
SlCy-8	AM949025	1	–	–	1
SlCy-9	AY249553*	9	–	–	9
SlCy-10	AY249548*	6	31	58	95
SlCy-11	AM949026	2	–	–	2
SlCy-12	AM949027	2	–	–	2
SlCy-13	AY249551*	2	1	–	3
Total		**28**	**49**	**76**	**153**

Based on mtDNA control region, a total of 52 haplotypes was obtained in 17 *S. rivulatus* populations; the most common haplotype was SrCR-28 (Table 23).

Table 23. Haplotypes obtained of different population based on control region of *Siganus rivulatus* (* GenBank)

Haplotype	**Accessions number**	**South-Mediterranean**	**North-Mediterranean**	**Red-Sea**	**Total**
SrCR-1	AM948972	1	–	–	1
SrCR-2	AM948973	1	–	–	1
SrCR-3	AM948974	1	–	–	1
SrCR-4	AM948975	1	–	–	1
SrCR-5	AM948976	1	–	–	1
SrCR-6	AM948977	–	–	1	1
SrCR-7	AM948978	2	–	–	2
SrCR-8	AM948979	–	–	1	1
SrCR-9	AM948980	–	–	1	1
SrCR-10	AM948981	1	–	–	1
SrCR-11	AM948982	–	–	1	1
SrCR-12	AM948983	1	–	–	1
SrCR-13	AM948984	1	–	–	1
SrCR-14	AM948985	1	–	–	1
SrCR-15	AM948986	1	–	–	1
SrCR-16	AM948987	1	–	–	1
SrCR-17	AM948988	1	–	–	1
SrCR-18	EU176973*	–	1	–	1
SrCR-19	AM948989	–	–	1	1
SrCR-20	AM948990	1	–	–	1
SrCR-21	EU176987*	–	1	–	1
SrCR-22	EU176985*	1	2	–	3
SrCR-23	AM948991	1	–	–	1
SrCR-24	AM948992	1	–	–	1
SrCR-25	AM948993	1	–	–	1
SrCR-26	AM948994	1	–	1	2
SrCR-27	AM948995	–	–	1	1
SrCR-28	EU176990*	8	7	1	16
SrCR-29	AM948996	–	–	1	1
SrCR-30	AM948997	1	–	–	1
SrCR-31	AM948998	1	–	–	1
SrCR-32	EU176991*	–	3	–	3
SrCR-33	AM948999	–	–	1	1
SrCR-34	AM949000	–	–	1	1
SrCR-35	EU176970*	–	–	1	1
SrCR-36	AM949001	1	–	-	1
SrCR-37	AM949002	–	–	1	1
SrCR-38	AM949003	–	–	1	1
SrCR-39	EU176988*	–	2	–	2
SrCR-40	EU176972*	–	–	1	1
SrCR-41	EU176989*	–	1	–	1
SrCR-42	EU176979*	1	1	–	2
SrCR-43	AM949004	–	–	1	1
SrCR-44	AM949005	–	–	1	1
SrCR-45	EU176981*	–	1	–	1
SrCR-46	AM949006	–	–	1	1
SrCR-47	EU176971*	–	–	1	1
SrCR-48	AM949007	1	–	–	1
SrCR-49	AM949008	–	–	2	2
SrCR-50	AM949009	1	–	–	1
SrCR-51	AM949010	–	–	1	1
SrCR-52	AM949011	–	–	1	1
Total		**34**	**19**	**23**	**76**

A total of 43 different haplotypes was obtained in 15 *S. luridus* populations, the common haplotypes were SlCR-23, SlCR-26 and SlCR-34 (Table 24).

Table 24. Haplotypes obtained of different population based on control region of *Siganus luridus* (* GenBank)

Haplotype	Accessions number	South-Mediterranean	North-Mediterranean	Red Sea	Total
SlCR-1	AM949012	1	–	–	1
SlCR-2	AM949013	1	–	–	1
SlCR-3	EU176900*	–	1	–	1
SlCR-4	EU176877*	–	–	1	1
SlCR-5	EU176875*	–	–	1	1
SlCR-6	AM949014	1	–	–	1
SlCR-7	AM949015	1	–	–	1
SlCR-8	AM949016	1	–	–	1
SlCR-9	EU176950*	1	1	–	2
SlCR-10	EU176897*	–	–	1	1
SlCR-11	EU176882*	–	–	1	1
SlCR-12	EU176887*	–	–	1	1
SlCR-13	AM949017	1	–	–	1
SlCR-14	EU176953*	1	5	–	6
SlCR-15	EU176938*	1	–	–	1
SlCR-16	EU176928*	–	2	–	2
SlCR-17	EU176876*	–	–	1	1
SlCR-18	EU176890*	–	–	1	1
SlCR-19	EU176938*	–	2	–	2
SlCR-20	EU176909*	–	1	–	1
SlCR-21	EU176951*	–	4	–	4
SlCR-22	AM949018	1	–	–	1
SlCR-23	EU176963*	3	15	3	21
SlCR-24	EU176891*	–	–	2	2
SlCR-25	AM949019	4	–	–	4
SlCR-26	EU176947*	4	8	1	13
SlCR-27	EU176948*	2	3	–	5
SlCR-28	EU176893*	–	–	1	1
SlCR-29	EU176888*	–	–	1	1
SlCR-30	EU176892*	–	–	1	1
SlCR-31	EU176896*	–	–	1	1
SlCR-32	EU176912*	2	3	–	5
SlCR-33	EU176894*	–	–	3	3
SlCR-34	EU176945*	1	16	1	18
SlCR-35	AM949020	2	–	–	2
SlCR-36	EU176949*	1	6	1	8
SlCR-37	EU176942*	–	1	–	1
SlCR-38	AM949021	1	–	–	1
SlCR-39	EU176898*	–	–	1	1
SlCR-40	EU176883*	–	–	1	1
SlCR-41	EU176889*	–	–	1	1
SlCR-42	EU176874*	–	–	1	1
SlCR-43	EU176903*	–	1	–	1
Total		**30**	**69**	**26**	**125**

Phylogenetic trees using Neighbour-Joining based on control region and cytochrome b sequence data show comparable topologies with those by HASSAN *et al*., (2003), AZZURRO *et al*. (2006). No indication for a separation between Red sea and Mediterranean populations, or within the Mediterranean Sea was found for *Siganus* spp. (Fig. 49; NJ trees for control region not shown). Four common haplotypes were shared between Red sea and Mediterranean seas for *S. luridus* (control region), and two common haplotypes were shared between Red sea and Mediterranean Sea for *S. rivulatus*. Based on cytochrome b three common haplotypes were shared between Red sea and Mediterranean for *S. luridus* and one, the most common (SrCy-4: n=152 out of 169), haplotype was shared between Red sea and Mediterranean populations for *S. rivulatus*. This suggests that *Siganus* spp. probably underwent a recent population expansion. The haplotype networks have been generally congruent with the Neighbour-Joining trees (45, 46, 47, 48), showing that mostly the most common haplotypes are in the Center of stars, whereas rare haplotypes were sometimes found in the Red sea and not in Mediterranean sea or vice versa. Again, all network analyses didn't show any phylogeographic pattern for both *Siganus* species from the Mediterranean and Red seas.

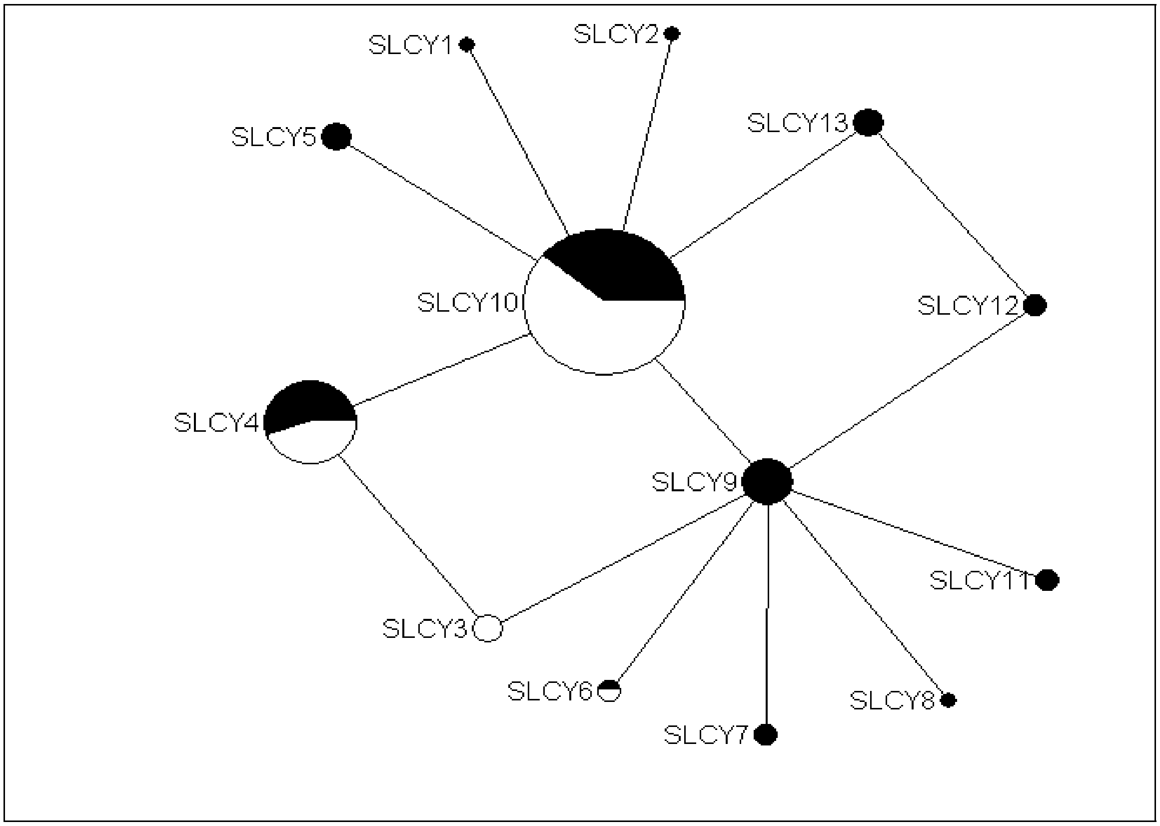

Fig. 45. Haplotype network based on cytochrome b. of *Siganus luridus* (White: Red sea; Black: Mediterranean Sea)

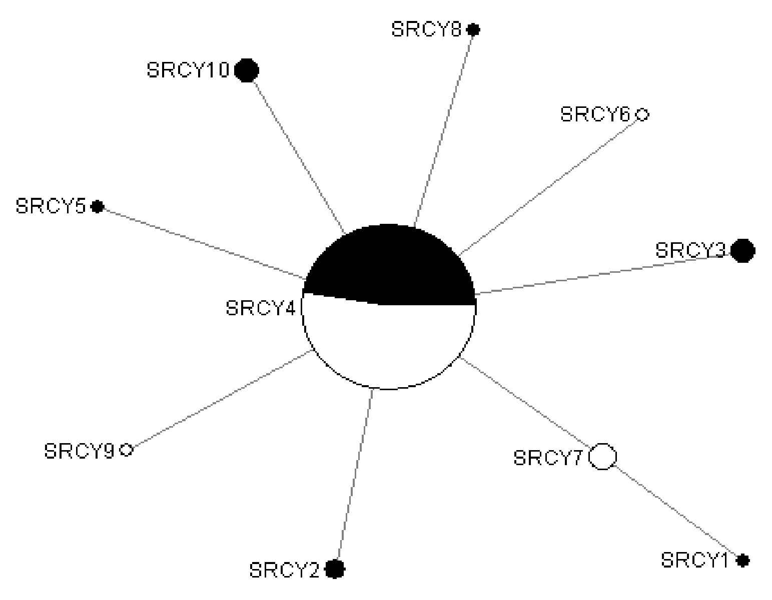

Fig. 46. Haplotype network based on cytochrome b. of *Siganus rivulatus* (White: Red sea; Black: Mediterranean Sea)

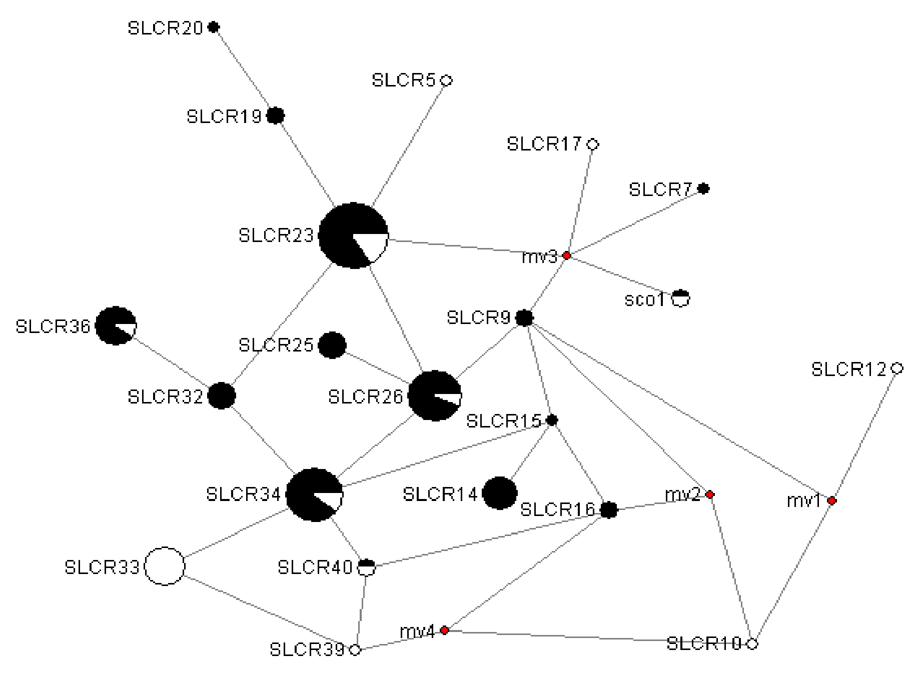

Fig. 47. Haplotype network based on control region of *Siganus luridus* (White: Red sea; Black: Mediterranean Sea)

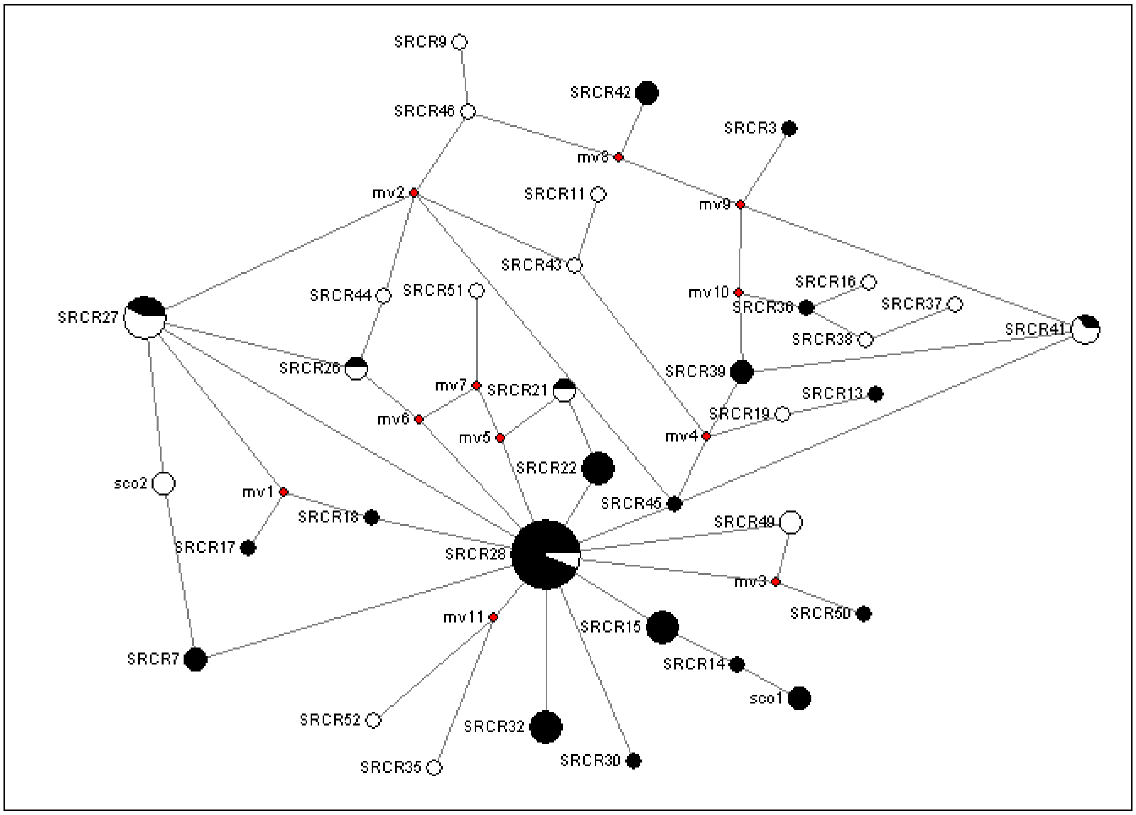

Fig. 48. Haplotype network based on control region of *Siganus rivulatus* (White: Red sea; Black: Mediterranean Sea)

The F_{ST} values was high between the populations based on the cytochrome b (Table 25) in particular between Red sea and north Mediterranean for both species and also between Red sea and south Mediterranean for *S. rivulatus*. Based on control region the gene flow was higher between east and north Mediterranean than other populations for *S. luridus*, and also was quit high between north and south Mediterranean for both species (Table 25)

Table 25. Gene flow for *Siganus rivulatus* and *S. luridus* that collected from Red sea and Mediterranean Sea

Population	**F_{ST}**	**NM**
***S. rivulatus* (Cytochrome b)**		
Red sea and North Mediterranean	0.01328	37.15
Red sea and South Mediterranean	0.03270	14.79
North Mediterranean and South Mediterranean	0.03212	15.07
***S. luridus* (Cytochrome b)**		
Red sea and North Mediterranean	0.01132	43.67
Red sea and South Mediterranean	0.26135	1.41
North Mediterranean and South Mediterranean	0.30083	1.16
***S. rivulatus* (Control region)**		
Red sea and North Mediterranean	0.09396	4.82
Red sea and South Mediterranean	0.05895	7.98
North Mediterranean and South Mediterranean	0.02935	16.53
***S. luridus* (Control region)**		
Red sea and North Mediterranean	0.08242	5.65
Red sea and South Mediterranean	0.10289	4.36
North Mediterranean and South Mediterranean	0.03785	12.71

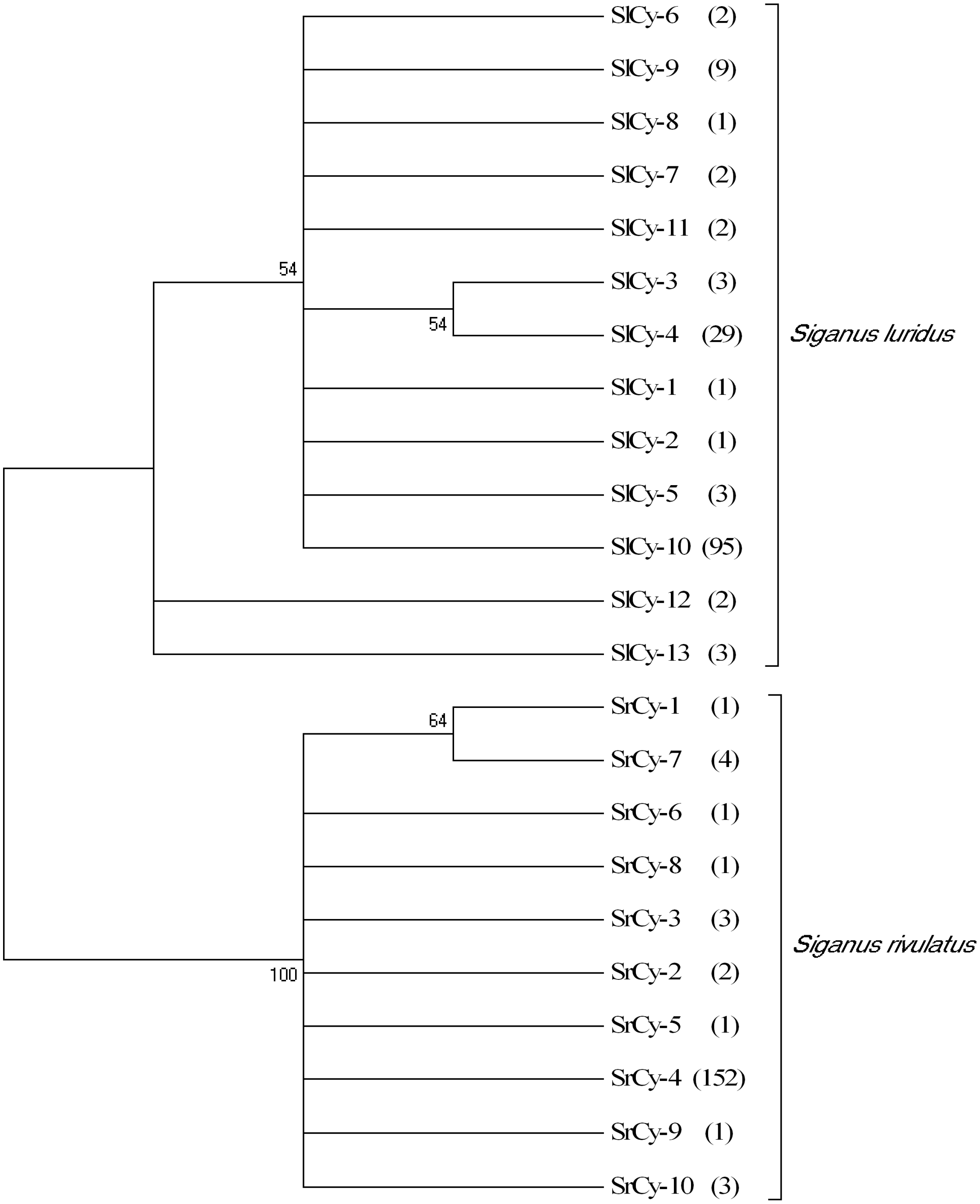

Fig. 49 Neighbour-joining tree of mtDNA cytochrome b haplotypes of *Siganus luridus* and *S. rivulatus*, Numbers indicate the bootstrap support for each node from 1000 bootstrap replicates (Number in bracket is number of haplotypes)

3.7.1 Discussion

When the ecological conditions of the new habitat are favourable, the introduction event develops into an anthropogenic range expansion and the migrating organism becomes a permanent resident. Several factors influence the genetic structure of an invasive population, including the genetic diversity of the source population and the effective population size of introduction event (HOLLAND 2000). The environmental conditions in the new habitat and the characteristic of invaders play a prominent role in determining the success or failure of invasions (REICHARD and HAMILTON 1997). Each of these invasive processes follows three subsequent phases: initial dispersal, establishment of self-sustaining populations within the new habitat and spread of the organism to nearby habitats (PUTH and POST 2005). The natural connection between Red and Mediterranean Seas since 1869 has allowed many marine species to invade the new subtropical area Mediterranean Sea. This migration was termed Lessepsian migration by POR (1978). *S. rivulatus* and *S. luridus* (Siganidae) were recorded in the south Mediterranean with some delay due to sea currents (SHAKMAN and KINZELBACH 2007a). In the present study, it was examined mtDNA (control region and cytochrome b) in 18 populations from Red sea and Mediterranean Sea (Fig. 4) of two non-native fish species *S. luridus* and *S. rivulatus*. The results have shown the high haplotype diversity (Hd) and low nucleotide diversity (π), this result is quite similar to the result that was obtained by HASSAN *et al*. (2003). They investigated three populations two of them in the Red sea and one in the Mediterranean sea of these species using cytochrome b. In addition, it is analogous to the study that has been done in the north Mediterranean and Red sea populations for the early stages of invasion of the *S. luridus* (AZZURRO *et al*. 2006). GRANT and BOWEN (1998) and TZENG (2007) propose that marine fishes can be classified into 4 categories based on different combinations of small and large values for haplotype diversity (Hd) and nucleotide diversity (π) of the mtDNA sequences for interpreting different scenarios of their population history. They indicate that fish with high haplotype diversity (Hd) and low nucleotide diversity (π) probably underwent population expansion after a period of low effective population size; in accordance, the high haplotype diversity and low nucleotide diversity in populations of *Siganus* spp. suggest that in these areas population expansion takes place.

Based on the neighbour-joining tree and haplotype networks using control region and cytochrome b the two species were well differentiated, and *S. luridus* and *S. rivulatus* did not separate into Red sea and Mediterranean geographic groups in the phylogenetic analysis, which was not unexpected considering the previously reported high levels of gene flow between these two regions (BONHOMME *et al*. 2003, HASSAN *et al*. 2003, AZZURRO *et al*. 2006). This result agrees with several studies that have been done in the north and eastern Mediterranean and Red sea populations of the same species (HASSAN *et al*. 2003, AZZURRO *et al*. 2006). No significant genetic differentiation was observed in this study at mitochondrial genes between Red sea and Mediterranean populations of *Siganus* spp. and all pair-wise F_{ST} value were not significantly different from zero. This result is in agreement with different studies that have been done on the *Siganus* spp. BONHOMNE *et al*. (2003) showed that the mitochondrial diversity (Cyt.b) of *S. rivulatus* has been preserved during the colonisation process, between Mediterranean and Red sea populations, which is probably not the result of settlement of a few successful individuals only. The absence of genetic differentiation between Mediterranean and Red sea populations in both *Siganus* showed that a great number of migrants participated to the colonisation of the Mediterranean, excluding any bottleneck event (HASSAN *et al*. 2003). These studies have been done on the populations in the area close to the Suez Canal (Syria, Israel). This means that the samples may come from the old population or from new successive waves of invaders; a situation that may wipe out specific signatures of any single recruitment event, making a genetic study of invading populations difficult (AZZURRO *et al*. 2006). Our results are quite similar to the case of *Atherinomorus lacunosus* (BUCCIARELLI *et al*. 2002), and for *Upeneus moluccensis* using Cytochrome b and nuclear (introns) sequence markers. No significant genetic difference was observed hence the passage through the Suez Canal does not seem to have affected the genetic diversity (HASSAN and BONHOMME 2005). In contrast to what we report here, AZZURRO *et al*. (2006) showed that there are differences between Red sea and invading *S. luridus*, with a lower mitochondrial diversity in the north Mediterranean than in the Red sea.

Due to the scarcity of the information on the mode of invasion for Lessepsian fish species, the spreading pattern and the invasive dynamics remain mostly unclear. BONHOMME *et al*. (2003) and HASSAN *et al*. (2003) believe that these species have been invading the Mediterranean Sea by adult active swimming. From our result, the migration to the west of Mediterranean might be via two pathways the first to north-west and the second to the south-west by active adult swimmers. The difference in the distribution of these species depends on the habitat and food variability. The comparative study of the parasitofauna of *S. rivulatus* in both source and target populations support this hypothesis (DIAMANT 1998, PASTERNAK *et al*. 2007). Despite the difference in the environment and climate between western and eastern Mediterranean, *S. luridus* has invaded the western part of the Mediterranean (Tyrrhenian Sea; CASTRIOTA and ANDALORO 2005). It is expected these species will become permanent residents in the western Mediterranean and will invade through Strait of Gibraltar into the Atlantic Ocean. Why was the spreading of Lessepsian species along the south coast delayed as compared to the north coast? AVSAR (1999) reports that after the Lessepsian migrant species had crossed the Suez Canal, and upon realizing the first reproduction activity in this environment, this current transported the eggs and larvae of this species northward. Large numbers of benthic adhesive eggs that hatch within 26-32 h of fertilization are produced by Siganids; larvae then swim actively near the water surface (POPPER *et al*. 1979). The pelagic larval phase is anticipated to last for approximately 30 days (BARICHE *et al*. 2004); within this period these larvae might be transported by the surface currents for up to 1000 km (WOODLAND 1999).

There are different theories about the spreading of these species to east-north before they migrated to the south-west after penetrating the Suez Canal. The first is the Mediterranean cyclonic Mediterranean shore current from west to the east in south-Mediterranean, the hydrographic barrier of Nile (AVSAR 1999) and the low surface water salinity before construction of Aswan Dam (decrease to 28 ‰) (BEN-TUVIA 1973). But now more than nineteen lessepsian fish species have been recorded in the south-west of the Mediterranean (SHAKMAN and KINZELBACH 2007a, KINZELBACH 2007); consequently the reason might be the different topography of the Mediterranean coast, the different habitats or even because no extensive comprehensive studies in the south Mediterranean were performed in the past time.

4 Summary

Sixteen Lessepsian fish species, representing 14 families, have recently been found along the Libyan coast, four of which are considered to be first records for Libya: *Herklotsichthys punctatus* (Rüppell, 1837), *Hemiramphus far* (Forsskål, 1775), *Pempheris vanicolensis* Cuvier, 1821 and *Liza carinata* (Valenciennes, 1836). Approximately 50% of the immigrants were found all along the Libyan coast, 12.5% in the east and central regions, and 37.5% were restricted to the eastern part of the Libyan coast, indicating by this distribution their origin from the Suez region situated in the east. All were found in the coastal area (1-50 m depth), 12.5% on vegetation, 31.3% on sandy bottoms, 12.5% on rocks, and most of them (43.8%) were pelagic. Regarding size, 75% were medium, 18.8% large and 6.3% were categorized as small. More than 37% of the recorded Lessepsian fish species are of commercial value, especially rabbitfish (*Siganus* spp.).

A total of 1.511 fishing boats of four types identified: 64.3% were “flouka”, 24.1% “mator”, 6.9% “lampara” and 4.8% “batah”. Most of them were concentrated in the western region (58.6%). The most important fishing gear used in the coastal area is the trammel net which is used by flouka, mator and batah. Depending on the fishing season, the fish size and the target fish species, some other fishing gear is also used occasionally. In this study 42 fish species of commercial value were found in the eastern region, 21 in the Gulf of Sirt region and 28 in the western region. The percentage of native fish species was 61.9% of the total number of fish species in the eastern region, while in the Gulf of Sirt region and the western region the percentages were respectively 54.6% and 71.4%.

Most of the work refers to the non-native herbivorous fish species *Siganus rivulatus* and *Siganus luridus*, which were found more abundant than the native herbivores *Sparisoma cretense* and *Sarpa salpa*. Their abundance varied in the different regions. *S. rivulatus* was abundant in the eastern part of Libya while *S. luridus* was more abundant in the Gulf of Sirt and the western region of Libya. The reason for this is probably that *S. rivulatus* is euyecous and adapts well to most habitats, since it was found on different habitats suitable for plant feeder (rock with algae, sand with algae and grass with algae), whilst the stenecous *S. luridus* was found on one specific habitat (rock with algae).

The overall sex ratio female to male was 1.4:1 for *S. luridus*. The spawning period lasted three months (May–July), the total fecundity (F_T), measured in numbers of oocytes was between 66,000 and 301,482; the relationship between fecundity and both body length and weight was investigated to make predictions about population structure and development of reproductive traits. The mean length at first maturity was estimated to be 12.9 cm for females and 12.8 cm for males; The species has adapted and successful breeding to the central Mediterranean region and reduced its spawning period by four months as compared to the original habitat, the Red Sea.

The overall sex ratio female to male was 1.3:1 for *S. rivulatus*. The spawning period covered only June and July, the total fecundity, measured in oocytes numbers, was between 94,259 and 490,898; the relationship between fecundity and both body length and weight was investigated to make predictions about population structure and development of reproductive traits. The estimated mean length at first maturity (Lt_{50}) was 14.1 cm for females and 13.5 cm for males. *Siganus rivulatus* seems to be well established in the central Mediterranean (Libyan coast) even though the temperature range and habitats differ considerably in comparison with the original area of distribution, the Red Sea

The age of both species was estimated based on otolith analysis, the age of *S. rivulatus* ranged from 1 to 6 years and from 1 to 7 years for *S. luridus*. The relationship between different morphometric measurements and total length of both species were positively correlated. Von Bertalanffy growth functions were estimated with $L_T = 35\,(1 - e^{-0.160\,(t + 1.04)})$ and $L_T = 30\,(1 - e^{-0.213\,(t + 0.784)})$ for *S. rivulatus* and *S. luridus,* respectively. The length-weight relationships were $W_T = 0.233\ L_T^{\,2.82}$ (*S. rivulatus*) and $W_T = 0.101\ L_T^{\,3.23}$ (*S. luridus*). Fulton’s factor (K), HSI and the development of gutted weight decreased during the spawning season in summer and increased again from autumn to summer for both species.

The Feeding Index shows that *S. luridus* displays more or less the same feeding intensity during all seasons, while *S. rivulatus* feeds more during spring and summer than in autumn and winter. The Occurrence Frequency shows that *S. luridus* prefers Phaeophyceae in spring and summer (85.1% and 63.5%, respectively), Chlorophyta (84.7%) in autumn, and Rhodophyta (97.0%) and Phaeophyceae (68.3%) in winter.

Siganus rivulatus feeds mostly on Chlorophyta in spring and summer (58.3%), on Phaeophyceae in autumn (55.6%), and on Rhodophyta in winter (65.3%). Seagrass is an important part of the diet in all seasons for both species. As for the overall food preference, *S. luridus* prefers Phaeophyceae (60.1%) and Chlorophyceae (55.3%), whereas for *S. rivulatus* the most frequent food category was Chlorophyceae (50.6%). Small invertebrates and sand were found in both species in very low percentages. Both species show very similar overall preferences with the only difference that *S. rivulatus* feeds less on Phaeophyceae and slightly less on seagrass than *S. luridus*. The differences in food preference between the two species have not changed considerably in the new environment.

Since the opening of the Suez Canal 1869, many marine fish species, named Lessepsian species, have been invaded the Mediterranean Sea and currently distributed in different parts of the Mediterranean Sea. The present study was conducted on *Siganus luridus* and *S. rivulatus* using mitochondrial DNA (cytochrome b, and control region). Samples were collected from 18 populations of the Mediterranean and Red seas. The results indicated high haplotypes diversity (Hd) and low nucleotide diversity (π), in all populations. The neighbour-joining and network analysis based on two genes revealed no significant phylogeographic structure for both species. The gene flow between the populations is high and indicates no significant differences in each pairwise combination of the three main sampling areas. These results suggest that both *Siganus* spp. belong to the same gene pool, respectively, and assuming the migration in the Mediterranean took two pathways, to the north-west and south-west.

5 Kurzfassung

Im Laufe der Untersuchung wurden 16 Lessepssche Arten von Fischen an der Küste Libyens nachgewiesen, aus 14 Familien, von denen vier als Neunachweise für Libyen gelten können: *Herklotsichthys punctatus* (Rüppell, 1837), *Hemiramphus far* (Forsskål, 1775), *Pempheris vanicolensis* Cuvier, 1821 und *Liza carinata* (Valenciennes, 1836). Etwa 50% der Einwanderer wurden an der gesamten Küste Libyens angetroffen, 12,5% im zentralen und östlichen Abschnitt, 37.5% waren allein auf den östlichen Abschnitt beschränkt; diese Verteilung zeigt ihre Herkunft vom noch weiter östlich gelegenen Bereich von Suez. Alle waren Küstenbewohner (1-50m Tiefe), 12.5% lebten in

Vegetation, 31.3% auf Sandböden, 12.5% auf Felsen, die meisten (43.8%) waren pelagisch. Nach Größenklassen waren 75% von mittlerer, 8.8% von beträchtlicher, 6.3% von geringer Größe. Daher erwiesen sich 37% der nachgewiesenen Lessepsschen Fischarten als wirtschaftlich wichtig, besonders Kaninchenfische (*Siganus* spp.).

Insgesamt wurden 1.511 Fischerboote von vier Typen registiert: 64.3% “flouka”, 24.1% “mator”, 6.9% “lampara”, 4.8% “batah”. Mit 58,6% arbeiteten die meisten im westlichen Küstenabschnitt. Das wichtigste Fanggerät der Küstenfischerei ist das Spiegelnetz, das von flouka, mator und batah eingesetzt wird. In Abhängigkeit von Jahreszeit sowie Größe und Art der Fangziele wird gelegentlich auch anderes Gerät eingesetzt. Bei vorliegender Untersuchung erwiesen sich 42 Arten von Fischen im östlichen Küstenabschnitt als wirtschaftlich wichtig, 21 im Abschnitt der großen Syrte, 28 im westlichen Abschnitt. Der Anteil einheimischer Fische betrug 61.9% im Osten, 54.6% in der Syrte und 71.4% im Westen.

Die zugewanderten herbivoren Arten *Siganus rivulatus* und *Siganus luridus* erwiesen sich als häufiger als die einheimischen Herbivoren *Sparisoma cretense* und *Sarpa salpa*. Ihnen galt der Schwerpunkt der Untersuchung. *S. rivulatus* war häufiger im östlichen Abschnitt der Küste Libyens während *S. luridus* in der Syrte und im westlichen Abschnitt der Küste überwog. Die Ursache dafür dürfte darin liegen, dass *S. rivulatus* als euryök gelten kann, denn er wurde in sehr verschiedenen Habitaten angetroffen (Fels, Sand oder Seegras) vorausgesetzt dort wuchsen reichlich Makro-Algen. *S. luridus* erwies sich als vergleichsweise stenök, indem er nur an algenbewachsenen Felsgründen angetroffen wurde.

Die Sexratio des Dunklen Kaninchenfischs *S. luridus* war 1.4:1 mit Überwiegen der Männchen. Die Laichzeit dauerte von Mai bis Juli, die Gesamtfruchtbarkeit (F_T), bemessen nach der Anzahl der Oozyten lag zwischen 66.000 und 301.482. Das Verhältnis zwischen Fruchtbarkeit und sowohl Körperlänge und Gesamtgewicht wurde festgestellt um Voraussagen über die Populationsstruktur und die Entwicklung der Fortpflanzung zu machen. Die mittlere Länge bei der ersten Reife betrug 12.9cm für Weibchen und 12,8cm für Männchen. In Anpassung an die Situation bim zentralen Mittelmeer veringerte die Art ihre Laichperiode um vier Monate im Vergleich zum Roten Meer.

Für *S. rivulatus* war die Sexration 1.3:1 bei Überwiegen der Männchen. Die Laichzeit erstreckte sich nur über Juni und Juli. Die Gesamtfruchtbarkeit (F_T), bemessen nach der Anzahl der Oozyten lag zwischen 94.259 und 490.898. Das Verhältnis zwischen Fruchtbarkeit und sowohl Körperlänge und Gesamtgewicht wurde festgestellt um Voraussagen über die Populationsstruktur und die Entwicklung der Fortpflanzung zu machen. Die mittlere Länge bei der ersten Reife (Lt_{50}) betrug 14.1cm für Weibchen und 13.5cm für Männchen. Der Rotmeer-Kaninchenfisch *S. rivulatus* ist offenbar im zentralen Mittelmeer gut etabliert, wenn sich auch Temperaturen und Habitate beträchtlich von der Situation im Herkunftsgebiet, im Roten Meer, unterscheiden.

Für beide Arten wurde das Alter durch Untersuchung der Otolithen festgestellt. Es lag für *S. rivulatus* zwischen 1 und 6 Jahren, für *S. luridus*. zwischen 1 und 7 Jahren. Zwischen einigen morphometrischen Daten und der Gesamtlängebestand für beide Arten eine positive Korrelation. Die Wachstumsfunktionen nach v. Bertalanffy wurden bestimmt mit $L_T = 35\ (1 - e^{-0.160\ (t + 1.04)})$ und $L_T = 30\ (1 - e^{-0.213\ (t + 0.784)})$ für *S. rivulatus* bzw. *S. luridus.* Die Längen-Gewichts-Beziehungen betrugen $W_T = 0.233\ L_T^{\ 2.82}$ (*S. rivulatus*) und $W_T = 0.101\ L_T^{\ 3.23}$ (*S. luridus*). Fulton's Faktor (K), HSI und die Entwicklung von Nettogewicht nahmen während der Laichzeit im Sommer ab und stiegen bei beiden Arten vom Herbst bis zum nächsten Sommer wieder an.

Der Nahrungsindex zeigt für *S. luridus* die gleiche Intensität der Nahrungsaufnahme in allen Jahreszeiten, während *S. rivulatus* in Frühjahr und Sommer mehr als in Herbst und WSinter verzehrt. Die Vorkommensfrequenz zeigt, dass *S. luridus* in Fühling und Sommer Phaeophyceae bevorzugt (85.1% bzw. 63.5%), Chlorophyta (84.7%) im Herbst, Rhodophyta (97.0%) und Phaeophyceae (68.3%) im Winter. *S. rivulatus* verzehrt überwiegend Chlorophyta im Frühling und Sommer (58.3%), Phaeophyceae im Herbst (55.6%) und Rhodophyta im Winter (65.3%). Seeegras ist für beide Arten zu alledn Jahreszeiten ein wichtiger Teil der Nahrung. Insgesamt bevorzugt *S. luridus* Phaeophyceae (60.1%) und Chlorophyceae (55.3%), während *S. rivulatus* überwiegend Chlorophyceae (50.6%) verzehrt. Klerine Invertebraten und Sand wurde in beiden Arten in sehr kleinen Anteilen deds Mageninhalts gefunden. Somit stimmen die beiden Arten sehr überein, außer dass *S. rivulatus* weniger Phaeophyceae und etwas weniger Seegras

verzehrt als *S. luridus*. Dieser Unterschied in der Nahrungspräferenz hat sich in der neuen Umgebung nicht merklich verändert.

Die genetische Untersuchung mitochondrialer DNA (Cytochrom b. und Kontrollregion) zeigte eine für alle Populationen eine hohe Diversität von Haplotypen (Hd) und eine geringe Nukleotidiversität (π). Der neighbour-joining Test unter Verwendung zweier Gene wies bei beiden Arten keine phylogeographisch relevante Struktur auf. Der Genfluss war hoch zwischen allen untersuchten Populationen. Dieses Ergebnis legt nahe, dass beide *Siganus*-Arten jeweils zu einem einzigen Genpool gehören, und dass die Ausbreitung innerhalb des Mittelmeeres auf zwei Wegen, nordwestlich und südwestlich, vor sich ging.

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Selbstständigkeitserklärung

Gemäß §4i der Promotionsordnung der Mathematisch-Naturwissenschaftlichen Fakultät der Universität Rostock versichere ich hiermit an Eides statt, daß ich die vorliegende Dissertationsschrift selbständig und ohne fremde Hilfe verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt wurden. Aus den benutzten Literaturquellen wörtlich oder inhaltlich entnommene Stellen sind als solche kenntlich gemacht.

Ich erkläre weiterhin gemäß §4k, daß ich weder früher noch gleichzeitig andernorts ein Dissertationsgesuch eingereicht habe. Die Promotionsordnung der Mathematisch-Naturwissenschaftlichen Fakultät der Universtät Rostock ist mir bekannt und wird von mir in vollem Umfang anerkannt.

Rostock, im April 2008