

BIOLOGY AND FISHERIES ASSESSMENT OF THE ARABIAN

PANDORA (*Pagellus affinis*) (Boulenger, 1887)

IN THE ARABIAN SEA, SULTANATE OF OMAN

By

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Abstract

Samples of Arabian pandora *Pagellus affinis* (Boulenger, 1887) were collected between April 2005 and March 2007, and from April 2008 to March 2009 from two landing sites (Al-Lakbi and Raysut) along the Arabian Sea coast of Oman. The samples were analysed to evaluate the biology and population dynamics of this species.

The marginal increment analysis of otoliths showed the formation of one opaque zone and one translucent zone every year. The timing of formation of translucent ring was approximately 4 months (June–September) and the opaque ring formed with the cycle depending on the annual changes in seawater temperature in the Arabian Sea. The fishery targeted the individuals ranging in ages from 2 to 6 years; while, the maximum age estimated was about 9 years.

The von Bertalanffy growth (VBG) constants calculated for males and females were not significantly different, so the suggesting common equation for both sexes' *P. affinis* was

$$L_t = 36.09 (1 - e^{-0.264(t + 0.525)})$$

As aging of fish using sectioned otoliths was time consuming, use of linear relationship between otolith weight (OWT) and age of fish to rapidly assess age was examined. This approach could be used to derive VBG curve, although there was significant difference from the curve obtained using sectioned otoliths. Thus, OWT–age relationships would be useful to age the fish.

The species *P. affinis* is a multiple spawner with males and females reaching maturity and spawning at almost same time. Seasonal changes in gonadosomatic index (GSI), hepatosomatic index (HSI) and relative condition factor (K_n) indicated the fish spawned from April to October with peak of spawning activity during August and September. The size-at-50% maturity was calculated at 22.1 and 23.53 cm TL and age-at-first maturity at 3.15 and 3.53 years for females and males, respectively. Four types of ova were observed: immature (0.03–0.176 mm), maturing (0.25–0.35 mm), mature (0.57–0.75 mm), and ripe (0.81–0.99 mm). Average fecundity was calculated at 199,524 eggs per female. Relationship of fecundity-to-ovary weight, body weight, and total length of fish exhibited a linear trend.

Food and feeding habits showed that *P. affinis* is a carnivorous feeder and the major part of its diet is sardines and other fish (primary item). The minor presence of algae may be an accidental inclusion during capture of benthic prey. A higher percentage of empty stomachs were observed during June and September.

Length–weight relationships of males and females showed no significant difference between sexes. *P. affinis* displayed a negative allometric growth for both sex as well as for sexes combined ($a= 0.0173$ & $b=2.954$).

Total mortality (Z) was estimated as 0.9363 y^{-1} , and the natural mortality (M) stood at to 0.488 y^{-1} . Length at 50% capture (L_c) of Arabian pandora was calculated as 19.8 cm TL. The yield and spawning biomass-per-recruit analyses indicated that the current fishing mortality rate (F_{curr}) is almost same as the target one ($F_{0.1}$), which suggest that it is exploited at optimum and should be maintained. This conclusion was supported by the following points: (1) estimated rate of fishing mortality ($F = 0.448 \text{ y}^{-1}$) was relatively close

to $F_{0.1}$ (0.572); (2) selective fishing gears targeting the species provide the bulk of the landing. However, further rise in the fishing effort may cause overfishing. The management models proposed for *P. affinis* in the Arabian Sea could be reflect the fishery status in the region. Finally, –10% decrease in natural mortality will be associated with an increase in the total yield-per-recruit and consequently the proportion of spawning stock biomass (SSB) will be more than its value (59.453 g) at current fishing mortality. In conclusion, the present study indicates that the current exploitation pattern needs to be sustained.

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1. General introduction

Sustainability has been accepted globally as the key management criterion for all finite natural resources including fisheries. The current fisheries scenario of the world has been passing through a difficult period due to stagnation in yield from capture, pollution of water bodies and several other factors. As a result, there is growing global concern of the state of fishery resources (Pauly, 1984; Watson & Pauly, 2001; FAO, 2009). In many developing countries, this situation still continuing and be worsen due to population growth, lack of definite employment opportunities and short-term socioeconomic consequences. Of the world's fisheries resources on which assessment information is available, about 52% of stocks are fished to capacity and about 28% of the stocks are overexploited (FAO, 2009). For any sustainable fisheries management, information on the life-history parameters of the exploited stocks is the primary requisite (Parent & Schriml, 1995; Jennings *et al.*, 1998; Musick, 1999; Marriott *et al.*, 2007; Heupel *et al.*, 2010). The increased fishing activity in recent years has adverse impact on aquatic environments worldwide affecting the life-history processes such as reproduction, growth, mortality and community structure (Beverton & Holt, 1957, Irlandi & Peterson 1991, Sainsbury *et al.*, 1993) and the differences in such life-history features would indicate that some species are more vulnerable to overfishing than others (Heupel *et al.*, 2010). The temporal variation in stock abundance could be the outcome of the early “critical period” of the juvenile life due to high mortality rates (Elliott, 1989; Einum *et al.*, 2003). Besides, seasonal variation in environmental conditions would influence oscillations in fish population (Shelton *et al.*, 1985).

Fishes of the family Sparidae, commonly called seabreams, are represented by 29 genera and 100 species (Randall, 1995). These demersal fishes occur in all the oceans from shallow coastal waters to deeper offshore reefs and at least 15 species are known from Omani waters (Al-Abdessalaam, 1995). Seabreams are commercially important fishes in the range of their distribution, not only for small-scale and semi-industrial fisheries; but also, for aquaculture (Hanel & Sturmbauer, 2000). As seabreams are highly preferred in Oman, their stocks are subjected to heavy fishing both by artisanal fisheries sector and by licensed industrial trawlers.

There are no specieswise catch statistics for sparids from Oman and the catches of all the sparids are reported under one group as ‘seabreams’. The estimated average annual catch of seabreams ranged between 6000 and 10000 t (Anon, 2010). While, the artisanal fishermen use handlines, gillnets and traps for capture of seabreams in the coastal waters, the industrial trawlers fish fairly in deeper waters (up to 150 m depth) in the Arabian Sea off Oman.

The biomass and potential yield of sparids in Oman have been estimated to be around 40,000 t and 9,000 t respectively; however, their catch hover around 6000 t annually (Al-Mamry, 2006). Among the sparids of Oman, the Arabian pandora *Pagellus affinis* (Fig. 1.1) is the common commercially important species. The Arabian pandora has a palatable flesh and is usually marketed fresh or frozen. Knowledge on the biology and stock characteristics of the species *P. affinis* from Oman is scanty. Hence, this species has been considered as the candidate for detailed studies for the thesis.

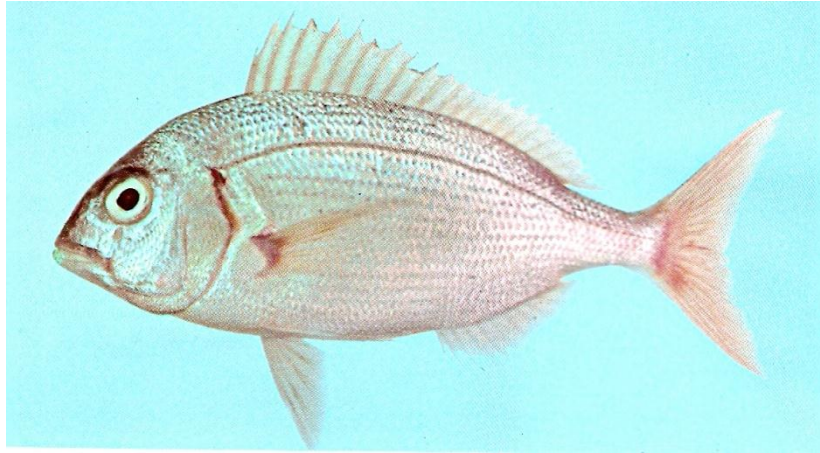


Figure 1.1 Arabian pandora, *P. affinis* (Boulenger, 1887) from the Arabian Sea

The species *Pagellus affinis* has a limited distribution and is apparently restricted to the northwestern Indian Ocean from the northern coast of Somalia, northward to the Gulf of Aden and the Sea of Oman (Randall, 1995). *P. affinis* is demersal and performs local migration between different water depths. Although, migration is initially determined by its size and age, factors such as sea bottom, food availability, water temperature and reproductive behavior influence movements of this species (Walker, 1978). The species has been observed in shoals of mixed sizes near fishing harbors suggesting that it prefers sandy and rocky bottom (personal observation).

Sparids have pelagic eggs and larvae (Leu, 1994). The larvae of the South African *Rhabdosargus sarba* attain 1 cm TL after 1 month of hatching and live in estuarine nursery areas (Wallace & van der Elst, 1975; Leu, 1994). Juvenile *R. sarba* remains in the estuarine environment until it attains sexual maturity at 26 cm TL and migrates back to the sea to spawn (Wallace, 1975; Radebe *et al.*, 2002).

The onset and duration of spawning season in seabreams appear to be influenced by seawater temperature (Morato *et al.*, 2003). Many species of sparids are hermaphrodites

and in some species concurrent development of both ovaries and testes occur (Radebe *et al.*, 2002, Hesp & Potter, 2003). Few species of sparids change their sex either from female to male (protogynous) or from male to female (protandrous) during part of their life (Buxton & Garratt, 1990; Randall, 1995). Many sparids are omnivores in their feeding (Figueiredo *et al.*, 2005). To date, the reproductive biology and diet composition of *P. affinis* fish in Oman has not been investigated.

1.1 Study area

The Sultanate of Oman is located in the northwest Indian Ocean (16° 25' 2" N and 54° 62' 2" E) bordered by three seas, the Arabian Gulf and the Sea of Oman in the north, and the Arabian Sea in the south (Fig. 1.2). Oman has a coastline of about 3165 km with varying depths and environments, and is characterized by unique locations.

The Arabian Sea borders two-thirds of the coastline of Oman starting from Yemen in the south to Ra's al Hadd at the entrance to the Sea of Oman in the northeast. Most part of the coast is facing the open Arabian Sea with sandy beaches amounting to nearly two-thirds of the coastal zone, while the rest is rocky. Except for the western Dhofar, the continental shelf is wider [35–50 nautical miles nm]. The coastal area is rich in fish resources varying from small crustaceans (e.g. shrimp) and small pelagics (e.g. sardine) to large pelagic fishes (e.g. kingfish, yellowfin tuna) as well as, a variety of demersal fishes (Mckoy *et al.*, 2009). Large trawlable areas are found in this region (approximately 60% of the shelf area). The Arabian Sea is subjected to reversal of SW/NE monsoonal winds that results in the seasonal upwelling during the SW monsoon season (May–September) along the coasts of Oman transporting cooler nutrient-rich bottom water to the surface that

triggers higher growth of phytoplankton, zooplankton, micronekton and macroalgae (Ashjian *et al.*, 2002; Al-Habsi *et al.*, 2008; Mckoy *et al.*, 2009). The coast is also known for the presence of low-oxygen zones (less than $0.2\text{--}1\text{ ml L}^{-1}$) between 200 and 1200 m due to sinking of organic matter from the highly productive surface waters (Sheppard *et al.*, 2000; McIlwain *et al.*, 2006) and this zone may be even found at depths of 40-50m (Baird *et al.*, 2009). Though, the sea surface temperature normally ranges from 21°C to 28°C , it drops to about 18°C during the upwelling season (Morrison *et al.*, 1998). The availability of higher levels of nutrients and their utilization by the phytoplankton during the SW monsoon season increase the zooplankton biomass five times compared to the late NE monsoon reversal (Luo *et al.*, 2000; Ashjian *et al.*, 2002). The Arabian Sea in which *P. affinis* dwells is accounted to be one of the most biologically productive areas of the world's oceans (Ryther *et al.*, 1966).

The fish catch from the Arabian Sea contributes to about 73% of the total annual fish landings of Oman (Al-Mamry, 2006). The artisanal fishery sector has helped to develop fisheries of Oman over the last few decades (Ben Meriem *et al.*, 2003, unpublished). Fishing activity in the Arabian Sea is widely controlled by the seasonal southwest monsoon winds associated with the strong Somali current. During this period and due to the rough weather in the Arabian Sea, fishing activities are reduced and fishermen use their time for repair and maintenance of the gears and boats.

The primary fishing gears used in the area are gillnets, handlines and fish traps. The handline fishery usually consists of smaller fiberglass boats (approximately 8 m in length) fitted with one or two outboard engines and usually five fishermen onboard and fishing is restricted to daylight hours only. Fish traps (halfmoon shaped) are constructed from plastic

coated steel wire (Al-Masroori *et al.*, 2004) and are used less frequently; each fisherman can own over 60 traps and operate them once in 3 days. The large licensed trawlers are approximately of 500 gross tons having about 2500 HP engine and carry about 30 crews (Mathews *et al.*, 2001; McIlwain *et al.*, 2006) and operate in depths beyond 50 m or in specified areas beyond 10 nautical miles.

Monthly random samples of *P. affinis* were obtained between April 2005 and March 2007 and, between April 2008 and March 2009 from the catches of the handline and gillnets operated in depths ranging from 20 to 70 m in the Arabian Sea off Oman and landed at the local fishing ports of Al-Lakbi (18° 11' 1" N 56° 32' 56" E) about 700 km southwest of Muscat and Raysut (16° 57' 37" N 53° 59' 52" E) which is about 300 km southwest of Al-Lakbi. Samples from trawl nets operated in deeper waters were also obtained (Fig. 1.2).



Figure 1.2 Map showing the Arabian Sea coast of Oman from which *P. affinis* were sampled.

1.2 Rationale for the thesis

To capture demersal fishes from the Arabian Sea off Oman, several fishing gears are used. Despite the long coastline, the local fishermen complain that fish stocks are declining and their livelihood is threatened (FAO, 2009; Al-Mamry, 2006). Further, as various fishing techniques are employed, overlapping of fishing activities has been recorded (Stengel & Al Harthy, 2002). Due to depletion of large pelagic fish stocks in Omani waters (e.g. the kingfish, *Scomberomorus commerson*), a shift in fishing activity from pelagic to demersal has taken place (Siddeek *et al.*, 1991). Hence, the Government of Oman introduced restrictions on some gears both spatially and temporally (Stengel & Al Harthy, 2002). However, trawl fishery activities in the Arabian Sea for the past several years have affected the demersal resources adversely (Mathews *et al.*, 2001). Therefore, the existing regulations need to be altered and fine-tuned.

Estimate of growth rate, size/age structure and longevity of fish are needed to understand the rates of replenishment of stock and their response to alerted mortality regimes (Choat *et al.*, 2003) as the above information is the central element in fishery management (Hilborn & Walters 1992). Also, study of maturation, spawning and fecundity is essential to gain knowledge on the reproductive strategies of the fish. To date, the only biological study that covers reproduction of *P. affinis* in Omani waters is that of McIlwain *et al.* (2006). As this study was based on 1-year sampling from the catches of licensed trawlers, it is not clear whether the results can match for artisanal sector. Further, estimation of age at maturity was not made. Moreover, not much is known on the feeding habits and stock parameters of *P. affinis* from the Omani waters. Though, data on the abundance and distribution of *P. affinis* are available in Oman from research trawl surveys

(Stromme, 1986), information on the mortality and population dynamics of the species is lacking. So, the main objective of this study was to explore the biological variability in the life-history characteristics of *P. affinis* from the Arabian Sea coast of Oman. The study addresses the aspects related to biological and dynamical characteristics of the species such as age and growth, reproduction, food and feeding, length–weight relationship, mortality and exploitation rates, yield per recruit and stock estimation based on exploited stock. The results of the study would be useful to develop strategies to manage the fishery of *P. affinis* in Oman.

The present study was undertaken based on monthly length frequencies of *P. affinis* collected from the commercial catches off the Arabian Sea coast of Oman. The sampling covered the periods from April 2005 to March 2007, and from April 2008 to March 2009. Age and growth were evaluated using both otoliths' readings and length–frequency. Stock assessment of this species has been made utilizing an appropriate analytical technique (Chapter 5). In addition, estimates of fishing mortality, yield and spawning biomass-per-recruit based on current fishing effort (F_{curr}) are presented for the first time. Additional information on the reproductive biology and feeding habits of the species is provided.

The thesis is divided into six chapters. The first one (this chapter) “General Introduction” introduces the problem and aim of the study. The second one deals with the investigation on the periodicity of otolith ring formation in *P. affinis*, the age structure and construction of von Bertalanffy growth curve (VBGC). The third chapter describes the stages of gonadal maturation in male and female, seasonal spawning cycle, age and length at 50% sexual maturity and fecundity of *P. affinis*. The fourth chapter is concerned with the food and feeding habits that describes the diet of two different size groups and during various months. The fifth chapter deals with the stock assessment of *P. affinis* along the Arabian

Sea coast of Oman. In addition to the above chapters, conclusion, management and research recommendations based on the current investigation are provided (sixth chapter). Bibliography and appendices are also given at the end.

2. Age and growth

2.1. Introduction

Age determination and growth modeling are of vital importance in the field of fisheries management and considered as critical input data needed to assess fish stocks (Hilborn & Walters, 1992; Dwyer *et al.*, 2003; Lou *et al.*, 2005; Tracey & Lyle, 2005). Age and growth studies of fish are also essential for estimating the biological and physiological aspects such as age-at-50% maturity, stock age structure, yield-per-recruit and adaptation of stock to change in habitat, exploitation and productivity (Morales-Nin, 1992; DeVries & Frie, 1996; Francis *et al.*, 1999; Campana, 2001; Welcomme, 2001; Robinson & Motta, 2002; Kanyerere, 2004; Sulikowski *et al.*, 2007; Simon *et al.*, 2010).

Most of physiological processes in fishes is influenced by the environmental conditions including food availability, spawning, behavioral interactions conditioned by intra- and inter-specific demographics, and genetic factors (Morales-Nin, 1992), and seasonal abiotic factors such as temperature, light, and salinity (Moghadam *et al.*, 2007; Björnsson *et al.*, 2011). Also, the fishing pattern affected the size of fish leading to decreasing of the average and maximum sizes of the fish in the population (Zhao & McGovern, 1997; Halpern & Warner, 2002; Choat *et al.*, 2003; Garcia *et al.*, 2007). This suggests that fishing is removing faster-growing fish from the population and may have genetic or physiological consequence in the life history of the species (Hood & Johnson, 1999).

Age of fishes was determined both directly by counting the growth rings on their hard structures such as scales, otoliths, fin spines, vertebrae. etc., and indirectly by using the length frequency analysis. Using of hard structures for fish age determination is well

documented (Campana, 2001; Dwyer *et al.*, 2003; Natanson *et al.*, 2007). However, owing to variation in the separation and clarity of observable increments, the above structures often yield variable results of age determination (Welch *et al.*, 1993; Howland *et al.*, 2004). Many authors indicated that the otolith is the dependable structures to age bony fish (Nedreaas, 1990; ICES, 1991, 1996; Stevenson & Campana, 1992; Saborido-Rey, 2001; Simon *et al.*, 2010), as scales underestimate age in larger specimens (Beamish & McFarlane, 1987; Simon *et al.*, 2010) and, fin spines and vertebrae are often difficult to interpret (Campana *et al.*, 2006). However, as age determination using otoliths is usually based on reading growth increments on thin sectioned otoliths, viewed under a microscope, this method is time consuming and expensive. Therefore, attempts were made to develop cost effective alternative methods of age determination for monitoring the age structure of fish populations. The method of linking otolith weight or length to age of fish was found useful to age fish (Newman & Dunk, 2002; Pilling *et al.*, 2003; Dougall, 2004).

It was found that there was proportionate increase in the weight of otolith with fish age in many species (Cubillos *et al.*, 2001 for *Trachurus symmetricus murphyi*; Pilling & Halls, 2003 for *Lethrinus mahsena* and Dougall, 2004 for *Lates calcarifer*). Hence, the weight of otolith would be a dependable tool to age the fish and to develop species-specific calibration curves to estimate the age structure of the population (Fletcher, 1991; Ferreira & Russ, 1994; Fletcher & Blight, 1996; Kamukuru, 2005).

The Arabian Sea is known for seasonal variation in temperature and productivity due to monsoon wind driven upwelling (Baird *et al.*, 2009). This variation in temperature might affect the growth and hence formation of growth rings within the otoliths microstructure of fish (Campana, 1999; Kanyerere, 2004). The process of growth in otoliths is influenced by deposition of microcrystals of calcium carbonate in a non-collagenous

organic matrix from the environment through a multi stage process depending on fish metabolism rates and water chemistry (Mugiya *et al.*, 1981; Campana, 1999; Rodríguez Mendoza, 2006). The difference in the intensity of amount of organic material deposition on the otolith is expressed as increments that vary from opaque band and translucent (hyaline) band (Campana, 1999; Rodríguez Mendoza, 2006). As the appearance of the translucent and opaque zones on otoliths is the result of periodic variations in growth, these zones can then be used to age fish (Rodríguez Mendoza, 2006). While, the opaque zone in the otoliths is formed during the period of faster growth, translucent zone is laid down during the period of slow growth (Beckman & Wilson, 1995; Rodríguez Mendoza, 2006).

Accurate age determination is necessary for providing accurate information and quality estimates on growth, mortality rates and productivity (Baker & Wilson, 2001; Natanson *et al.*, 2007), and to ensure that appropriate decisions are made to prevent overexploitation of fish populations (Campana, 2001). Historical aging inaccuracies have resulted in numerous fishery collapses around the world (Campana, 2001). Therefore, A major requirement of all aging studies is that the annual growth zones used are validated as being formed annually (Beamish & McFarlane, 1983; Francis & Francis, 1992; Hyndes *et al.*, 1992; Campana, 2001).

Marginal increment analysis (MIA) is a common method of validating growth zones in otoliths (Hyndes *et al.*, 1992; Campana, 2001). The marginal increment is measured as the distance from the inner margin of the outermost zone to edge of the otolith (Rodríguez Mendoza, 2006). The annual formation of such zones (opaque & translucent) would lead to the marginal increment to drop once a year. For example, as a newly formed opaque zone first becomes delineated, a new translucent zone begins to form at the otolith's edge (Rodríguez Mendoza, 2006). This translucent zone increases progressively with fish growth

until a new opaque zone is formed due to a seasonal change in growth rate (Hyndes *et al.*, 1992). Due to reasonable sample requirement and lower cost, MIA is a commonly applied procedure for age validation in fish.

Pagellus affinis is a common fish species in Oman that is targeted by artisanal and foreign licensed fishing fleets that export their catch to other countries. As a result there is concern about the current level of exploitation. The lack of detailed biological information on the species and understanding its ecosystem-level interactions, delays the development of species-specific management policies. Hence, details on the species population dynamics are imperative to develop reliable stock assessments. Consequently this study aimed at determining size at age characteristics of *P. affinis*, validating age estimates using MIA, developing growth models from size at age data, and investigated the reliability of using whole otolith weight as a cheap and quick monitoring tool to predict age of *P. affinis*.

2.2. Materials and methods

2.2.1. Fish sampling

Random samples of *P. affinis* were obtained every month at landing sites (Al-Lakbi and Raysut) from catches observed from the Arabian Sea using gillnets (144–148-mm mesh size), handlines (artisanal fishery) and trawls (110 mm mesh size) from April 2005 to March 2007, and from April 2008 to March 2009. For each specimen, total length (TL: ± 1 cm), total weight (TW: ± 1 g) and sex were recorded prior to otolith removal. During dissection both the sagittal otoliths were removed and then they were cleaned in running water, dried and stored in marked paper envelopes for processing and reading. To support

the age determination techniques and the growth modeling analyses undertaken in this study, an alternative method was also employed by using the weight of the otoliths.

2.2.2. Preparation of otoliths for examination

As symmetry in otolith shape was apparent, from each fish one sagittal otolith was randomly taken to weigh (± 0.001 g) and measured the length (± 0.001 mm) before embedding in epoxy resin. The embedded otolith was positioned transversally and 0.5 mm thick sections were cut through the otolith core using a Buehler Isomet low-speed saw containing a diamond wafering blade. The sectioned otolith was polished over a series of silicon carbide paper (400–800 grit), rinsed with water and onto glass slides was mounted. At 4 \times and 10 \times magnification mounted otoliths were examined using transmitted light microscopy. To enhance the clarity of growth zones castor oil was used to each section.

2.2.3. Interpretation of growth zones

Determination of age was made by enumerating the opaque and translucent zones on the otolith. When a fish sampled before September had a new ring mark, its age was determined as -1 year. In contrast, when a fish sampled after September lack a new ring mark, age was determined as $+1$ year. An opaque core was defined as the first complete increment followed by a translucent band plus an opaque band. Thereafter, one translucent band and one opaque band together constituted a complete growth zone or “annulus”. Otoliths were examined twice, at 3-week intervals without the knowledge of sample details. Each otolith was assigned a readability scale of 1–3 following the criteria (Table 2.1) given by Fossen *et al.*, (2003) and (Kanyerere, 2004). Where differences occurred between two readings, a third reading was made to assign the final age estimate. An additional reading

by an independent reader was also taken on a blind randomized sample ($n = 71$) of fish to assess inter-reader variability.

Table 2.1 Criteria used for classifying otolith readability in *P. affinis* (adapted from Fossen *et al.*, 2003; Kanyerere, 2004).

Readability	Growth zone appearance
1	Otolith structure is exceptionally clear unambiguously definition between translucent and opaque zones.
2	Relatively clear zonation, but not well defined; two possible interpretations of banding patterns.
3	The zones are vaguely marked, multiple interpretation possible.

2.2.4. Precision of estimates

Aging precision was quantified using two indices, the average percent error (APE) and coefficient of variation (CV) (Beamish & Fournier 1981; Chang 1982). APE was calculated as:

$$APE_j(\%) = 100 \times \frac{1}{R} \sum_{i=1}^R \left| \frac{X_{ij} - X_j}{X_j} \right|$$

where R is the number of times each fish was aged, X_{ij} the i th age determination of the j th fish, and X_j the mean age calculated for the j th fish.

Chang (1982) modified this index to a CV, substituting the absolute deviation by the standard deviation from the mean age as:

$$CV_j(\%) = 100 \times \frac{\sqrt{\sum_{i=1}^R \frac{(X_{ij} - X_j)^2}{R-1}}}{X_j}$$

2.2.5. Validation

The MIA was used to validate the periodicity of zone formation. Marginal increments were measured from the inside of last opaque zone to the ventral apex of the otolith edge using image analysis LS report Five. Mean marginal increments were analyzed on a monthly basis ($n = 422$); for the pooled samples across the years. Marginal increment data were also pooled for fish aged between 1 and 3 years and fish ≥ 5 years. Fish aged as 0+ were excluded from MIA.

2.2.6. Estimation of growth and longevity

Nonlinear regression procedure of Statgraphics (1994) was applied to calculate the growth parameters (L_∞ , K and t_0) by fitting the observed age-length data to the von Bertalanffy (1938) equation:

$$L_t = L_\infty (1 - e^{-K(t-t_0)})$$

where L_t is length at time t , L_∞ the asymptotic length, K the growth coefficient that determines the rate at which L_∞ is attained and t_0 the theoretical age of fish at zero length. Assigned age data were adjusted to a relative monthly age based on the capture date and

both the birth date and increment formation being assigned as occurring on the 1st September (see Chapter 3) before modeling growth. Theoretical longevity was estimated based on Alagaraja (1984); $(Te) = 4.605/M$, where Te is longevity and M is natural mortality. The procedures for estimating natural mortality are given in Chapter 5.

2.2.7. Length–frequency distribution

Data of length–frequency distribution were also used to assess growth parameters of *P. affinis*. Total lengths (TL) of fish were collected from trap, gillnet and trawl fisheries. The combination of fishing gears used would minimize bias attributable to gear selectivity (Lucena & O'Brien, 2001).

Asymptotic length (L_{∞}) and growth coefficient (k) of von Bertalanffy Growth Formula (VBGF) were estimated by Electronic Length–Frequency Analysis (ELEFAN-1) technique using FISAT-II (Pauly & David, 1981). To calculate the growth performance index (ϕ) of *P. affinis*, Pauly & Munro (1984) equation was used. This equation was as follows:

$$\phi = \log K + 2 \log L_{\infty}$$

2.2.8. Data analysis

One-way ANOVA test was applied for the difference in the monthly marginal increments for all combined ages. The log likelihood assuming an additive normally distributed error structure was minimized to estimate the parameters. A likelihood profile technique (Efron, 1981; Punt, 1994) was applied to calculate the confidence intervals (95%) of the estimates

of parameters of selected growth model. The keys of age-length were constructed separately for females, males and combined sexes. Growth curves for females and males were compared using the analysis of residual sums of squares (ARSS) method described by Chen *et al.* (1992). The otolith weight (Wo) and total length of fish relationship was determined by linear regression (Labropoulou & Papaconstantinou, 2000). To compare the relationships between otolith weight and age between the sexes, analysis of covariance (ANCOVA) was used, with age as the dependent variable, otolith weight as the covariate and sex as the categorical variable (Zar, 1996).

2.3. Results

2.3.1. Otolith reading for aging

Of the 1070 fish processed, 89.9% could be aged (males = 463; females = 487). In the remaining samples, otolith breakage, failed preparation, or poorly defined increments prevented age determination. Aged otoliths typically displayed clear and easily identified annuli, with sections displaying alternating patterns of zones (translucent and opaque) when viewed under microscope with transmitted light (Fig. 2.1). These patterns were particularly evident along the proximal side of the otolith section and indicated that the fish attained up to 9 years of age. Inter-reader age determination from a subsample of 71 otoliths, indicated that the majority of readings were in agreement (66.2%), and that disagreements differed by only one (29.6%) or two (4.2%) opaque zones (Fig. 2.2). The APE and CV between the two readers were 2.98% and 7.76%, respectively. Bowker (1948) χ^2 tests of symmetry

indicated that inter-reader variability in age determinations were due to random error ($\chi^2 = 3.11$, $P > 0.05$) and not systematic bias.

The periodicity of annuli formation in *P. affinis* was tested by tracking the monthly marginal increment of otoliths (Fig. 2.3). Analysis of monthly marginal increments for fish aged between 1 and 5 years suggested an annual formation of bands occurs (Fig. 2.3). Once mean marginal increments reached their lowest values (Sept and Oct) they steadily increased through to March. Marginal increments with all ages combined were significantly different between months ($F = 138.29$, $df = 11, 413$, $P = 0.0006$).

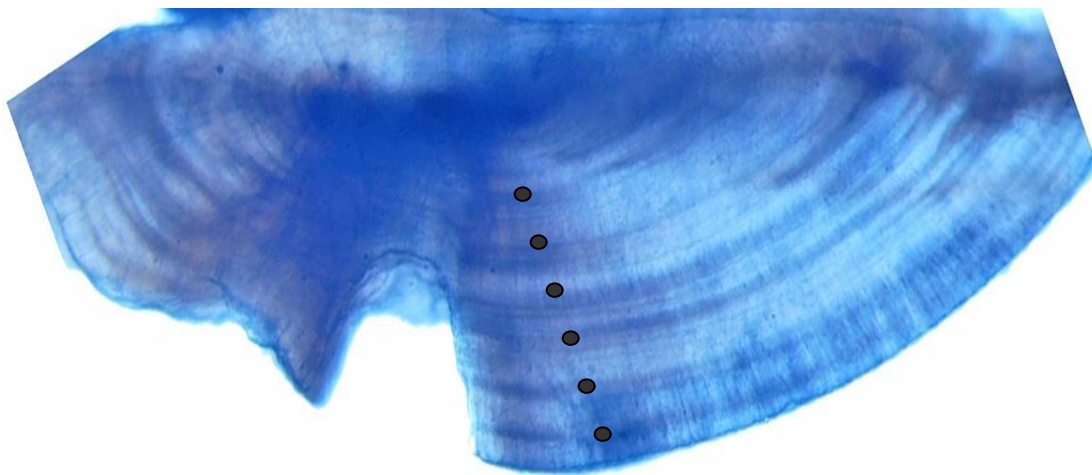


Figure 2.1 Sectioned otolith of *P. affinis* from a 6+ years old fish showing annual bands that are marked here with black dots.

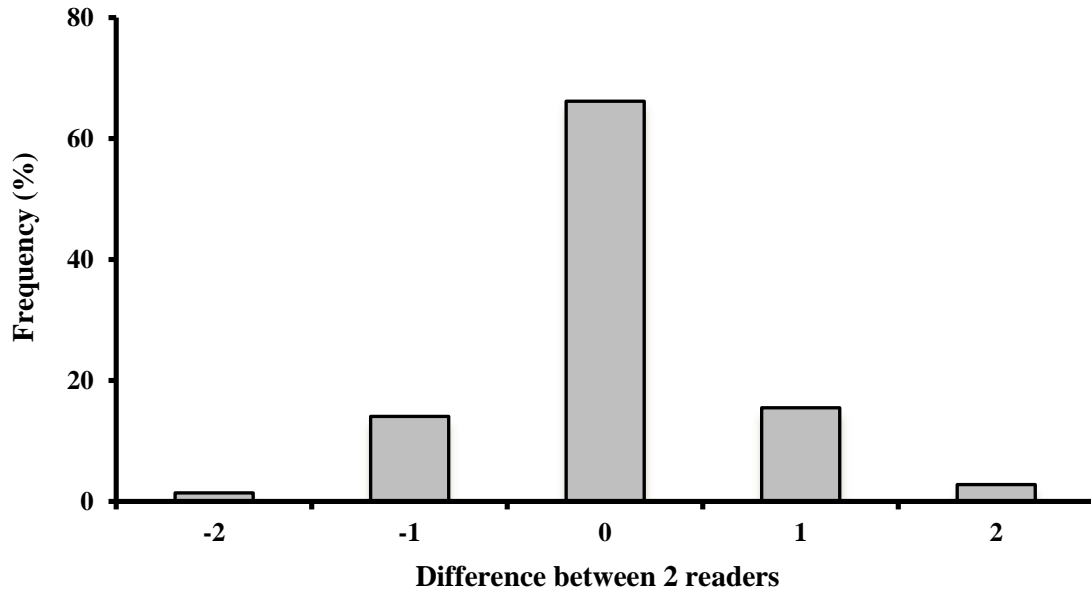


Figure 2.2 Frequency distribution of the differences in the age of *P. affinis* counts by two independent readers, $n = 71$.

The results show that one opaque zone and one translucent zone, regardless of status of maturity of the individual fish, considered as an annulus. Since spawning of *P. affinis* takes place in the Arabian Sea during the monsoon season (Chapter 3), we considered 1st September (peak of the spawning season) as the birth date for each cohort. Therefore, the age was determined by counting the number of both translucent and opaque zones and it was decided that each pair of growth rings (one translucent and one opaque) corresponded to an individual year.

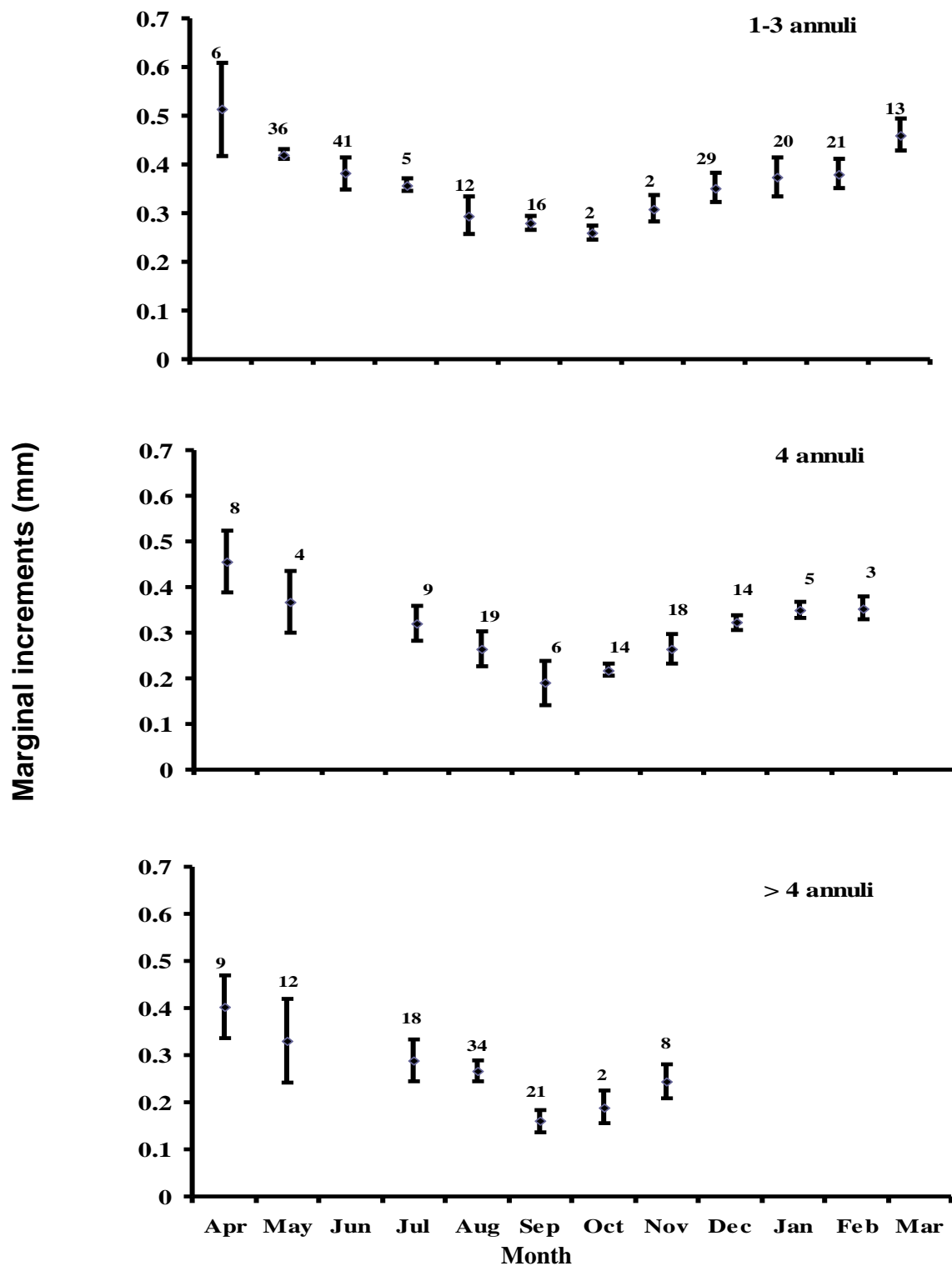


Figure 2.3 Monthly mean (\pm SD) marginal increments for *P. affinis* of ages 1–5. Numbers above data points represent sample sizes; only samples having two or more fish have been used.

2.3.2. Growth modeling from sectioned otoliths

The analyses of the length–age keys for both sexes separately are provided in Tables 2.4–2.6 (Appendix A). The estimated ages of fish based on annual rings in otolith section was from 0 to 9 years with a high proportion between 2 and 6 years. Age of females and males ranged between 0 and 9 years and sex indeterminate individuals aged from 1 to 6 years. Age and size estimates of females, males and pooled sexes displayed relatively good fits with the von Bertalanffy growth model with coefficient of determination (R^2) values being 0.688, 0.676 and 0.667 respectively (Fig. 2.4). Growth parameter estimates (L_∞ , K and t_0) and their confidence limits corresponding to male, female, and sexes combined data are detailed in Table 2.2. For males and females an analyses of residual sum of squares (ARSS) indicated that growth curves were not significantly different (ARSS $F_{3, 943} = 1.453$; $P = 0.226$). The combined growth curves had a ϕ value of 2.535 with the $R^2 = 0.667$. The calculated asymptotic length (L_∞) was lower than the observed maximum TL (39.8 cm). As, the total sample comprised only two individuals greater than 8 years of age, result and L_∞ appeared as an underestimates. The fish relatively had faster growth for the first 4 years attaining 66% of their asymptotic length. Thereafter, growth rate slowed down with increasing in age (Fig. 2.4). The details of the fish analyzed for each age class are provided in Table 2.6. Table 2.3 shows the mean observed lengths (cm TL) and standard deviations of pooled data from Arabian Sea for all *P. affinis*. The mean expected length is always same as the observed length for most age classes.

Using the VB growth coefficient, the theoretical longevity was estimated at 9.43 years, which is similar to the observed maximum age of 9+ years.

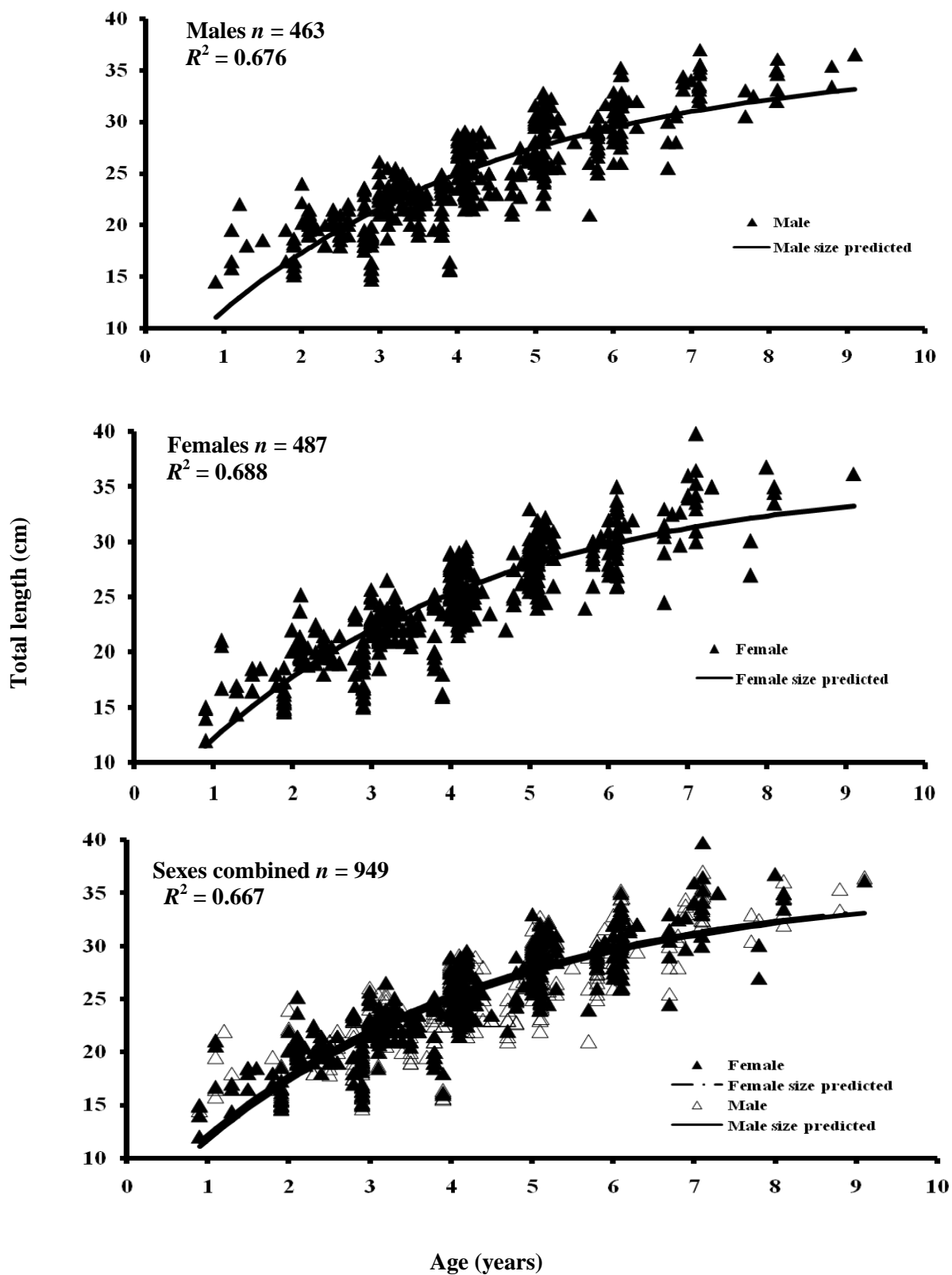


Figure 2.4 Length-at-age scatterplots with modeled von Bertalanffy growth curves for male, female, and combined sexes of *P. affinis* caught in Arabian Sea (2005–2009). *Note:* Y-axis does not start at zero.

Table 2.2 von Bertalanffy growth parameter estimates [L_{∞} cm, K y^{-1} and t_0 y] and confidence intervals (CI) for *P. affinis* from Arabian Sea ($n = 905$)

Sex	Parameters	Estimates	95% CI Lower	95% CI Upper
Female	L_{∞}	36.02	34.05	40.28
	K	0.268	0.214	0.299
	t_0	-0.539	-0.390	-0.946
Male	L_{∞}	36.09	35.17	42.43
	K	0.261	0.192	0.274
	t_0	-0.508	-0.256	-0.843
All	L_{∞}	36.09	35.4	40.05
	K	0.264	0.214	0.273
	t_0	-0.525	-0.409	-0.813

Table 2.3 Mean observed and expected total lengths (cm TL) of all *P. affinis* sampled from Arabian Sea

Age (y)	n	Size range (cm TL)	Mean length (cm TL) \pm SD	Modeled length (cm TL)
0	6	12–15	13.9 (1.18)	8.54
1	47	14–22	16.94 (1.76)	14.93
2	153	14.7–25.2	19.67 (2.05)	19.83
3	212	15.6–26.5	22.29 (1.95)	23.59
4	202	21–29.6	25.37(2.13)	26.49
5	197	21–33	28.42 (2.32)	28.71
6	99	24.5–35.2	30.22 (2.47)	30.42
7	31	27–39.8	33.59 (2.47)	31.72
8	13	32–36.8	34.49 (1.29)	32.73
9	2	36.2–36.5	36.35 (0.21)	33.14

Standard deviation in parentheses.

n = number of fish examined.

2.3.3. Growth modeling from whole otolith weight

A total of 513 undamaged otoliths were obtained for otolith weight (OW) analysis. Otolith weights ranged from 0.021 (g) for a 0+ year fish to 0.179 (g) for a 9+ year fish. (Table 2.7) shows sample size, the weight of otolith range and mean otolith weight (\pm SE) for every age class of fish. The age and otolith weight relationship displayed positive linear relationships in males, females, and combined sexes (Fig. 2.5 and Table 2.8). The otolith weight–age relationship was not significantly different between the sexes (ANCOVA, $F_{1, 512} = 0.098$; $P = 0.754$). The estimated ages of fish using otolith weight are shown in Table 2.9. Males and females had no significantly different growth curves (ARSS, $F_{3, 507} = 1.34$; $P = 0.261$). The phi prime was calculated as 2.54. The coefficient of determination for growth rate of males and females were 0.82 & 0.86 respectively. Figure 2.6 reveals the growth functions of the sectioned otolith and whole otolith weight. Two methods were detected when plotting whole otolith weight relationship and sectioned otolith were found to be significantly different (ARSS, $F_{3, 1456} = 55.76$; $P < 0.05$).

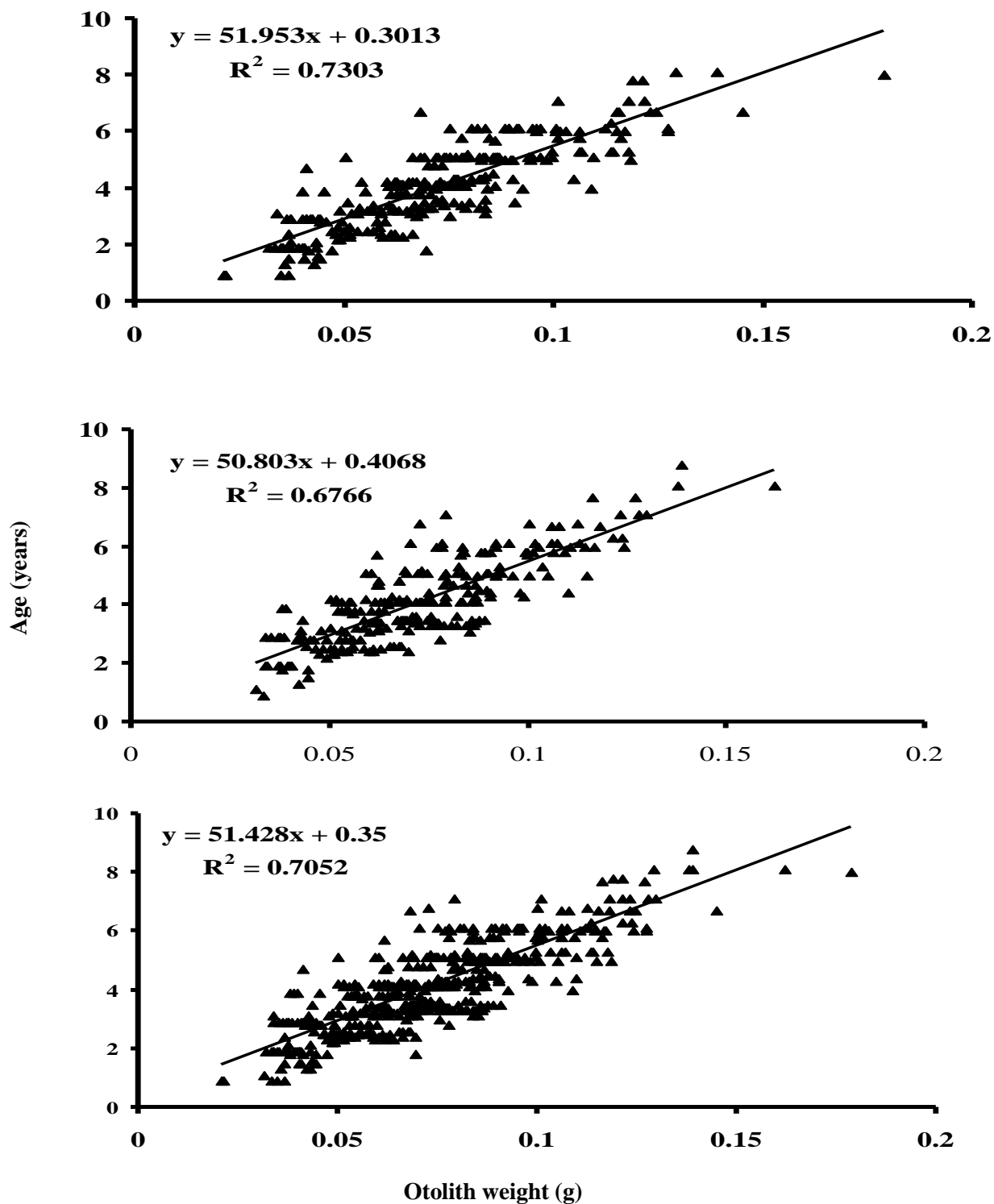


Figure 2.5 Relationship between otolith weight (g) and age (y) for (A) female, (B) male of *P. affinis* in the Arabian Sea and (C) the regression line fitted to this data is based on the equation (Age = 51.428OW + 0.35).

Table 2.7 Sample size (*N*), mean otolith weight (OW), standard error (SE) and range of otolith weight (wt) for different ages of 225 fishes collected during 2008

Observed age (y)	<i>N</i>	Mean otolith weight \pm SE (g)	Range
0	5	0.0294 \pm 0.0032	0.021–0.037
1	37	0.0396 \pm 0.0013	0.031–0.069
2	85	0.0502 \pm 0.0011	0.024–0.078
3	126	0.0645 \pm 0.0012	0.029–0.091
4	111	0.0736 \pm 0.0012	0.041–0.144
5	90	0.0882 \pm 0.0016	0.05–0.138
6	56	0.1011 \pm 0.0023	0.068–0.145
7	11	0.1166 \pm 0.0044	0.079–0.13
8	7	0.139 \pm 0.011	0.087–0.179

Table 2.8 Relationship between otolith weight (OW) and age of *P. affinis* in the Arabian Sea

Sex	<i>n</i>	Equations	<i>r</i> ²
Female	263	Age = 51.95 OW + 0.301	0.73
Male	250	Age = 50.89 OW + 0.407	0.68
Sexes combined	513	Age = 51.43 OW + 0.35	0.71

Table 2.9 von Bertalanffy growth parameters estimated from otolith weight of *P. affinis*

Sex	<i>n</i>	<i>t</i> ₀ (y ⁻¹)	<i>K</i> (y ⁻¹)	<i>L</i> _∞ (cm)
Males	250	0.004	0.250	37.03
Females	263	–0.0104	0.256	36.99
All	513	–0.0039	0.252	37.01

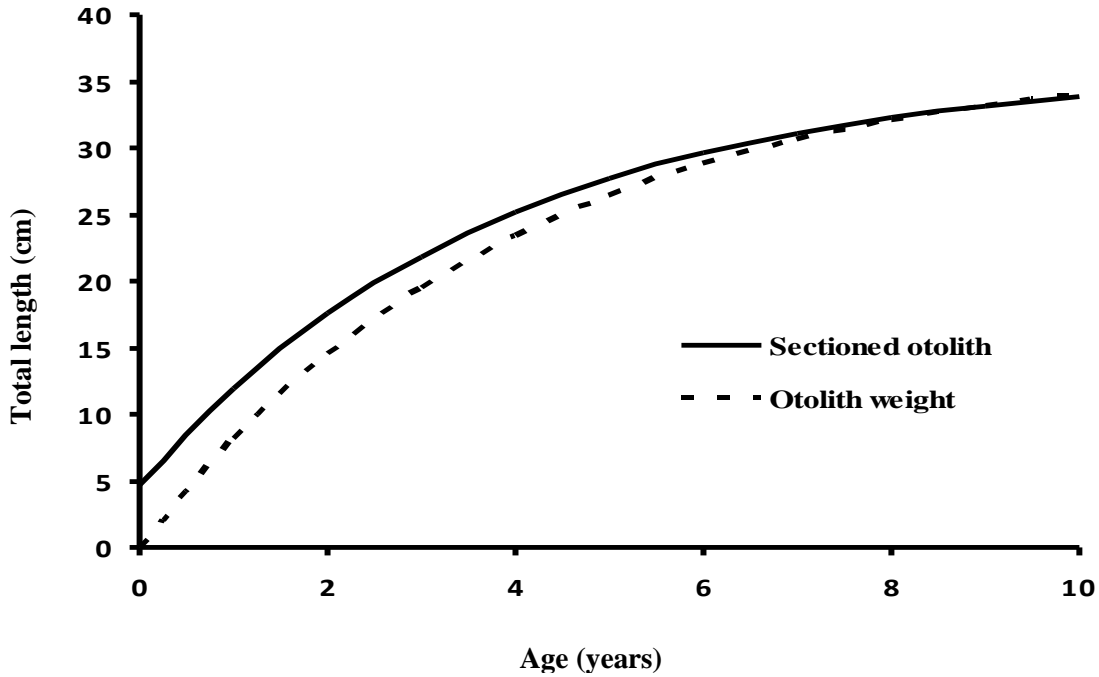


Figure 2.6 Plot of growth curves based on sectioned otolith and whole weight of otoliths of *P. affinis* in the Arabian Sea.

2.3.4. Growth modeling from length–frequency analysis

The estimated asymptotic length (L_{∞}) and growth coefficient (k) by ELEFAN-1 technique using all the fish sampled for length frequency distribution for *P. affinis* were 43 cm and 0.320 y^{-1} respectively. The growth curve with these parameters superimposed over the restructured length distribution is given in Fig. 2.7. The curves which pass through most peaks and avoiding most troughs indicate the accumulation of large number of points, called ESP(explained sum of peaks). The curves clearly indicate that at smaller size of fish, the growth was faster which comparatively as the age of fish advanced. The calculated growth performance index (ϕ) of *P. affinis* was 2.77.

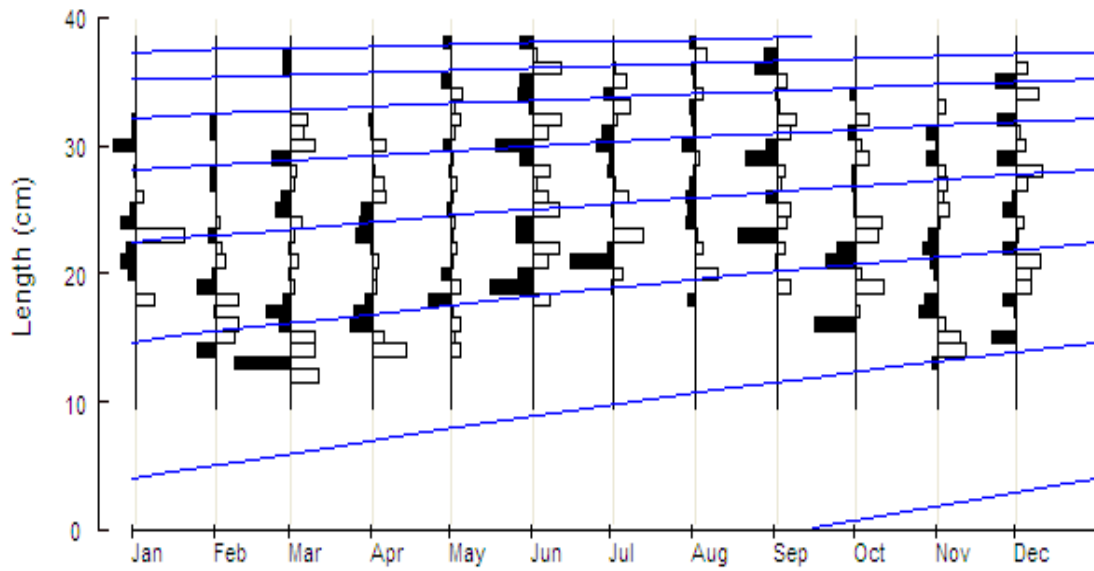


Figure 2.7 von Bertalanffy growth curves for *P. affinis* superimposed on restructure length–frequency histograms. Black and white bars = positive and negative deviations from weighted moving average of three length classes representing pseudocohorts.

2.4. Discussion

The growth zone pattern in the fish otolith can be considered as biological archives and are commonly used for age and growth calculations of fish (Campana & Neilson, 1985; Edeyer *et al.*, 2000). In the current study, the sagittal otoliths of *P. affinis* were used for the first time to estimate the age and growth characteristics. Although, in tropical fishes, especially around the equator the formation of periodic increments in otoliths is not consistent (Sparre & Venema, 1998), the otoliths of *P. affinis* showed the same growth zones pattern commonly seen in teleost fishes (Williams & Bedford, 1974). Each year one opaque and one translucent zone are formed and the distance between the translucent and the opaque zones became smaller with increasing in age. Despite, the growth zones were stacked in the direction of the otolith's margin in older individuals of certain sparids, (Buxton & Clarke, 1991, 1992; Pajuelo *et al.*, 2003), I could successfully validate the age of *P. affinis* from growths rings in the otolith. The results of the present study would contribute to the expanding knowledge of otolith based age determination in tropical fishes. However, MIA is viewed as a difficult method to accurately validate the age due to the technical difficulties in viewing the otoliths variable light refraction, as well as by light reflection due to curvature at the margin of otolith (Campana, 2001).

The assignment of a “birthday” and “increment formation date” is needed for standardizing the age determination of fish in years and months (Anderson *et al.*, 1992). The time of annulus formation was demonstrated in this study by marginal increment analysis MIA. The lower monthly mean of MIA was recorded in September and increased throughout the year indicating that the annulus was laid for one time in the year. The deposition of one opaque and one translucent zone in a year has been reported in certain South African sparids (Smale & Punt, 1991; Buxton, 1992; Van der Walt &

Beckly, 1997; Mann, 2000; Chale-Matsau *et al.*, 2001) and in the Canarian Archipelago sparids (Pajuelo & Lorenzo, 1996, 1998, 1999, 2000, 2001).

However, an understanding of the factors affecting annuli formation on fish otoliths is required before using increment number and rings width to assess growth rate (Neilson & Green, 1982). In the Arabian Sea, the average seawater temperature in the fishing ground decreases from 26°C in April to 21°C in September (this study) which triggers translucent zone formation and the completion of the annual ring cycle. The change in Arabian Sea water temperature occurs annually during the SW monsoon season (June–September) and is associated with upwelling that brings high levels of nutrients and food to the area which is reflected in growth of the opaque zone over the following months. The associated decrease in seawater temperature and monsoon season in the Western Indian Ocean and Arabian Sea are the two factors which markedly affect the spawning cycles of this species. The same results were reported in many studies (Panella, 1980; Pajuelo & Lorenzo, 1999; Sun *et al.*, 2002; Grandcourt *et al.*, 2004). Though the timing of annulus formation is associated with spawning season of *P. affinis* in the Arabian Sea, the deposition of annulus could also coincided with environmental changes such as changes in water temperature.

The aging precision estimate of 2.98% obtained in this study agrees well with the value (APE 2.4%) found for *Diplodus puntazzo* (Domínguez-Seoane *et al.*, 2006). Hence, the sectioned otoliths can be reliably used to age *P. affinis* as there are comparatively well demarcated zonations. It also confirms the relative ease in counting annuli in sectioned otoliths (Brouder, 2005). Also, the present value of APE is acceptable as Shepherd (1988) suggested that 10% of error in age would largely affect stock assessment. The longevity from sectioned otoliths of *P. affinis* was nearly the same as that calculated from Alagaraja (1984) equation (9.43 years) for both sexes.

Fish age was determined also from the otolith weight (OW). It is apparent that the otolith weight and fish length relationship could provide a key-age structure of the population. Although, the VBG curves derived from these data were significantly different from the actual growth models ($P < 0.05$), indicating this to be an undependable method to use in fish growth modeling. Generally, age determination based on otolith weight overestimates the lower age and underestimates the higher age groups of fish (Lou *et al.*, 2007). Hence, this technique has to be improved before considering as a dependable method. However, weight of the otolith to the age the fish would be cheaper and quicker technique than studying otolith sections. The fit of this model showed that otolith weight or length increased with time (Worthington *et al.*, 1995). Cardinale *et al.* (2000) found that otolith weight could be a valuable tool for estimating fish age as the regression analyses between otolith weight and age indicated the predicted ages were unbiased. In the current study, though a significant relationship existed between otolith weight and fish age for both sexes, widespread data points scattered around the fitted linear regression line with overlapping of age groups having similar otolith weights. Such a trend will lead to error onerous prediction of fish age (Cardinale *et al.*, 2000). Araya *et al.* (2001) correlated the relation between the otolith weight and the age of jack mackerel (*Trachurus symmetricus morphyi*) and found that this relationship may be used for estimating the age structure of the species. The significant relationships between weight of the otolith and age shown in the current study allowed the age of a fish of known length to be determined and a VBG line fitted to the length–age data to model the fish growth in the two sexes.

In this study we recorded faster growth rate than *A. berda* in South Africa (James *et al.*, 2003); *A. spinifer* in Southern Arabian Gulf (Grandcourt *et al.*, 2004). Different growth rates in certain sparids were apparent between the sexes (Sarre &

Potter, 2000; Potts & Manooch, 2002). This may be due to the differential energy partitioning in females and males for reproduction and growth (Dwyer *et al.*, 2003). Though there was no significant difference between growth rates in males and females in *P. affinis*. In the present study the estimation of growth parameters indicates that no considerable differences in the growth characteristics between sexes for *P. affinis* as stated by Grandcourt *et al.* (2004) for *A. bifasciatus* and *A. spinifer*. Some fishes demonstrate similar bioenergy needs in male and females in their life, such as benthopelagic fish, roudi escolar *Promethichthys Prometheus* (Gempylidae), off the Canary Islands (Lorenzo & Pajuelo, 1999). This could be attributed to different environmental factors, for instance hydrographic nature which is essential for its characteristics (Jardas, 1996). However, similar pattern of growth rate for both female and male may be owing to same evolutionary forces or limits that could act on the life stages of the fish. Many factors affect growth and prey availability may negatively enhance energy requirement for movement. The overall determination of factors influencing age, growth and mortality in the fish population would be difficult (Peters & Parham 2008).

The estimate of growth performance index (ϕ) provides the basis for comparing the growth of fish in terms of length (Grandcourt *et al.*, 2005) and to evaluate the reliability of growth parameters (Raja Prasad *et al.*, 2005). The comparison of growth curves using ϕ , showed close agreement with VBG parameters estimated from observed otolith age ($\phi = 2.535$), modeled age from otolith weight ($\phi = 2.54$), and length–frequency analysis ($\phi = 2.77$). The above suggests that the estimated growth pattern of *P. affinis* is reliable and support the use of otolith as a dependable tool to estimate age. The growth parameters are the basic inputs to the analytical models used for stock assessment and fisheries management. In this study, the growth parameters of *P. affinis*

have been estimated for the first time. The VBG curves generated from the length–age relationships obtained from both direct measurement of age from the otoliths and indirectly from relationship between otolith weight and length were almost closer. The information obtained on age and growth in this study will form as input data for analytical fisheries models to develop appropriate management strategies for exploitation of this species. Also, as weight of the otolith is indicative of age of fish, random sampling and weighing of *P. affinis* otoliths could be used to assess the age structure of the population. Fisheries managers require fish age data for routine fish stock assessment. Results of this study would be useful to managers since the otolith weight can be used to determine the age of this species, similar to annuli reading in sectioned otolith. The growth parameters of *P. affinis* established in the present study will be useful in stock assessment investigation to develop appropriate strategies for sustainable harvest of the species in the Omani waters.

3. Reproductive biology

3.1. Introduction

Reproduction is an important aspect of the biology among fishes, as recruitment and to stock abundance depends on its success. Among fishes the success of reproduction relies on the sources allocated for reproduction and the time and ground for reproduction (Healey *et al.*, 2003; Crossin *et al.*, 2004). To evaluate the reproductive potential of fish stocks, knowledge of pattern of reproduction and associated mechanisms is essential (Lambert *et al.*, 2003). The reproductive strategy of an organism is influenced by the size and age at 50% maturity, spawning periodicity and fecundity (Stearns, 1992), and the population characteristics such as spawner biomass, sex-ratio, egg viability and hatching success (Lambert *et al.*, 2003). Many of these characteristics display considerable spatial and temporal variability due to different populations exposed to different environmental and biological conditions (Stearns, 1992; Rundle & Jackson, 1996). Furthermore, the environmental factors greatly influence a stock's ability to recruit into the adult population (Fowler *et al.*, 2000). Ideally, any study should focus on these characteristics and include a fisheries management plan to obtain the sustainable yield of fish species (Yoneda *et al.*, 2002).

Teleosts display a variety of reproductive strategies in relation to seasonality of spawning. Fish can be defined as either single spawners where all oocytes develop synchronously and are released at once or multiple spawners where a number of oocyte batches at different times during the spawning season (Wallace *et al.* 1987; Pankhurst, 1998). Many marine fish species display a discrete seasonal peak in reproductive activity and spawn several times over this season (Gordon & Bills, 1999). A variety of abiotic and biotic factors including water temperature, day length, lunar cycle and food availability play a role in regulating reproductive activity (Nakai *et al.*, 1990; Gordon &

Bills, 1999; Neat & Balshine-Earn, 1999; Duponchelle *et al.*, 2000). Many tropical and subtropical fish species typically have long spawning seasons; whereas, temperate species usually have short and clearly defined reproductive periods (Conover, 1992). Besides the geographical impact, inter-annual variations in environmental conditions also influence the initiation and speed of gonad development for subsequent spawning (Scott & Pankhurst, 1992).

Size or age at 50% maturity is commonly evaluated for wild population as a key biological reference point for management decisions of harvest (Roa *et al.*, 1999). Any shift in sexual maturity would significantly influence the composition and subsequent reproductive output of the spawning stock (Marteinsdottir & Thorarinsson, 1998). Also, any reduction in size of maturity has been related to compensatory response in production of total egg of species (Marteinsdottir & Begg, 2002). In some fish species, average size and age at maturity varied between populations and/or between individuals (Godø & Haug, 1999; Takahashi, 2008) and such variability could be due to variations in population density (Chuwen *et al.*, 2011), inheritability traits (Dieckmann & Heino, 2007), pressure of predation (Abrams & Rowe, 1996) and availability of food (Haug *et al.*, 1989; Godø & Haug, 1999).

The process of maturation can greatly influence longevity and growth rates in fishes. For example, growth is typically fast in juvenile fish, but once maturity is reached, growth rate is reduced. The mechanics of this influence is the change in energy allocation into the somatic growth and differentiation of germinal tissues in the gonads to produce high-quality gametes (Thorpe, 2007). As a consequence of abundance of food and changes in seasonal environmental factors, there is elasticity in the allocation of energy for reproduction and somatic growth of fishes (Siems & Sikes, 1998). During non-reproductive periods, surplus energy is directed to somatic tissues such as muscles

and liver. As liver is the key organ responsible for production of yolk protein vitellogenin (Barbieri-Lowerre *et al.*, 1996; Plaza *et al.*, 2007), determination of the hepato-somatic index (HSI; a liver–body weight index) has been used as a measure of fish condition during reproductive and non-reproductive periods (Lambert & Dutil, 1997). The amount of stored energy or somatic state of fish can significantly influence the process of gonad development. In fish, an increase in reproductive investment will result in decrease of somatic growth (Heino & Kaitala, 1999), as maturing fish allocate energy to produce and storage lipids in the liver and the subsequent uptake of these lipids into gonadal tissues (Hansen *et al.*, 2001). HSI indicates that during the spawning period the fish tends to feed less in relation to other months (Lampert *et al.*, 2004). During non-reproductive periods of fish, the intense feeding could be the strategy to store energy for reproduction (Barbieri-Lowerre *et al.*, 1996), where these reserves would be used on vitellogenesis (Abdel-Aziz & El-Nady, 1993). The total energy contained in liver of mature female Northeast Arctic cod, was proportional to egg production (Marshall *et al.*, 2000); however it may vary with condition and age–size of fish (Marteinsdottir & Begg, 2002). Conversely, in the Atlantic cod variations in liver sizes could not be related to development of gonadal stages (Dahle *et al.*, 2003).

Estimation of the amount of eggs produced by a female in a season is difficult as the number of eggs produced is related to spawning frequency and batch fecundity (DeVlaming, 1983). The number of mature oocytes within the ovary, represent fecundity (Melville-Smith, 1989; Ingles & Braum, 1989) and are liberated during spawning. Some fish species release multiple batches of eggs during a spawning season (Bani & Moltschaniwskyj, 2008). Multiple-spawning fishes with group-synchronous ovaries display discrete multi-modal oocyte size–frequency distributions with distinctive gaps between different stages of oocytes before spawning (Plaza *et al.*,

2007) and existence of such gaps help to determine fecundity, that is all the eggs in advanced stage produced during the spawning season (Kjesbu *et al.*, 1996; Hesp *et al.*, 2004). However, certain species release eggs in batches several times during the spawning period at distinct intervals (Stéquert *et al.*, 2003) through asynchronous oocyte development. Hence, fecundity may fluctuate among individual spawners in a given year and between years (Kjesbu *et al.*, 1996; Manning & Crim, 1998; Rickman *et al.*, 2000).

In many fish stock assessment models, annual fecundity estimates are used as reproductive output (Nichol & Acuna, 2001). In the fish population, the recruitment depends on the quality, number, and size of eggs released during the spawning season (Rickman *et al.*, 2000).

Knowledge of maturation and spawning of exploited stocks is essential to protect spawning stocks (Noble & Jones, 1993; Koslow *et al.*, 1995; Mackie & Lewis, 2001; Yoneda *et al.*, 2002). Despite the importance of those aspects for *P. affinis* fisheries management in Omani waters, there is no studies were done before. The only previous study on the reproductive biology of *P. affinis* from Oman focused on the component of the population caught by the Oman-based industrial trawl fishery for one year from deeper waters (McIlwain *et al.*, 2006). However, several aspects of reproduction including fecundity still remain unknown. The present study was carried out to address the knowledge gap on the seasonal patterns of reproductive biology of *P. affinis* landed by artisanal fishing sector from coastal waters and from trawl sector from deeper waters in the Arabian Sea, where seasonal upwelling takes place. The objectives of the study were to (i) determine the spawning period based on the occurrence of mature/spent gonads; (ii) study the seasonal changes in the HSI, GSI, and relative condition factor (K_n); (iii) estimate size/age at 50 % maturity; (iv) describe

the distribution of ova in different maturity stages of ovary; (v) calibrate the macroscopic maturation scale for this species through histological investigation; (vi) quantify the fecundity of females; and (vii) to estimate spawning frequency based on histological investigations. The above information would help to plan for rational exploitation of *P. affinis* stock from the Arabian Sea coast of Oman.

3.2. Materials and methods

3.2.1. Sample collection and analyses

Fish were sampled monthly from April 2005 to March 2007 from artisanal fishing gears operated in the Arabian Sea from Lakbi and Raysut (see Chapter 1 for details). Additional samples were obtained from artisanal gears and trawlers during April 2008–March 2009 for histological studies. Immediately after collection, fish were stored in cool box with ice and took to the laboratory for analyses within 4 hours. During dissection of each fish, the total length (TL; ± 1 cm), total weight (TW; ± 1 g), sex, macroscopic gonad condition, gonad weight (GW; ± 0.01 g) and liver weight (LW ± 0.01 g) were recorded. A six-stage gonadal maturity key (Table 3.1) modified from Ntiba & Jaccarini (1990) was adopted for macroscopic staging of fish. Five ovaries from each stage except stage VI were preserved in 5% neutral formalin for ova size–frequency distributions. For the estimation of fecundity, 25 ovaries in Stage IV were used from fish ranging from 21.5 to 34 cm TL selected during the peak of spawning. Average monthly sea surface temperature (SST), salinity and dissolved oxygen for 2008 in the Arabian Sea were obtained from the Ecology Section at the Marine Science and Fisheries Centre (MSFC).

Table 3.1 Macroscopic maturity stages of male and female *P. affinis* in the Arabian Sea (Ntiba & Jaccarini, 1990) and microscopic classification of female modified from Scott & Pankhurst (1992)

Stages of maturity	Testes	Ovary	
	External features	External feature	Histological features
I Immature	Small, transparent, pale, occupying a very small portion up to 1/3 of body cavity length	Small, transparent, pale in color, occupying a very small portion to 1/3 of body cavity, ova invisible to naked eye	Previtellogenic oocytes (Fig. 3.12A)
II Maturing 1 /resting Previtellogenic	Whitish, translucent, occupying about 1/2 of body cavity	Pale yellow, granular ova visible to naked eye, occupying about 1/2 of body cavity	Cortical alveoli stage oocytes appear (Fig. 3.12B)
III Maturing 2 /vitellogenic	Creamy white, occupying about 3/4 of the body cavity	Pale yellowish, blood vessels visible on dorsal side, ova clearly visible, occupying about 3/4 of the body cavity	Oocytes in exogenous vitellogenesis (Fig. 3.12C)
IV Mature /hydrated	Creamy white, soft, occupying about full length of body cavity	Pinkish yellow, blood vessels prominent, large ova prominently visible, occupying about full length of body cavity	Final oocyte maturation and hydration (Fig. 3.12D)
V Ripe/Running /ovulated	White, occupying entire length of the body cavity, exudes milt on slight pressure	Yellowish, occupying entire length of the body cavity, slight pressure extrudes eggs	Hydrated oocytes in the oviduct and postovulatory follicles present (Fig. 3.12E)
VI Spent	Flabby, little reddish, occupying about 1/2 of body cavity	Flaccid, reddish, occupying about 1/2 of body cavity	Atretic vitellogenic oocytes but predominantly vitellogenic

3.2.2. Biological data

The monthly gonado-somatic index (GSI) was calculated for females and males separately using the formula given by June (1953) and Yuen (1955):

$$GSI = \frac{GW}{TW} \times 100$$

where GW is the gonad weight (g) and TW the total body weight (g).

The hepato-somatic index (HSI) was calculated for each month sex-wise as follows:

$$HSI = \frac{LW}{TW} \times 100$$

where LW is the liver weight (g) and TW the total body weight (g).

The relative condition (K_n) was estimated as

$$K_n = \frac{TW}{aL^b} \times 100$$

where TW is the total body weight, a and b the allometric coefficients of length–weight relationship estimated separately for each sex by nonlinear regression (parameter data were obtained from Chapter 5) and TL the total length.

The determination of ova maturation was established through the analysis of five ovaries each preserved in 5% neutral formalin from stages I to V. From each ovary, approximately 200 ova were measured using an ocular micrometer fitted in the eye piece of a dissecting microscope following the method of Clark (1934). A random sample of oocytes was made by taking small pieces from posterior and middle of the ovary and mixed well and placed on a clean slide. Ocular micrometer division was calibrated and each micrometer division was equal to 0.016 mm. Diameters of the ova were measured and

recorded. Frequencies of the ova diameters were compared for different ovarian stages (Vazzoler, 1996).

Length-at- maturity (L_{50}) was defined as the TL at which 50% of fish were mature. A logistic function was fitted to the proportion of mature fish per 1-cm length interval using non-linear least-squares regression (King, 1995) for both sexes separately. For predictions from a logistic model, to attain nominal coverage rates, bootstrapping has been used to evaluate coverage rates and recalibrate the endpoints of confidence intervals. The logistic equation was

$$P = \frac{1}{1 + \exp(-r(L - L_{50\%}))}$$

where P is the proportion of mature fish in length class L , r the width of the maturity curve and L_{50} the length at 50% maturity. Age at 50% maturity (t_{50}) was calculated using the estimated length at 50% maturity and the von Bertalanffy growth parameters rearranged to the form:

$$t_{50} = t_0 + 1/k \left[\ln \frac{L_{\infty}}{L_{\infty} - L_{50}} \right]$$

3.2.3. Fecundity

Fecundity was estimated gravimetrically from mature ovaries collected during the spawning from sample of mature females. From the ovaries preserved in 5% neutral formalin for few days, two to three sub-samples from each ovarian lobe were taken and weighed (± 0.005 g). The sub-samples of ovaries were preserved in modified Gilson's fluid of Simpson (1951) for 2 weeks for easier separation of eggs. Each sub-sample was distributed evenly over a cell counting chamber divided into 100 squares, each square

measuring 5 mm × 5 mm. The numbers of mature ova in 20 randomly chosen squares were counted using a binocular microscope and were recorded. The absolute fecundity and relative fecundity were calculated using the following formulae:

$$F = \frac{C}{SW} \times GW$$

where F is the absolute fecundity, C the number of mature eggs in the sub-sample, SW the weight of the sub-sample and GW the weight of the ovary.

$$RF = \frac{F}{TW} \times 1000$$

where RF is the relative fecundity (per kg total body weight), F the absolute fecundity, and TW the total weight of the fish (g).

3.2.4. Histological assessment of gonad maturation

A histological examination of the ovaries was conducted to validate macroscopic stages and to determine the maturation of the eggs. The description of gametogenesis was with reference to Scott & Pankhurst (1992) (Table 3.1). The ovaries of fish used for histological analysis were dissected out, weighed (± 0.001 g), and fixed in FAAC (formalin acetic-acid calcium-chloride) fixative. As no significant differences in maturation and oocyte–frequency distributions between right and left ovaries are usually found (LaRoche & Richardson, 1980; DeMartini & Fountain, 1981; West, 1990), the left ovary was used for all histological analysis. The ovary from the middle portion was sectioned to minimize probable variation in the developmental stage of oocytes due to their position in the ovary (Forberg, 1982; Gooley *et al.*, 1995). The middle portion of the

ovary was dehydrated in alcohol series, cleared in toluene, and infiltrated with and embedded in paraffin wax. Sections (5 μm) were cut and stained with hematoxylin and counterstained with eosin. For each maturity stage of ovary, the diameters (μm) of 103–146 oocytes were measured using light microscope at 10 \times magnification.

From mature females sampled from July to November in 2008 spawning frequency was determined. The fraction of daily spawning for females was estimated by the occurrence of postovulatory follicles (POFs) within ovaries (Hunter *et al.*, 1986). The spawning frequency was the inverse of the average percentage of spawning females, and the average percentage of spawning females was calculated as the total quantity of mature and reproductively active females in the spawning season (McPherson, 1991).

3.2.5. Data analysis

One-way ANOVA, followed by Tukey's post-hoc tests were used, to find out the differences among the mean GSI, HSI, and relative condition factor (K_n) as a function of month. To look at the changes in the individual's frequency in each maturity stage for males and female during different months, χ^2 test of independence was used. Following significant χ^2 analysis, standardized residuals were used to determine whether observed frequencies were different from expected frequencies under the assumption that the number of individuals in each maturity stage was independent of month. χ^2 tests of homogeneity were used to describe whether sex ratios differed significantly from unity across the whole sample. Since the size at 50% maturity is defined as the median (L_{50}) of the size distribution of maturing fish, median tests (Zar, 1984) were used to relate length at 50% maturity between the sexes. To find out relationships between fecundity and ovary weight, fish weight, fish length and relative fecundity linear regression analysis with log–

log-transformed data were used. SPSS version 16 was used for all statistical analysis and a significance level (α) of 0.05 was applied in all tests.

3.3. Results

3.3.1. Sea surface temperature and salinity

The mean maximum SST for the available three years data was found in November (Fig. 3.1). SST was declining markedly from their maxima (April–May) to their minima (June–September). The mean monthly salinities showed seasonal patterns throughout the year; however, in September no data were available. The minimum salinity of 34⁰/₀₀ was found in July and October (Fig. 3.2). Figure 3.2 shows also the pattern of dissolved oxygen which increased from April to June, dropped in July and climbed up again from August to October.

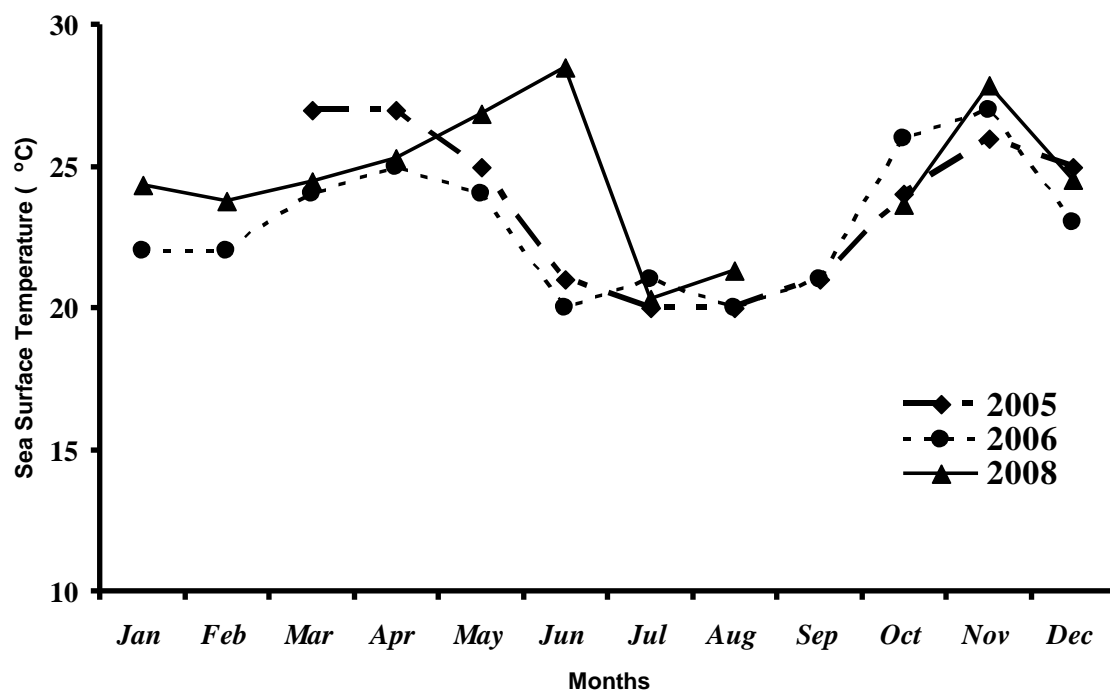


Figure 3.1 Monthly sea surface temperatures (SST) during 2005, 2006, and 2008 in Arabian Sea.

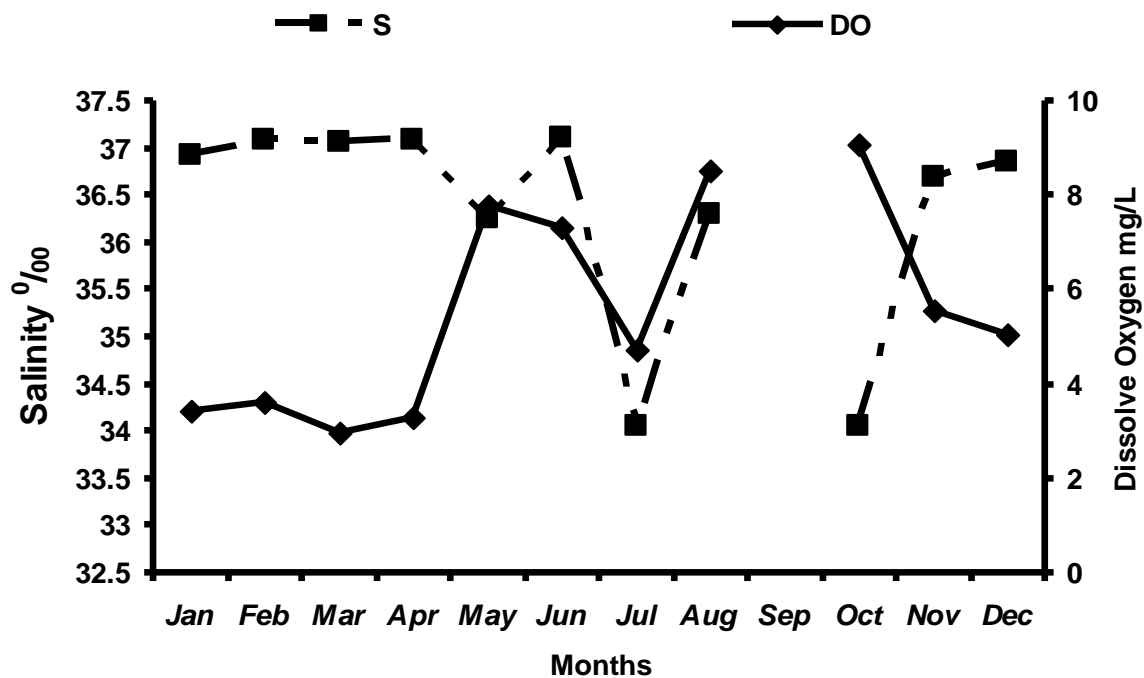


Figure 3.2 Monthly salinity (S) and dissolved oxygen (DO) in 2008 in Arabian Sea.

3.3.2. Gonado-somatic index, hepato-somatic index & relative condition factor (K_n)

The GSI values in female and male were significantly different among the months (females $F = 35.23$, $df = 28, 673$, $P < 0.001$; males $F = 69.72$, $df = 28, 639$, $P < 0.000$). The mean monthly GSI in females and males followed identical patterns in all the 3 years. The mean GSI increased sharply from April to reach peak values in September and rapidly falling to minimum values by November (Fig. 3.3). In general, smaller GSI was recorded during November when SSTs were high (27°C) and at lower monthly temperature, the mean GSI values were greater for female and male.

The monthly HSI values for females and males showed significant differences among months (females $F = 20.341$, $df = 28, 656$, $P < 0.001$; males $F = 9.548$, $df = 28, 603$, $P < 0.001$) during the study period. While the HSI values of females showed a similar trend to that of female GSI profile with high values in September and low values in May and November, an irregular trend was noticed in males (Fig. 3.4). The decline in HSI values in females was associated with the appearance of ovaries in stages immature and regressed during November and the increase in HSI in December was due to the females with stage III ovaries. Higher values of HSI for females coincided with the peaks of GSI during reproductive period (April–October) (Fig. 3.4). While, there was significant correlation for the HSI values of females in the 3-year study period ($r^2 = 0.742$, $df = 1, 27$, $P < 0.0004$), the values of males were not consistent across and there was no correlation in the 3-year study period ($r^2 = 0.137$, $df = 1, 27$, $P > 0.479$).

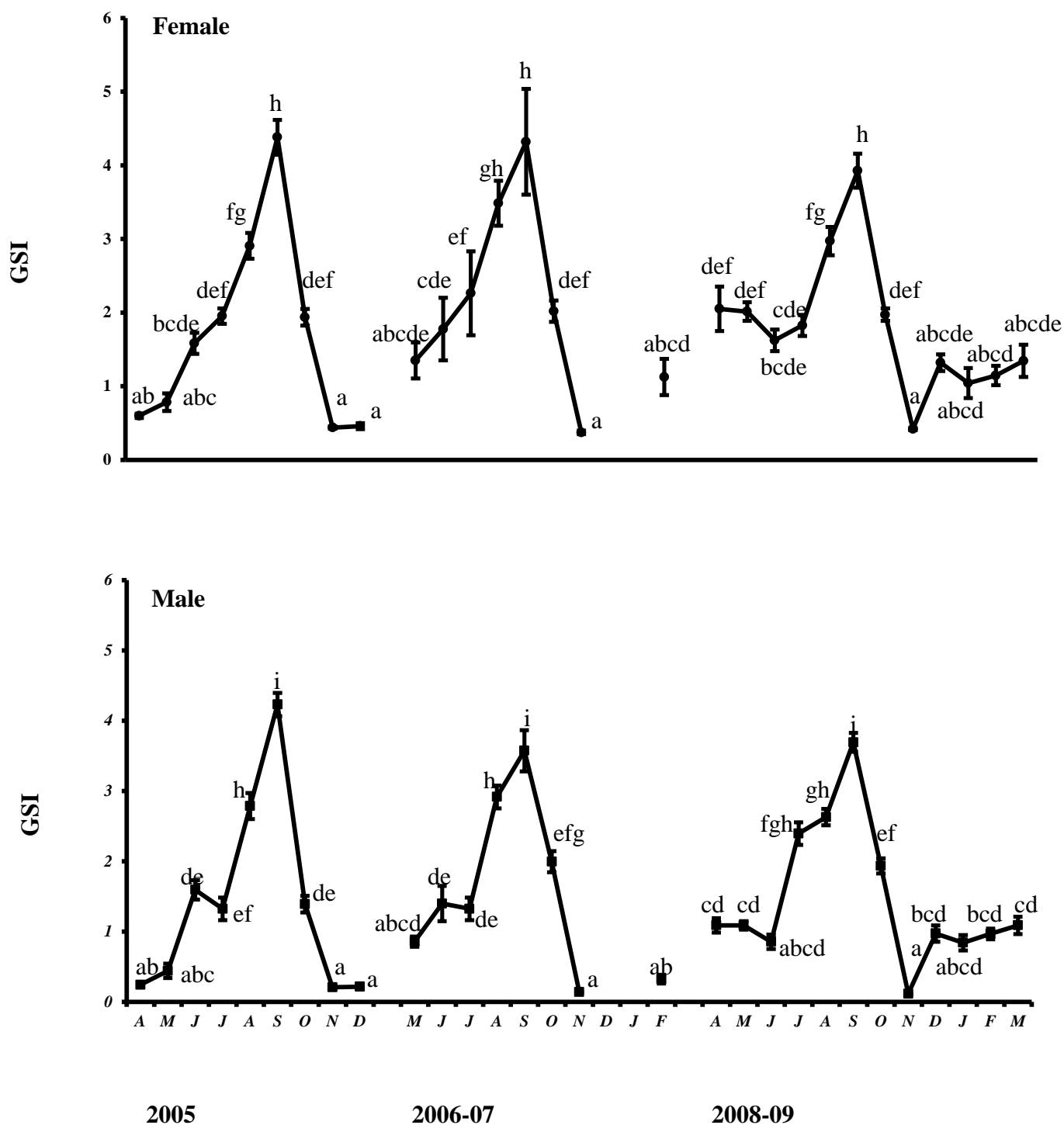


Figure 3.3 Monthly gonado-somatic indices (GSI) of females and males of *P. affinis*. Error bars represent the standard error of the mean. Means with different letters are significantly different from one another. Sample size of females and males ranged from 9 to 48 and 5 to 45 respectively.

Although significant differences in K_n values between months (females $F = 4.22$, $df = 1, 28$, $P < 0.001$; males $F = 14.606$, $df = 1, 28$, $P < 0.001$) were detected, average K_n values displayed an irregular pattern over the 3-year period (Fig. 3.5). The monthly K_n did not coincide with peaks of GSI or HSI values in both females and males; whereas, the K_n values were higher for males in 2005 and 2006, decreased to a lowest value of 0.89 in November in same year. This pattern was not same in 2008. This shows that the changes in K_n values were not influenced by the gonadal maturity. It could be due to the changes in feeding intensity of the fish or other unknown factors (Jayabalan *et al.*, 2011).

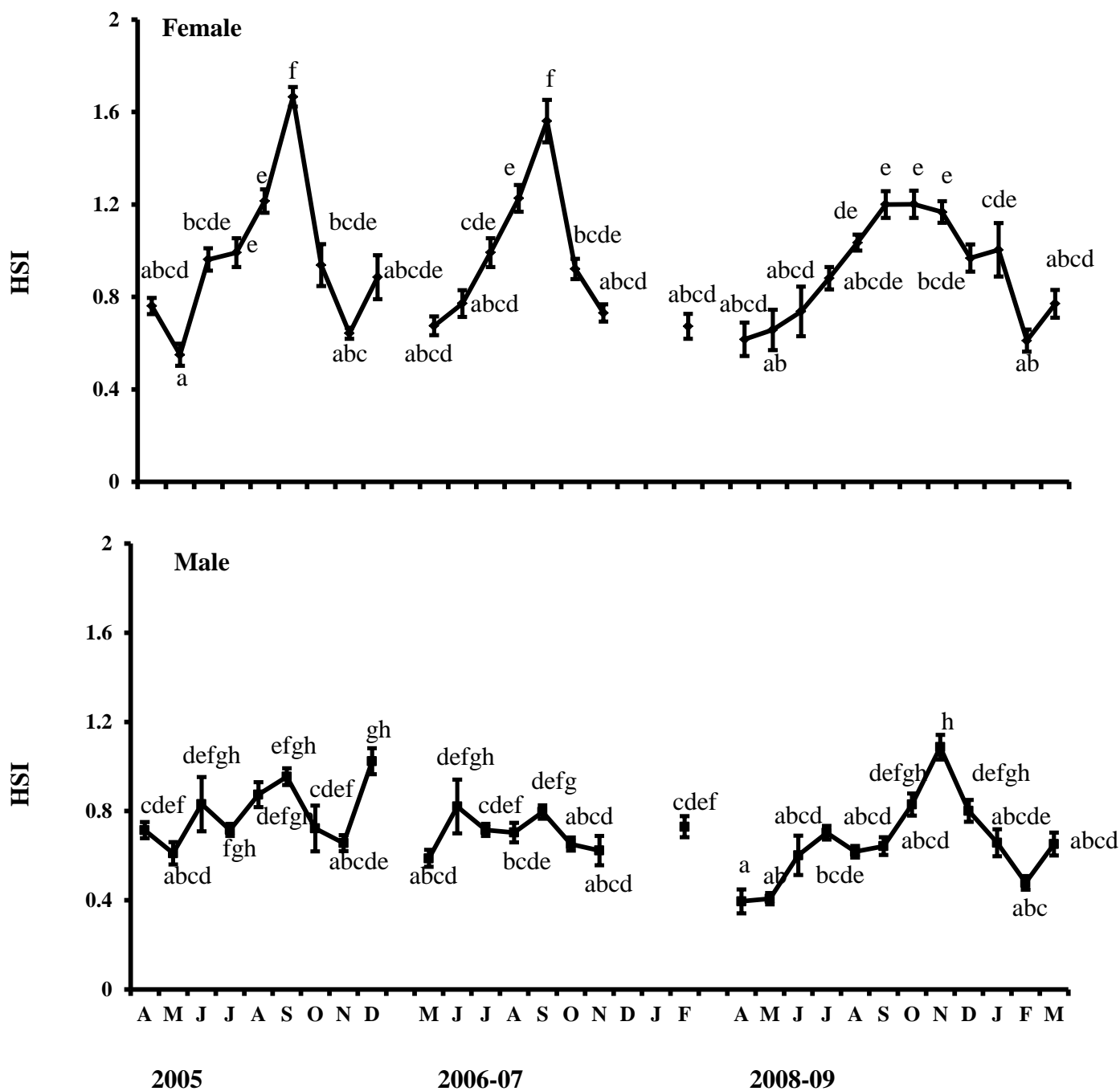


Figure 3.4 Monthly hepato-somatic index (HSI) estimated for females and males of *P. affinis*. Error bars represent the standard error of the mean. Means with different letters are significantly different from one another. Sample size of females and males ranged from 7 to 48 and 5 to 37, respectively.

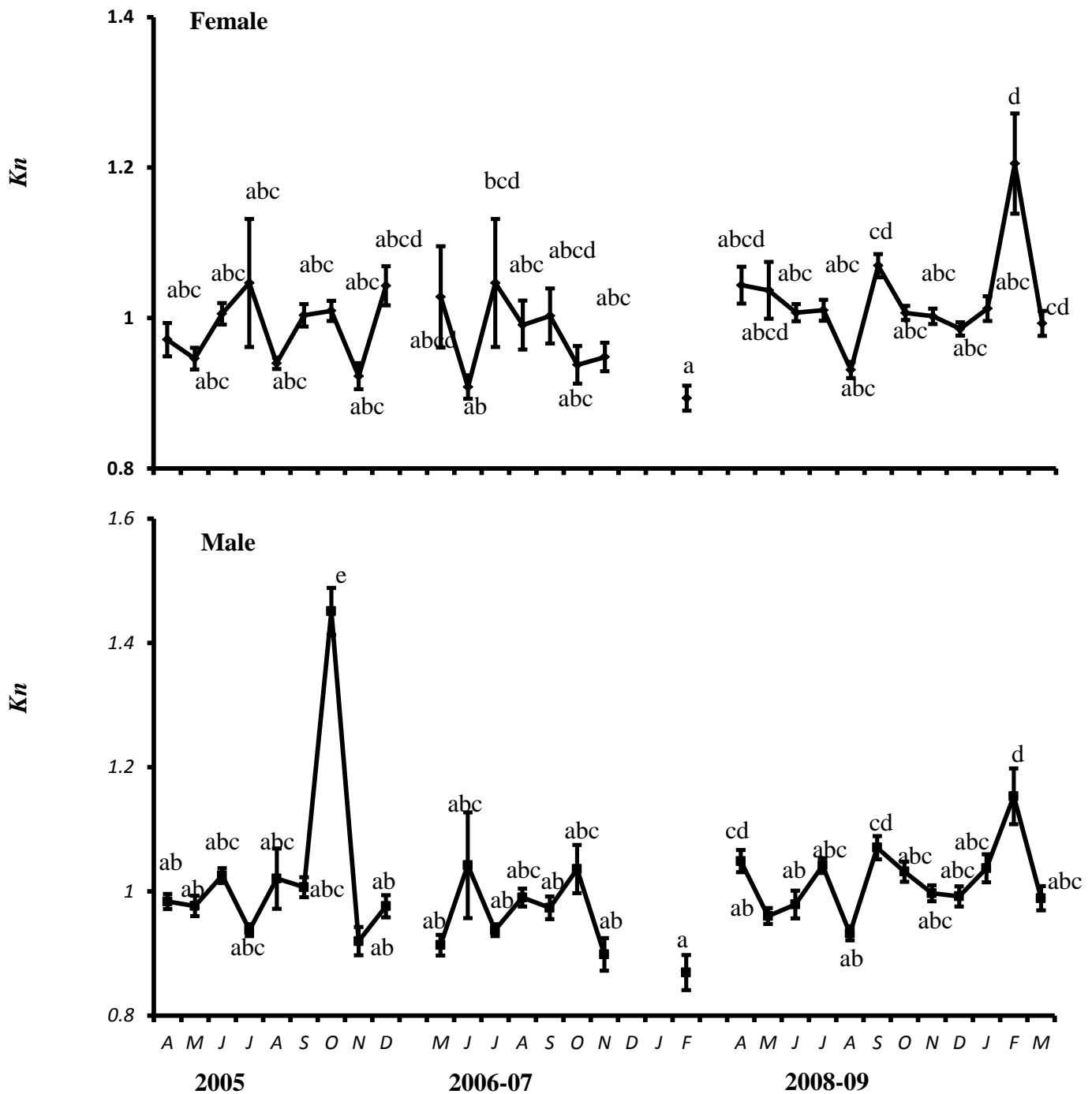


Figure 3.5 Monthly relative condition index (K_n) for females and males of *P. affinis*. Error bars represent the standard error of the mean. Means with different letters are significantly different from one another. Sample size of females and males ranged from 7 to 48 and 5 to 46, respectively.

3.3.3. Spawning pattern from macroscopic studies

The maturity stage frequency of occurrence of male and female was dependent on months (males $\chi^2 = 394.83$, $df = 33$, $P < 0.05$; females $\chi^2 = 359.43$, $df = 33$, $P < 0.05$). Fish with advanced stages of gonad development were observed between April and October with a greater proportion of running/ripe gonads occurring in July and September (Figs. 3.6 and 3.7). The pooled maturity stage frequency distributions in female during different months showed an occurrence of stage vitellogenic and hydrated individuals; however, stage-ovulated individuals occurred in greater frequencies between June and September (Fig. 3.6). Stage-regressed females were very frequent in November. There was a greater frequency of stage V males between July and October (Fig. 3.7). In contrast, the frequencies of stage V individuals in both sexes were less than expected in the remaining months. The frequency of male and female stage II individuals was significantly more and less than expected, respectively. Frequency of males in stage IV was greater and smaller than expected in August–September and February–March, respectively. However, females in stage III were found at a lower frequency than expected during the peak of spawning months. Therefore, occurrence of mature, ripe/running and spent gonads indicates that *P. affinis* may spawn for about 7 months between April and October in Omani waters. The overall sex-ratio male to female of *P. affinis* was 1:1.04, which was not significantly different from 1:1 ($\chi^2 = 0.58$, $df = 1$, $P > 0.05$).

(29) (60) (67) (89)(90)(78)(95)(90) (42)(13)(27)(13)

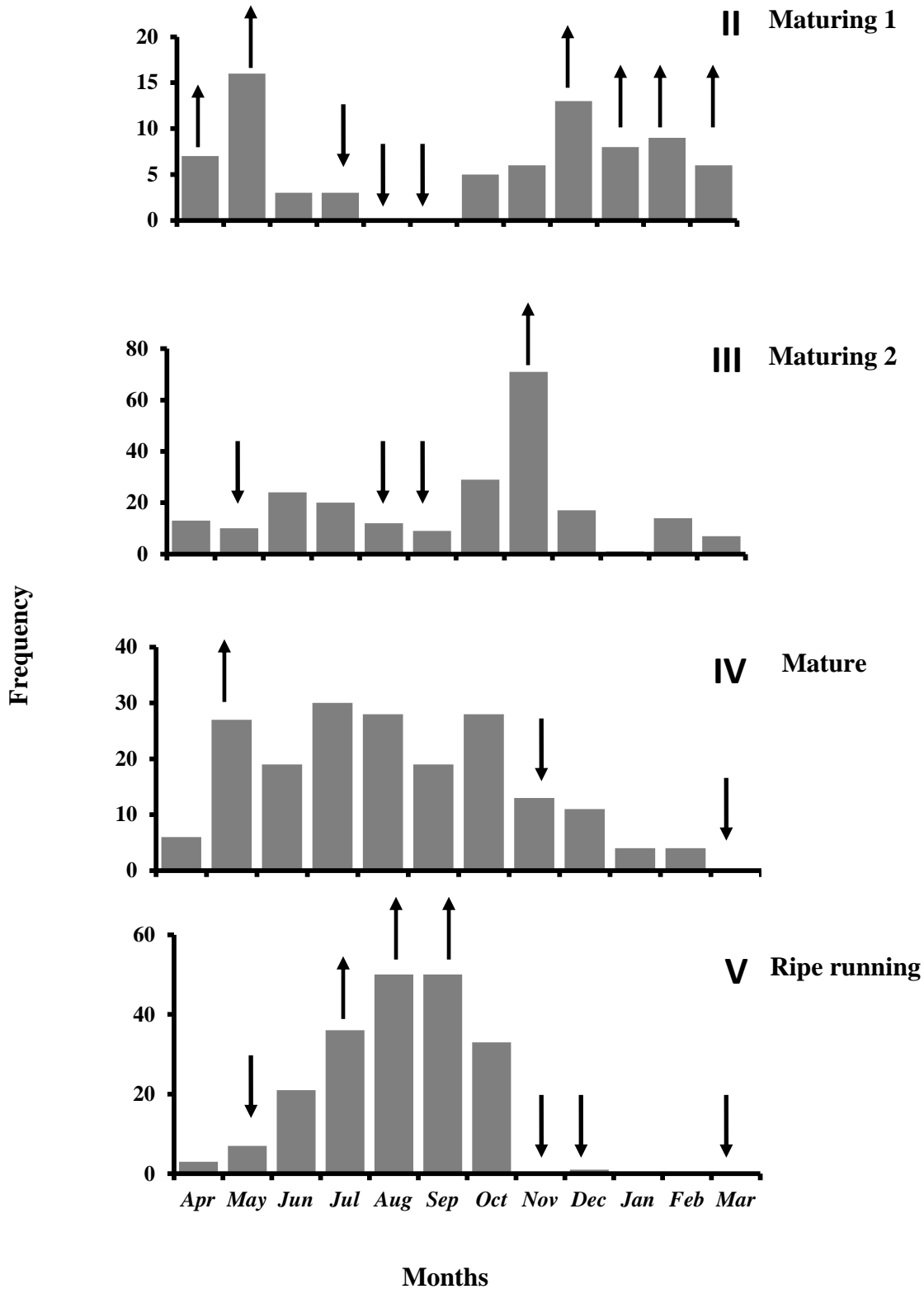


Figure 3.6 Frequency distribution of female *P. affinis* in each reproductive stage (II, III, IV, and V) in each month for data pooled across years. Arrows indicate the direction in which the observed frequencies differed from expected frequencies, generated under the assumption that stages were independent of months. Numbers in parentheses are values of *n*.

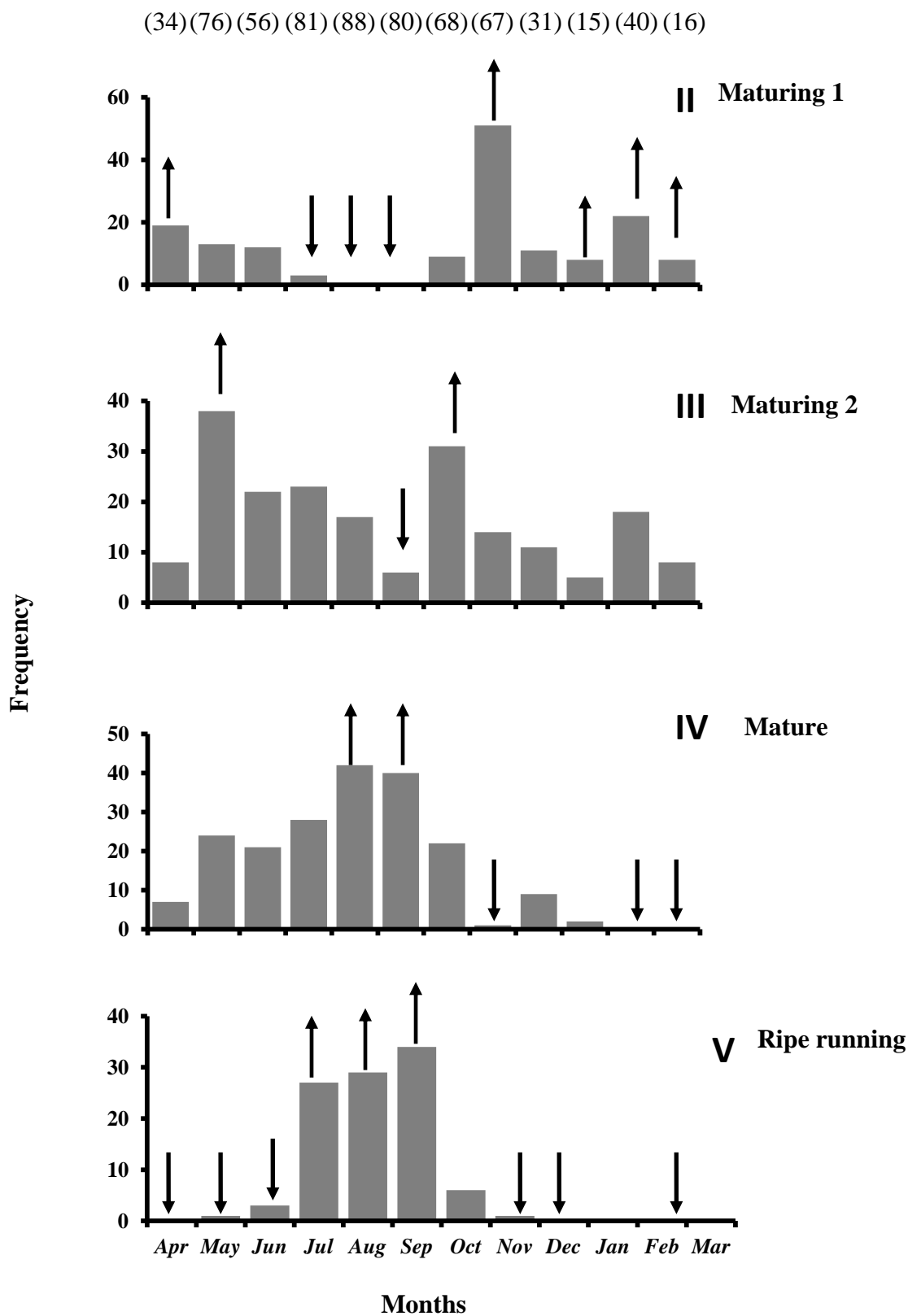


Figure 3.7 Frequency distribution of male *P. affinis* at stages (II, III, IV, and V) for pooled data. Arrows indicate the direction in which the observed frequencies are different from expected frequencies, generated under the assumption that stages were independent of months. Numbers in parentheses are values of n .

3.3.4. Ova size–frequency distribution

A total of 7037 ova were measured from 25 ovaries of I–V maturity stages. Five types of ova (immature, maturing, mature, nucleus migrated, and ripe) were observed in the studied ovaries (Fig. 3.9). Immature ova had a greater frequency in all ovarian stages. They represent the reserve ova from which a batch of ova will be withdrawn for further maturity. Immature ova were irregular in shape with clear nucleus and unyolked. Maturing ova were round with a partially visible nuclei and little yolk. The mature ova were opaque and fully yolked, and the ripe ova were partly transparent and hydrated (Fig. 3.9). The size–frequency distributions of the ova show the developmental sequence of maturation. As maturation progressed, there was no clear gap between size modes of unyolked and yolked ova. Immature ova (0.03–0.176 mm), were present in all maturity stages (Fig. 3.8). In stage II ovaries, a batch of immature ova increased in size to a mode of 0.25–0.35 mm (Fig. 3.8), which increased further to a modal diameter of 0.40–0.55 mm in stage III ovaries (Fig. 3.8). In stage IV ovaries, the mature ova (0.57–0.75 mm) emerged from other ova as it becomes a distinct and separate mode. There was significant overlap in size of mature ova and ova with migrated nucleus in stage IV (Fig. 3.9). A number of groups of ova at different development stages were observed in stage V ovaries. Ova diameter clearly shows a polymodal distribution with some overlap between stages and ripe ova at mode 0.81–0.99 mm (Fig. 3.8).

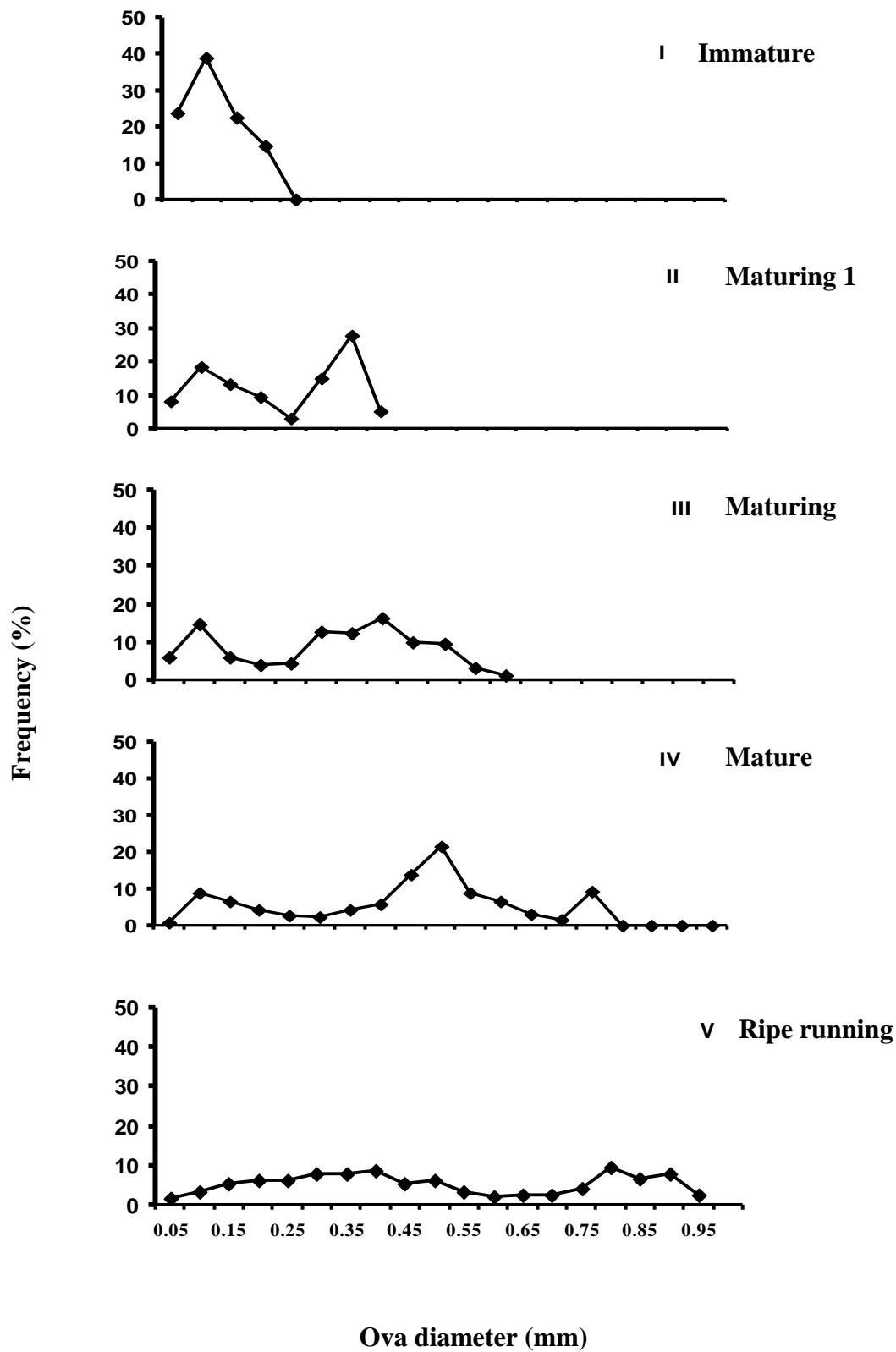


Figure 3.8 Oocyte size–frequency distributions (mm) from representative females of various reproductive stages.

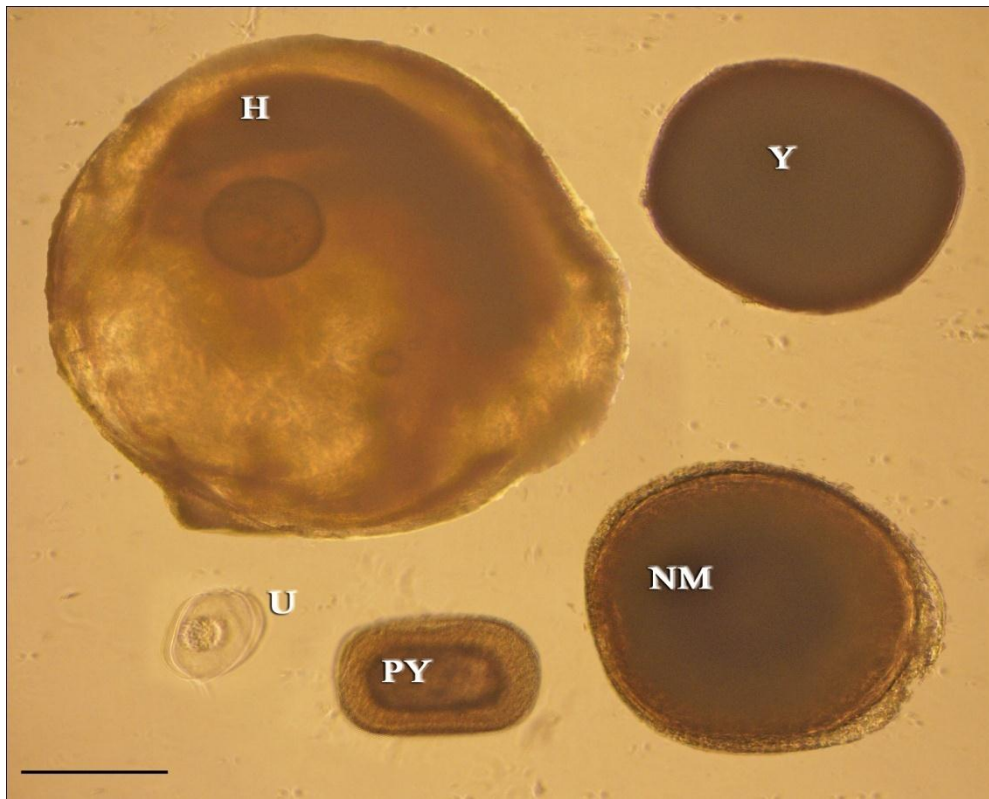


Figure 3.9 Photomicrograph of whole ova of *P. affinis* representing un-yolked (U), partially yolk (PY), yolked (Y), nucleus migrated (NM), and hydrated (H) ova. Scale bar 200 μ m.

3.3.5. Fecundity

The fecundity of *P. affinis* ranged from 14,460 to 757,830 eggs in females measuring between 21.5 cm and 34 cm TL total length with weight varying from 128 to 718 g. There was a general increase in fecundity with the increase of the ovary weight (Fig. 3.10A), total weight (TW) (Fig. 3.10B) and total length (TL) of the fish (Fig. 3.10C). The relationship between fecundity and relative fecundity also showed similar trend (Fig. 3.11). Relative fecundity showed significantly positively correlated. The regression of log-transformed analyses showed significant linear relationships between fecundity and total weight, ovary weight, total length, and relative fecundity. The coefficient of determination indicated fecundity in relation to the weight of the fish was highly correlated ($R^2 = 0.83$) than the total length and weight of the ovary. There was significant linear relationship between fecundity and total length of fish ($F = 68.37$, $df = 1, 24$, $P < 0.05$, $R^2 = 0.74$).

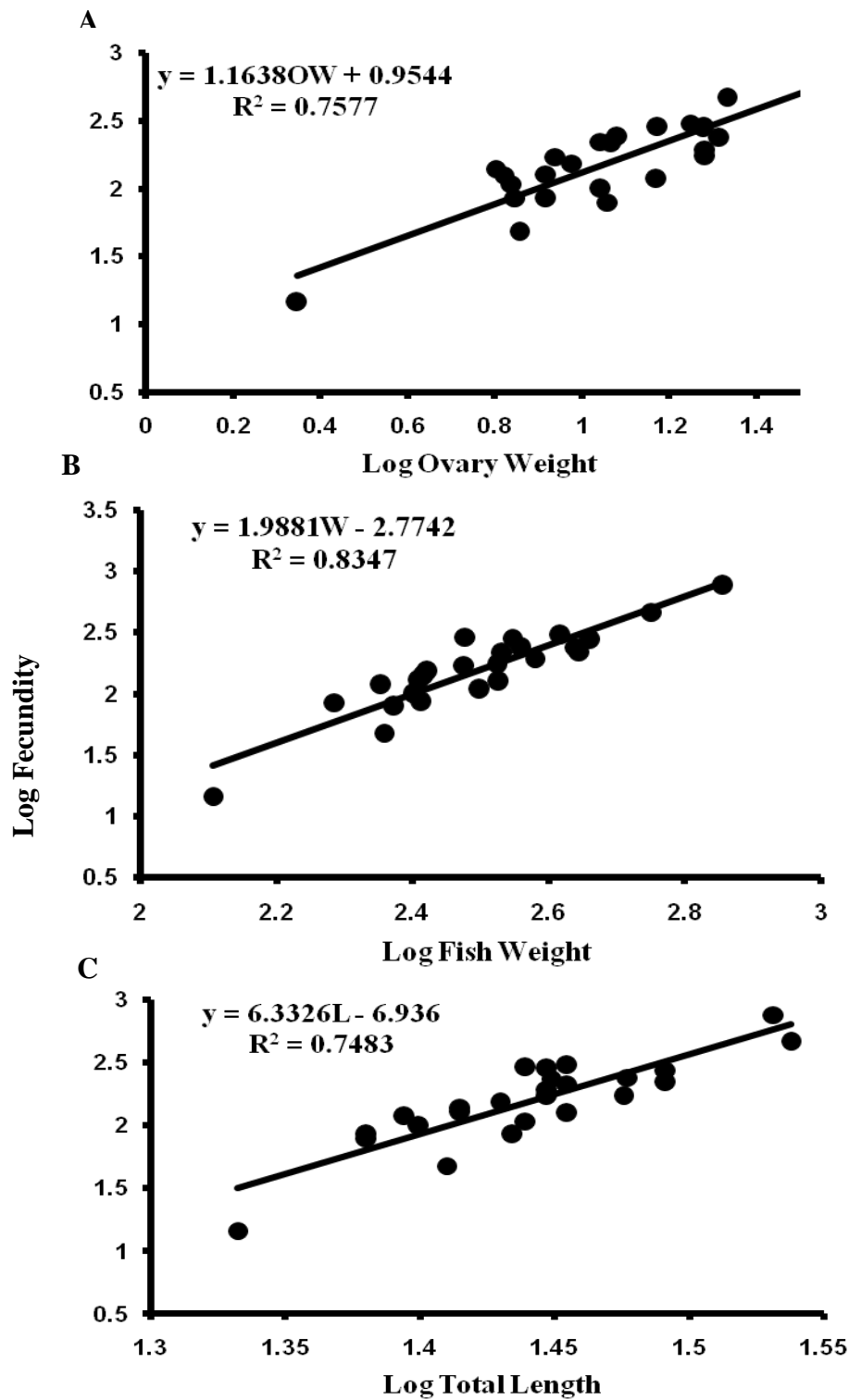


Figure 3.10 Relationships between log fecundity and log ovary weight (A), log fish weight (B), and log total length (C); r^2 the coefficient of determination for *P. affinis* from the Arabian Sea.

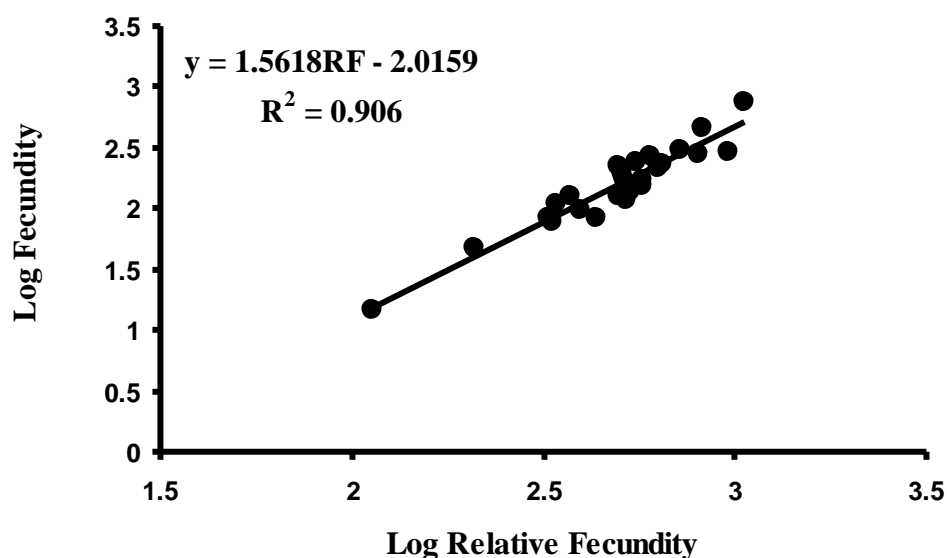


Figure 3.11 Relationship between log relative fecundity and fecundity for *P. affinis* from Arabian Sea; R^2 = the coefficient of determination.

3.3.6. Histological assessment of gonad maturation

The images of the histological assessment of ovarian development in female *P. affinis* are shown in Figs. 3.12 and 3.13 (mature and spawning/ripe stages). Oocytes were classified based on the criteria outlined in Table 3.1. Figure 3.12A shows the primary phase of oocyte development. In *P. affinis*, oogonia increased and turned into primary oocytes (early and late perinucleolus stages), which later developed within follicles, grew into cortical alveoli, become vitellogenesis, go through maturation, and ovulated as a final point. In males, both identifiable testicular and ovotestis tissues were observed in November (Fig. 3.14A). The testicular zone contained spermatogonia and occasionally spermatids in cysts, while the ovarian zone possessed immature oocytes (the primary growth phase EP and LP). The developmental stages of testes are also illustrated in Fig. 3.14, where a clear difference could be seen between mature (active) (Fig. 3.14C) and

immature (inactive) males (Figs. 3.14B and D). Mature male contained spermatozoa concentrated in the lumen and spermatogonia restricted to the periphery of the testes; whereas, immature testes possessed a higher proportion of spermatogonia and very few spermatids or spermatozoa.

On the basis of histological classification of the ovary, the distribution of oocyte diameters during the various stages of ovarian development are shown in Table 3.3 and Fig. 3.12. The sizes of oocytes ranged from 10 to 700 μm and within this size range included the maturation stages EP to H. The mean size of the immature stage early perinucleolus stage (EP) was $24 \pm 0.5 \mu\text{m}$; whilst, the mean size of the spawning ripe oocyte (H) was $656 \pm 8 \mu\text{m}$ (Table 3.2). The average oocyte diameter in stage MN was smaller ($360 \pm 7 \mu\text{m}$) than the average size during the spawning ripe stage (H) ($656 \pm 8 \mu\text{m}$) and this can be attributed to the swelling oocytes due to hydration just before spawning. Three types of POF stages were identified in samples collected during October. The structures established by the thecal and granulose layers of the oocytes surround the zona radiata externa (Figs. 3.13A–D). Recently, ovulated follicles formed convoluted folds of the thecal and granulose layers with darkly staining nuclei (Fig. 3.13B), whereas older POF were less structured, compact, and displayed nuclei that were in various stages of degeneration (Figs. 3.13C and D).

3.3.7. Spawning patterns from histological appearance

During July, ovaries had different vitellogenic phases of oocytes, migratory nuclear oocytes, and hydrated oocytes (Fig. 3.12C). The presence of varied types of POF and vitellogenic oocytes in ovaries (Fig. 3.12E) collected during August-October indicated occurrence of recent spawning and the potential for additional eggs. This shows that *P.*

affinis is multiple spawner. Thus, the continual ovulation of the oocytes and simultaneous addition of vitellogenic oocytes form the succeeding batches of eggs to be spawned subsequently. Hence, the spawning in *P. affinis* appears to be cyclical and is achieved through the discharge of sequential batches of eggs at ripe stage.

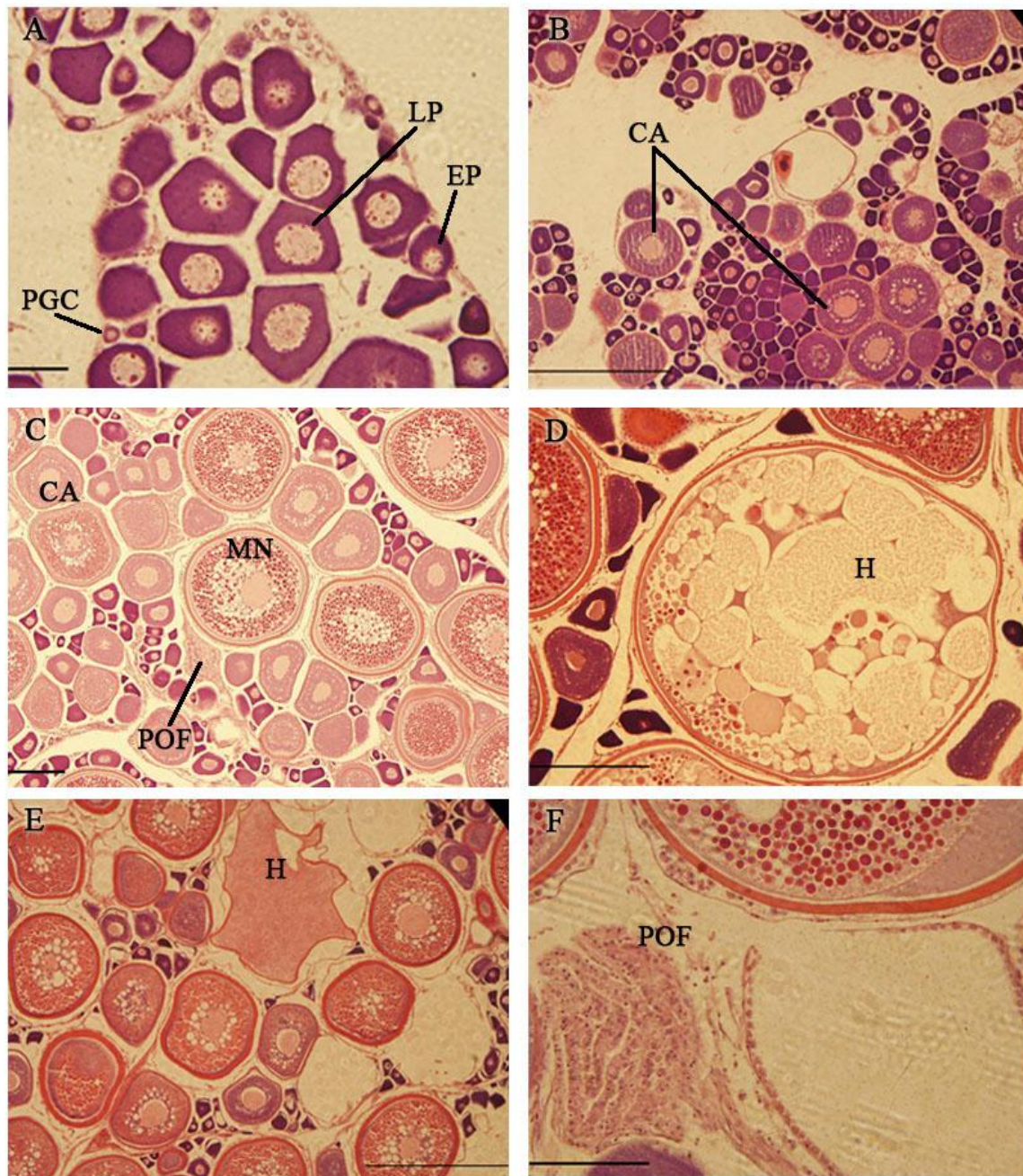


Figure 3.12 Sections of ovaries of *P. affinis*: (A) early perinucleolar oocyte (EP) and late perinucleolar oocyte (LP); (B) cortical alveoli (CA); (C) migrating nucleus (MN), cortical alveoli (CA) and postovulatory follicles (POF); (D & E) hydrated oocytes (H) and (F) POFs in stage 2. Scale bar = 100 μm (D), 500 μm (B & E), 50 μm (A), and 200 μm (C).

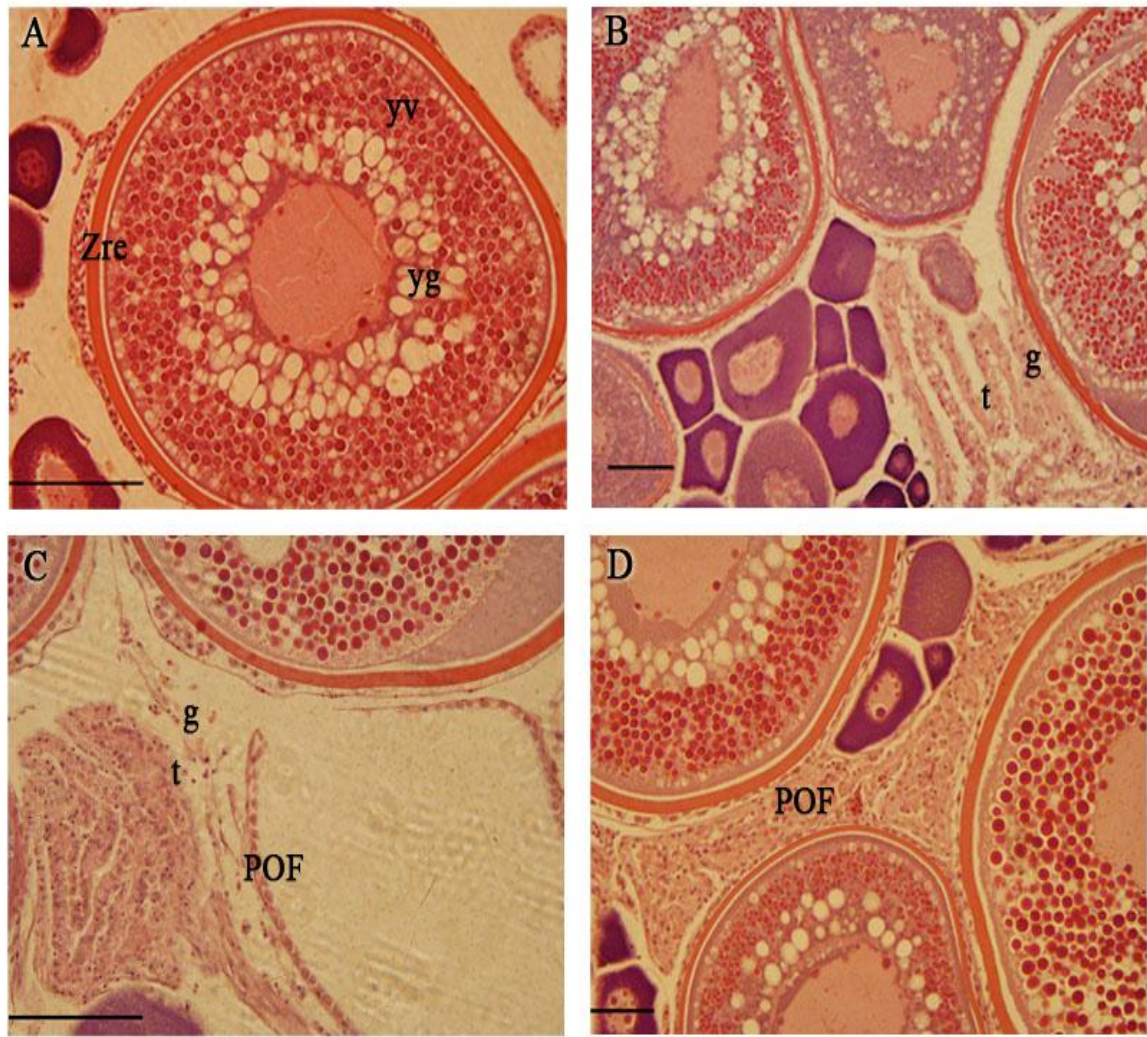


Figure 3.13 Sections of ovaries of *P. affinis*: (A) the outer layer of yolk granule. Yg: yolk granule; yv: yolk vesicle; zre: zona radiata externa; (B) POFs in stage 1. (g), granulosa and t, thecal layer; (C) POFs in stage 2. (g), granulosa and t, thecal layer; (D) POFs in stage 3. Scale bar = 100 μ m (A & C), 200 μ m (D) and 50 μ m (B).

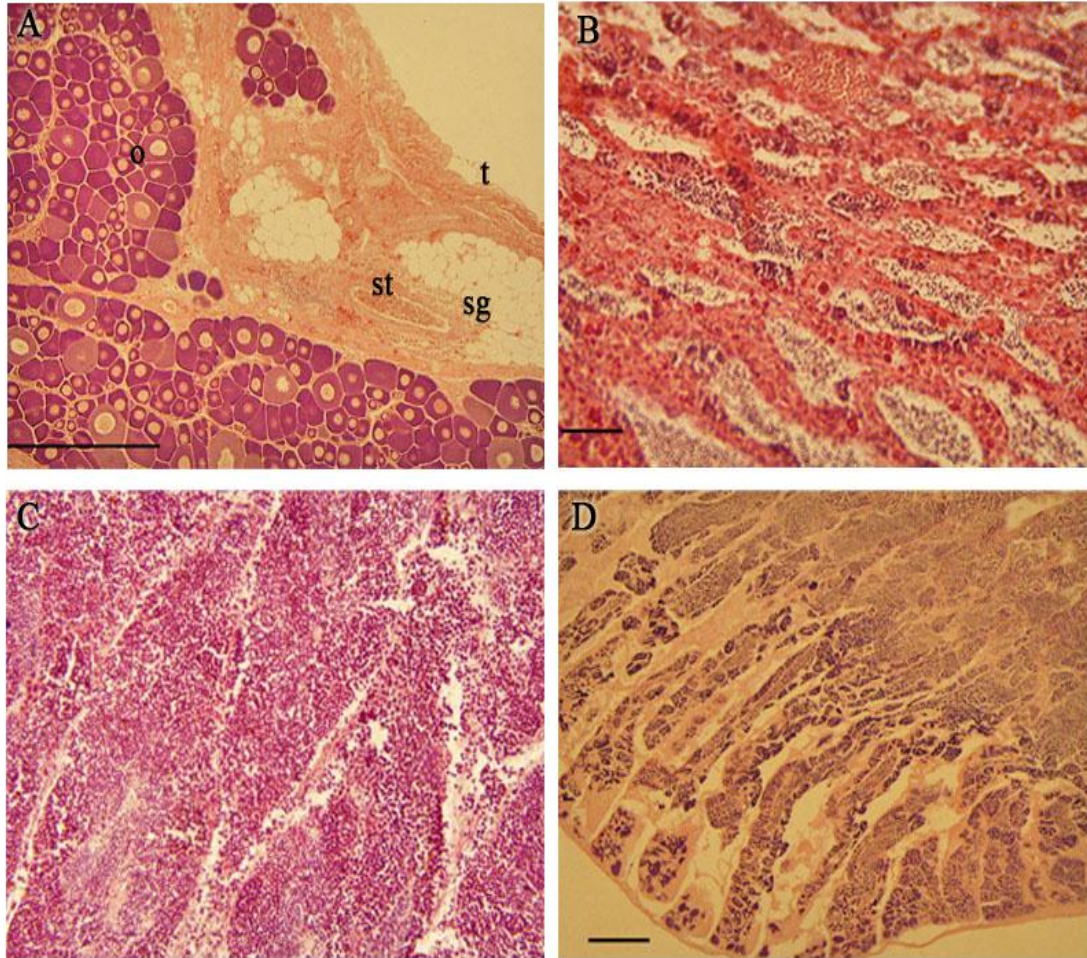


Figure 3.14 Sections of testis of *P. affinis*: (A) region of ovotestes in which the testicular tissue (t) predominated and oocytes in the ovarian zone (o), spermatogonia (sg) , spermatid (st) and spermatozoa (sz). Scale bar = 500 μ m, (B & D) show immature and inactive gametes, (C) main sperm duct during spermatogenesis, showing that both spermatids and spermatozoa are present. Scale bar = 500 μ m (A) and 200 μ m (B & D).

3.3.8. Spawning frequency

The mean monthly spawning frequency was greatest in August and September compared to October (Table 3.3). The proportion of spawners from July to October in *P. affinis* ranged from 0.24 to 0.69. These values indicate that females spawn at intervals of 1.44–4.17 days. The overall mean for the spawning months was 1.89 days in all period (Table 3.4).

Table 3.2 Mean diameters (\pm SE) and size ranges of oocytes in different maturity stages of ovaries of *P. affinis*.

Stages of maturation	No. of oocytes measured	Mean size \pm SE (μ m)	Size range (μ m)
EP	139	24 \pm 0.5	10–34
LP	132	58 \pm 2	32–97
CV	118	137 \pm 3	80–189
V	146	228 \pm 2	145–300
MN	115	360 \pm 7	257–594
H	103	656 \pm 8	466–700

Table 3.3 Spawning frequency of female *P. affinis* in Arabian Sea, Oman

Month	Number of female		Spawning frequency	Spawning interval (d)
	Mature	POFs		
July	7	7	0.5	2
August	6	7	0.54	1.86
September	4	9	0.69	1.44
October	19	6	0.24	4.17
November	0	0	0	0

3.3.9. Length at 50% maturity

The lengths at which 50% maturity attained by females and males are given in Fig. 3.15; with 95% confidence interval (CI). Males matured at 23.53 cm TL (CI, 22.5–23.8) with an estimated age of 3.5 years from inverse von Bertalanfy growth function (VBGF). Females matured at 22.1 cm TL (CI, 21.5–22.5) and the estimated age was 3.14 years. Although, males matured at a slightly larger size than females, there was no significant difference between the sizes of maturity for males and females (Median test, $\chi^2 = 0.0045$, $df = 1$, $P > 0.05$).

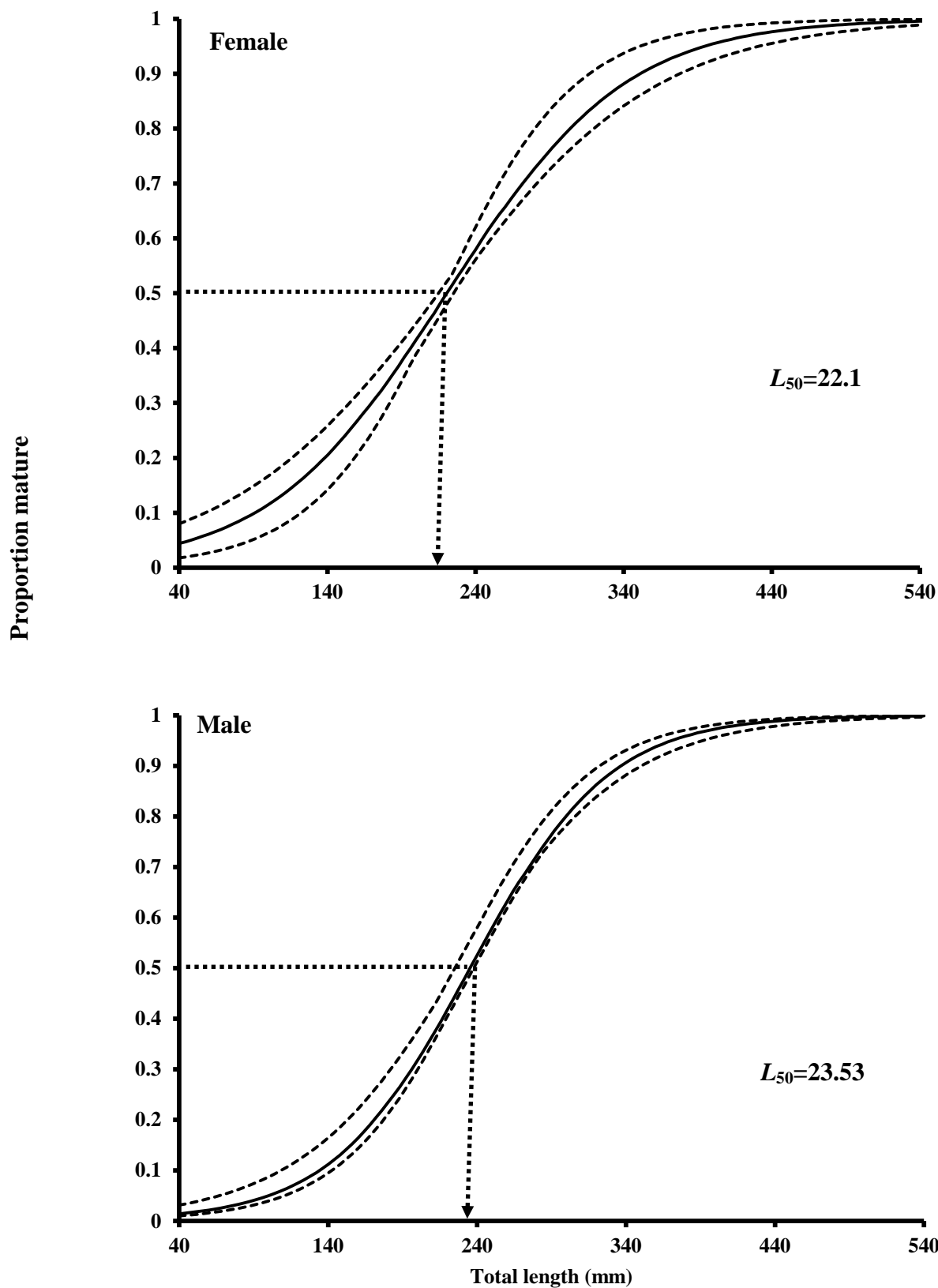


Figure 3.15 Proportion of sexually mature female and male *P. affinis* (data were fitted to the logistic equation with 95% confidence interval).

3.4. Discussion

This study confirms several aspects of spawning in *P. affinis*. Monthly distribution of maturity stages, GSI and relative condition factor, ova diameters, fecundity and length and age -at-50% sexual maturity are discussed here to elucidate maturation and spawning. In this study, the spawning season of *P. affinis* was evaluated from occurrence of mature gonads and mean monthly GSI profiles. These findings showed that *P. affinis* spawns for 7 months from April to October, with peak activity during August and September. The monthly evolution of gonado-somatic indices demonstrated only one peak a year for both sexes. Many reproductive studies concentrate on quantifying the reproductive traits of individual stock for better understanding of the mechanisms underlying population fluctuation. Several approaches help to understand the reproductive aspects of fish populations (Firedland *et al.*, 2005). Obtaining data on gonad weights and the proportions of different reproductive stages are common method used to determine the reproductive season (Fowler *et al.*, 2000).

Although the use of GSI is a commonly applied index of reproductive development (Claramunt & Roa, 2001), it can be a poor indicator of actual spawning activity (DeVlaming *et al.*, 1982; DeMartini & Lau, 1999) if not used in conjunction with other techniques like oocyte diameter and histological analysis (McDonough *et al.*, 2003). In *P. affinis*, the sharp rise in the mean monthly GSIs from June to October and drop in November evidently showed that the species spawned during these months. Thus, based on maturity stages and GSI, it is clear that *P. affinis* has a prolonged spawning season with peak activity in August and September in the Arabian Sea. There were clear development in gonads maturity of *P. affinis* over time. The wide period characterizes by this fish might be to guarantee high recruitment (Shapiro, 1992). Other seabreams have protracted spawning season, which owing to environmental condition of tropical fish (Mytilineou,

1987; Vassilopoulou & Papaconstantinou, 1990). However, an earlier study from the same area based on 1-year data from trawl catches alone, estimated spawning of fish during August-October, and a smaller peak for females in December (McIlwain *et al.*, 2006). The period of reproductive development of *P. affinis* agrees with other species of sparids (Andaloro, 1982). In *P. affinis*, the peak reproduction is associated with monsoon season, when SSTs averaged between 20.5°C and 21°C, less saline water and high nutrition (Luo *et al.*, 2000). This agrees with the observations of Sadovy (1996) who concluded that many fishes spawn in cooler periods. In tropical fishes, spawning patterns are associated with seasonal changes in environmental conditions that might influence spreading of larvae, growth and availability of food (Grimes, 1987; Robertson, 1991). Seasonal monsoons or the rains and photoperiod, which were not explored in this study, are also considered as important factors that regulate the timing of spawning in tropical fishes (Munro *et al.*, 1995; Sivakumaran *et al.*, 2003).

Sex ratio is an important parameter of population structure. If sex ratio differs from the unity, this can be the result of several factors such as mortality rate (Mazzoni & Caramaschi, 1997), selective capture influence (Hood & Johnson, 1999), partial segregation by sex (Mejuto *et al.*, 1995), season (Hoey, 1991; Mejuto *et al.*, 1991), migration patterns (Sadovy & Shapiro, 1987) and change in population structure between inshore and offshore locations (Hyndes & Potter, 1996). In this study, the overall male to female ratio indicated homogeneity (1:1); but differed from the ratio reported earlier as 1 M:0.88 F (McIlwain *et al.*, 2006). Differences in sex ratio between the two studies could be due to the variation in depths of fishing and fished area as trawlers operated in deeper waters and the artisanal gears fished in coastal waters. Our result agreed with sex-ratio reported for the related species *Diplodus puntazzo* (Micale *et al.*, 1996).

Monthly HSI and GSI in females in this study were correlated which may reveal the enhanced metabolic activity of the liver due to production of vitellogenin. Normally, higher monthly HSI indicates the storage of energy for reproduction (Lambert & Dutil, 2000). As the liver is the primary organ involved in vitellogenin synthesis, livers commonly enlarge in female during the reproductive season in response to the increased demand for vitellogenin (Htun-Han, 1978; Wallace & Selmen, 1979). Reductions in liver size and fat content are also observed during spawning as stored energy is utilized to meet the increased reproductive needs (Karlsen *et al.*, 1995; Hansen *et al.*, 2001). In *P. affinis*, a strong positive relationship existed between ovary weight and liver weight. The difference in HSI trends in males and females might be due to their different energy demands during reproduction, as the rates of metabolism for egg production in females is much larger than that production of sperm in males (Kokka & Jennions, 2008). In fishes the somatic condition factor indicates the physiological state of the fish, that results from the interaction between biotic and abiotic factors (Tavares-Dias *et al.*, 2010; Lemos *et al.*, 2012). The condition factor often varies in relation to nutritional availability and the demands for energy storage during reproductive activity (Vazzoler, 1996). However, as K_n values showed irregular trends in both sexes throughout the study period. Thus, they were not helpful for the determination of spawning season of *P. affinis*.

In this study, the process of forming of the ovary of *P. affinis* did not vary much from that described for the sparid *Acanthopagrus spp.* (Abu-Hakima, 1984). The process of ovarian development also agreed with the basic development defined for other teleost species (Abu-Seedo & AL-Khatib, 1995; Coward & Bromage, 1998; Dadzie *et al.*, 2000). From the histological data on the changes in maturity stages with months, the presence of mature fish from April to October indicated that *P. affinis* in waters of Oman has a prolonged spawning season and reflected the seasonal changes taking place in Arabian Sea. During the spawning season POFs were observed together with oocytes at yolk stage

in histological section of ovaries of mature pandora. Females that have mature oocytes and POFs are suggested to have recently ovulated (Lambert *et al.*, 2000). The occurrence of developing oocytes and POFs together indicates that the fish spawns more than once in a spawning season (Collins *et al.*, 1998; Yamaguchi *et al.*, 2006). The process of follicular regression in *P. affinis* was divided into three stages of regression because they presented well-defined characteristics (Leonardo *et al.*, 2006). From histological information hydrated oocytes were rarely observed. This may be explained by short lifespan of this stage of oocytes development before spawning (Brown-Peterson, 2000). The appearance of translucent (hydrated) oocytes is a sign that spawning would be imminent within a day or perhaps hours (West, 1990). In the present study, histological observations showed ovaries containing both testes and ovaries reflecting sex change in this species (Lee *et al.*, 2001; Lee *et al.*, 2002). In sparids, a complex sexuality such as protogyny, simultaneous and rudimentary hermaphroditism have been described (Buxton & Garratt, 1990).

In this study, the sexual maturity in *P. affinis* was estimated and found that this species attains its maturity at an age of about 3.14–3.5 years, which matched to a mean total length of 22.1 cm in female and 23.53 cm (TL) in males. As the reproductive potential of a fish stock is influenced by the size and age-at-50% maturity (Trippel *et al.*, 1997), they are used as significant parameters in fish stock assessment models to evaluate spawning biomass (Abookire, 2006). Furthermore, length-at-first maturity has a great importance in the determining the optimum mesh size for fishing regulation. Fish integrate their physiological function with environmental cycles which is also influenced by genetic factors (Hassin *et al.*, 2000). The time of sexual maturity is a vital transition in the life history of an organism as energy resources that were formerly distributed to growth and survival are now needed for reproduction (King, 1995).

The difference in the size and age-at-50% maturity between females and males has been found in related species such as *Pagrus auriga* (Pajuelo *et al.*, 2006) and *Argyrozona*

argyrona (Brouwer & Griffiths, 2005) where the males were larger and older than females at maturity. Similarly, in *P. affinis* of Oman McIlwain *et al.* (2006) found the females to mature at 21.4 cm and males at 22.3 cm (TL). The difference in size-at-first sexual maturity among males and females is a common feature occurring in sequential spawners due to different birth dates (Lowerre-Barbieri *et al.*, 1998). In general, fisheries selectively remove larger, older individuals from the population (Jennings & Lock, 1996). Moreover, the mean size of fish may vary from year to year naturally (McBride & Thurman, 2003) and in different geographical locations of species distribution (Bromley *et al.*, 2000). Furthermore, availability of food (Sampson & Al-Jufaily, 1999); oceanographic conditions (Brodziak & Mikus, 2000) and growth patterns (Stearns, 1992; Tripple, 1995) would also affect the variation in sizes. However, our study indicated the females to mature at marginally a lower size and age than males. Reasons for the variation in the observation between McIlwain *et al.* (2006) and the present study could be explained by changes either through phenotypic plasticity or the genetic composition of the stock (Thorpe, 2007).

The following evidences show that *P. affinis* is a serial spawner: (a) the prolonged spawning season revealed by the monthly GSI values and occurrence of mature gonads and (b) the presence of different developmental stages of oocytes as well as several modes of greater diameter oocytes. The restricted occurrences of resting fish further argue that *P. affinis* is a multi-spawner and show that the fecundity of *P. affinis* is a batch fecundity. This indicates a characteristic asynchronous type of ovarian formation. Fish species that have extended spawning seasons are usually multiple spawners and individual females produce several batches of eggs (Hontela & Stacey, 1990). In fishes to find out whether the fish has determinate fecundity, size frequencies of oocytes from various stages have been used (Hunter *et al.*, 1992). In the mature ovaries of most multiple spawners more than one group of yolked oocytes are present with continuous distribution of different

sizes of oocytes (Blaxter & Hunter, 1982). Furthermore, they are correlated to oocyte development “synchronized in more than two groups” in which each set of oocytes develop simultaneously and are released when they reach total maturation (Lampert *et al.*, 2004). A relationship might exist between the pattern of oocyte and ovarian development for either synchronous or asynchronous oocyte development (Somarakis *et al.* 2004). The frequency distributions of the oocyte sizes in this species show a continuous development from the smallest to the largest size groups indicating several batches of eggs at all stages of maturity (Seifali *et al.*, 2012) . It could be concluded that in *P. affinis*, the production and extraction of ova from the ovary are a continuous process and that may spawn several times a year (Bless, 1994) . The gonads with advanced stages of maturity (Stages III and IV) seen throughout and different types of ovas present in the ovaries; indicated that the eggs are released in successive batches.

This study is the first account of fecundity of *P. affinis*. Fecundity of *P. affinis* in the present study is correlated allometrically to individual mass, largely it is nearby a function of the cube of fish length. Fecundity in fishes is highly variable between individuals (Sadovy, 1996). The intermittent spawning of fish might compensate for lower fecundity (McBride & Thurman, 2003). However, in *P. affinis* the fecundity appears to be moderate. A reduction in population fecundity, might be due to the decreased average female size even if the sex ratio of the population is maintained (Sadovy, 1996). In most cases, fecundity increases with fish size as observed in the present study (Collins & Sedberry, 1991; Wilson & Nieland, 1994; Cuellar *et al.*, 1996; Collins *et al.*, 1998). Hence, larger females are relatively more important for egg production than small ones. The size of the ova is possibly related to the amount of food that females can metabolize, integrate, and store in each egg (El-Agamy *et al.*, 2004). Though, compared to most marine teleosts, and particularly other coral reef fishes, *P. affinis* has normal-sized egg, high spawning frequencies, and moderate fecundity. Differences in amount of fecundity have been

related with temperature, population density, availability of food, stress and other environmental influences (Lambert & Dutil, 2000; Lambert *et al.*, 2003). However, for comparison, the available information for similar species was used. The results of present study followed the same trend like those of Zaki *et al.* (2004) for *Diplodus vulgaris*, Algamdi (2001) for *Acanthopagrus bifasciatus*, and El-Greisy (2000) for *Diplodus sargus*. Similar to *P. affinis*, an average sized female coral reef fish can produces about 100,000 eggs (Takemura *et al.*, 2004) and fecundity increased with increase in fish size (Degani, 1990).

The information of fecundity will be important to assess the spawner biomass of *P. affinis*. At present there is no restriction on the size of *P. affinis* to be landed or the fishing season. It is hoped that the results of the study would be helpful to formulate suitable management measures for sustainable harvest of the resource.

4. Diet

4.1. Introduction

Details of specific diet composition and feeding habits of targeted species are important factors in the development of fisheries management plans. Fish populations constitute an important component of the resources in aquatic environment. Until recently, dynamics of fish population have been studied as single species in isolation from the aquatic system in which they live. It was documented that the conventional approaches in the management of fisheries are incomplete and partially unsuccessful and hence there is need to move the single stock- and species-based management considerations to broader conservation of ecosystem-based management (Pauly *et al.*, 2002; Garcia *et al.*, 2003). As food partitioning allows coexisting fish species to exploit the available food supply with minimal competition, diet is considered an important feature that regulates the structure of fish communities (Gerking, 1994).

The study of stomach contents provides insight on the feeding habits of fish. Removal of small pelagic fishes occupying lower trophic levels would reduce the food available to larger trophic levels species resulting in a decline of species composition at higher trophic levels (Wallace, 1999; Hartvig, 2011). This is extremely a worrisome situation that will lead to gradual removal of long-lived, larger species of fishes in the marine ecosystem (Pauly *et al.*, 2002). Analysis of stomach-contents of fishes provides information on feeding habits of the fish species, which will vary markedly with food availability, depth, season and ground (Morato *et al.*, 2003). The main factor of structuring benthic communities depends on predators that regulate the populations of species at lower trophic levels (Shears & Babcock, 2002). If any change in this balance occurs, for example overexploitation of predatory fish, it will cause population destabilization in lower levels through a process known as trophic cascade (Polis *et al.*, 2000).

The survival, growth, and reproductive output of fish are dependent on the input of energy and nutrients obtained through feeding (Wootton, 1990). Therefore, essential dietary items for species that support valuable fisheries may need to be identified so that the trophic balance necessary for their survival can be maintained. In general, the features such as habitat, availability of food, competition and the physiology of fish influence the condition of a fish (Francis, 1997; Lee & Khan, 2000; Yaragina & Marshall, 2000). The condition status of fish can influence the health survival, reproduction, etc. of the population (Lambert & Dutil, 1997; Marshall & Frank, 1999; Shulman & Love, 1999). Insufficient energy reserves would reduce reproductive potential in some fishes by lowering quality of eggs and fecundity and larvae (Lambert & Dutil, 2000). Also, to construct trophic models of marine ecosystems for fisheries management, information on food composition, consumption rates, biomass and mortality of various groups of organisms is essential (Christenen & Pauly, 1993; Begg & Hopper, 1997). However, the seasonal gut content analyses of the fish would indicate the occurrence and abundance of the preferable food items in space and time.

Sparids feed on both plant material and a wide range of benthic prey organisms (Havelange *et al.*, 1997; Tancioni *et al.*, 2003). The opportunistic feeding behavior in fish (Sarre *et al.*, 2000; Mariani *et al.*, 2002; Tancioni *et al.*, 2003) is supported by the large mouth gape, and the presence of molariform teeth and canine teeth (Gomon *et al.*, 1994; Linde *et al.*, 2004). Sparids have different types of feeding habits. While *Diplodus annularis* is an omnivore (Matic-Skoko *et al.*, 2007); *P. acarne* and *P. borgaraves* are attracted towards the abundant food item occurring in the region (Olaso *et al.*, 2002); *Pagrus pagrus* is a carnivore feeding on epibenthic invertebrates, mainly decapods (Labropoulou *et al.*, 1999); and *Pterogymnus ianiarius* is an opportunistic benthic predator (Booth & Buxton, 1997). On the other hand, study of stomach contents and feeding habits of *P. affinis* is very rare. The knowledge on the food and feeding of this species is needed

for an understanding of tropho-dynamics and food web in the Omani waters. However, no information is available on the feeding ecology of *P. affinis* from Oman.

The purpose of this study was to investigate the feeding pattern of *P. affinis* based on the examination of gut contents and to explore whether their diets change with respect to size, sex, reproductive status, and season in the Omani waters. These data will be used to help develop trophic modeling and ecosystem-based fisheries management in Oman.

4.2. Materials and methods

A total of 1373 individuals of *P. affinis* were randomly collected monthly from artisanal fisherman from Al-Lakbi and Raysut landing sites (Fig. 1.1) from April 2005 and March 2007 and, between April 2008 and March 2009. This species was exploited by different fishing techniques; trawler, gillnet, and longline, so the sampling procedure covering all those types. In the laboratory, each fish was measured to its total length and then the stomach was dissected out and kept in 70% ethanol. Stomach fullness was examined visually before preservation and assigned to a fullness category; empty, $\frac{1}{4}$ full, $\frac{1}{2}$ full, $\frac{3}{4}$ full, or full (Al-Marzouqui *et al.*, 2009). Full and $\frac{3}{4}$ full stomachs were considered as active feeding, $\frac{1}{2}$ full stomach as moderate feeding, and $\frac{1}{4}$ full stomach was recorded as poor feeding intensity in fish. The preserved stomach contents were emptied into a petri-dish observed under a binocular microscope and the food items assigned into the prey categories of fish (sardine and other fish), molluscs (cuttlefish and squid), crustacean (crab and shrimp), and/or others taxa (algae and unidentifiable material recorded as semidigested matter).

Dietary importance of prey items were assessed by abundance (%N) and percentage of prey item occurrence (%O) (Mohan & Sankaran, 1988). Percentage

occurrence was defined as the frequency of fish that ingested a particular prey item regardless of prey frequency,

$$\%O = \frac{n_i}{\sum_{i=1}^n n_i} \times 100$$

where n_i is the number of fish in which item i occurs; whereas % abundance was based on the numerical abundance of all identified prey items, as (Total number of one genus organism /Total number of all organisms) x 100; whereas vacuity index (VI%) is as

$$VI\% = \frac{\text{Number of empty stomachs}}{\text{Total number of stomachs}} \times 100$$

Variation in dietary composition was examined as a function of month, season, and fish length (<23 and >23, the size at the maturity $L_{50} \approx 23$ cm) from pooled male and female data. To look at the trends in prey for each season and two groups (<23 and >23), the frequency of individuals at each size and season was analyzed using a χ^2 test of independence. Feeding intensity, (stomach fullness) in fish was examined in relation to month, size and maturity stages of females and males (Chapter 3), and tested using a χ^2 test of independence. Standardized residuals (the normalized difference between the observed and expected frequencies in each category) were applied to find out which of the categories had observed frequencies that differed from the expected frequencies. ANOVA test was carried out to explore the monthly variation in the composition of diet and feeding intensity in relation to different maturity stages.

4.3. Results

4.3.1. General food composition of *P. affinis*

From a total of 1373 stomachs examined, 833 (61%) contained food items. Eight prey groups were identified in stomach contents, approximately half (50.66%) of the ingested food items could not be identified and was classified as semidigested matter. Fish as a group dominated the identifiable prey items and were followed in abundance by molluscs (cuttlefish and squid) and crustaceans (crabs and shrimps), respectively (Table 4.1). The diet did not vary throughout the period of sampling for both sexes, except in food item category “other fish” ($\chi^2 = 11.65$, $df = 1,123$, $P=0.001$). The diets of both sexes were almost identical, and a high degree of similarity existed in the food of females and males depending on the availability.

Overall, sardines and other fish were the most frequently found prey items and contributed approximately 40% and 31%, respectively, of the identifiable prey items. In contrast, the other prey items were comparatively few and considered as secondary prey items with percentages ranging between 1.2% and 8.2%. In the present study, the abundance of different food categories recorded in the stomachs of *P. affinis* indicated that fishes (sardine and other fishes) are the preferable food items where their abundance was 40.39 and 31.14, respectively. Of the total stomachs examined, 540 were empty (VI% = 39.33). The percentage of fish with empty stomach was greatest (63.36%) in June and smallest (9.38%) in March. The percentage of fish with empty stomach were different ($\chi^2 = 4.14$, $df = 1,531$, $P = 0.042$) between males (54.40%) and females (45.54%), throughout the period of the study and most obvious in May ($\chi^2 = 6.72$, $df = 1,41$, $P = 0.0095$).

Table 4.1 Frequency of occurrence (%O) and abundance (%N), of *P. affinis*.

Major taxa and dietary categories	%O	%N
Fish	35.29	71.53
Sardine	19.93	40.39
Other fish	15.37	31.14
Molluscs	7.32	14.84
Cuttlefish	4.10	8.27
Squid	3.24	6.57
Others	0.72	1.46
Crustacean	5.40	10.95
Crab	3.00	6.08
Shrimp	2.4	4.87
Other taxa	1.32	2.68
Algae	0.60	1.22
Semidigested matter	50.66	NA
Mean gut fullness	12.50	NA

4.3.2. Monthly variation in the percentage composition of diet

Semidigested matter was the dominant item in the stomachs of *P. affinis* in most months, with the percentage contribution ranging between 17.24% (March) and 64.06% (August) (Fig. 4.1). Among the identifiable food items, sardines were present in all months and were the dominant prey item in April, June–September and November (up to 49.43%). Other fish also occurred in most of the months that ranged from 4% to 32.3.8%. In contrast, shrimps dominated the ingested prey item in May and January and squids dominated in March. While crab was recorded in January, February, and March, cuttlefish were encountered in lesser percentages between October and March (2% and 10%). The monthly variation in diet composition showed significant differences among months ($F = 16.46$, $df = 19,833$, $P < 0.001$).

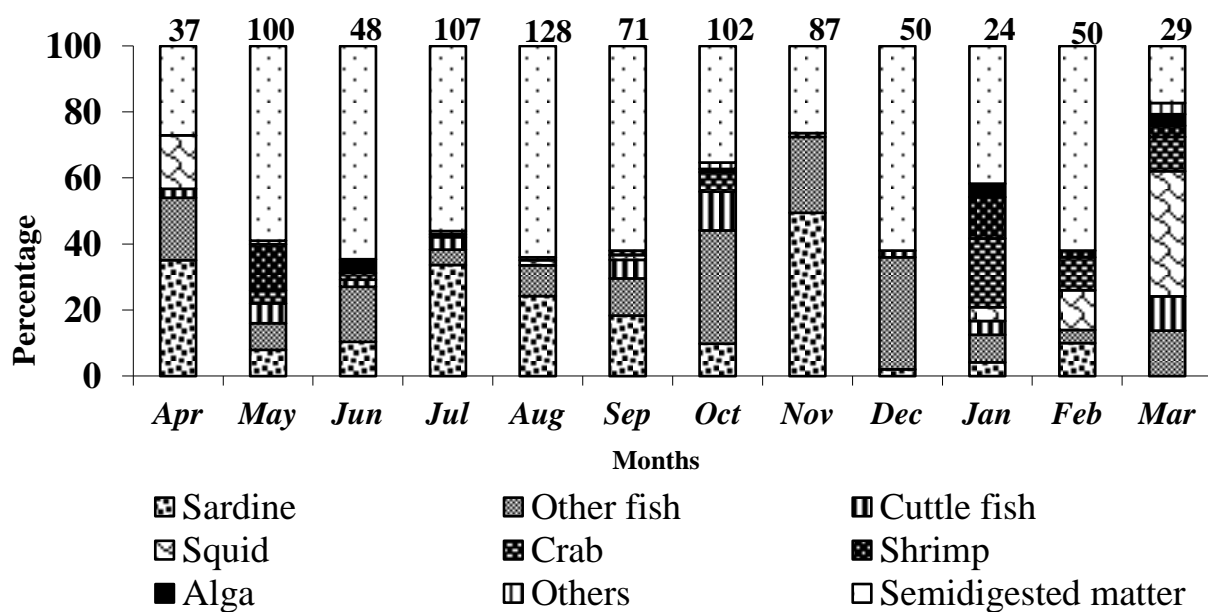


Figure 4.1 Monthly percentage occurrence of different prey items in *P. affinis* during 2005–2009.

4.3.3. Food composition in relation season

The relative frequency of different prey items differed among the four seasons ($\chi^2 = 106.1$, $df = 1,12$, $P = 0.001$). Though sardines were the primary food item in all seasons, their occurrence was higher in autumn and summer. The frequency of occurrence of sardines was less in winter and spring; and greatest in summer. The “other fish” frequency in most season was observed equal to expected frequency except in autumn when the observed was higher than the expected frequencies. The frequency of crustaceans was greatest in winter and spring and formed a small frequency in summer and autumn. Other categories were of food items that differed significantly among the seasons (Fig. 4.2).

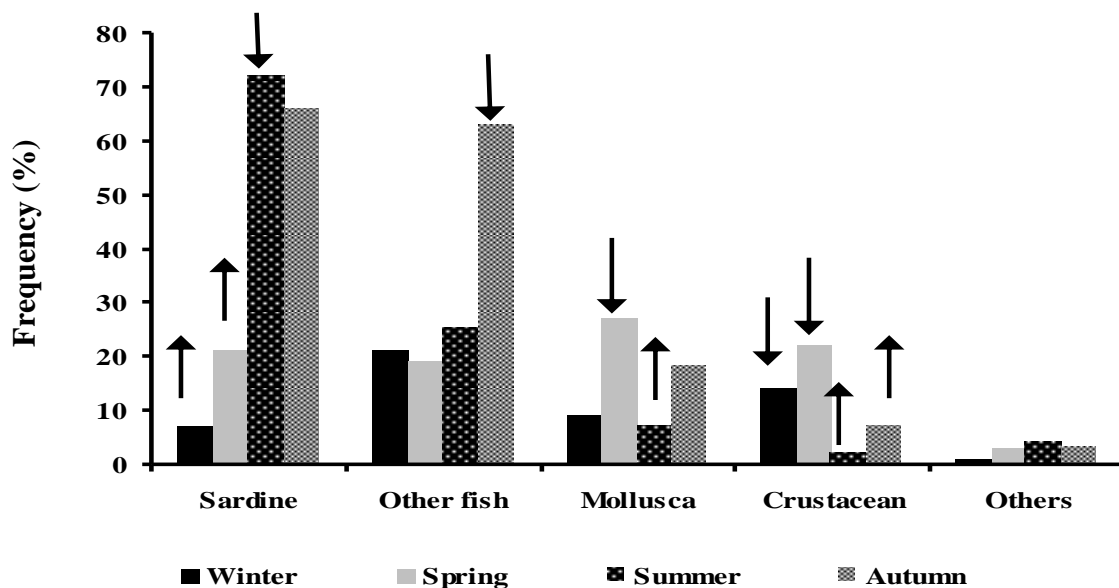


Figure 4.2 Difference of food items in *P. affinis* according to seasons (2005–2009 pooled). Arrows indicate the direction in which the observed frequencies differed from expected frequencies generated, under the assumption that a food item was independent of seasons.

4.3.4. Feeding intensity in relation to months

In *P. affinis*, 26.9% and 27.09% of the individuals fed actively during October and November and fish were encountered with 5.5% active feeding in December (Fig. 4.3). Moderate feeding was observed in all the months and the highest percentages were noted in April (30.3%) and January (40%). Poor feeding was recorded in more than 44.4% and 46.7% of fish in December and March. Although, empty stomachs occurred in all the months, higher percentages were observed during June (74.2%) and September (51.8%). The variation in feeding intensity in relation to months showed significant differences among months ($F = 13.04$, $df = 15,1092$, $P < 0.001$).

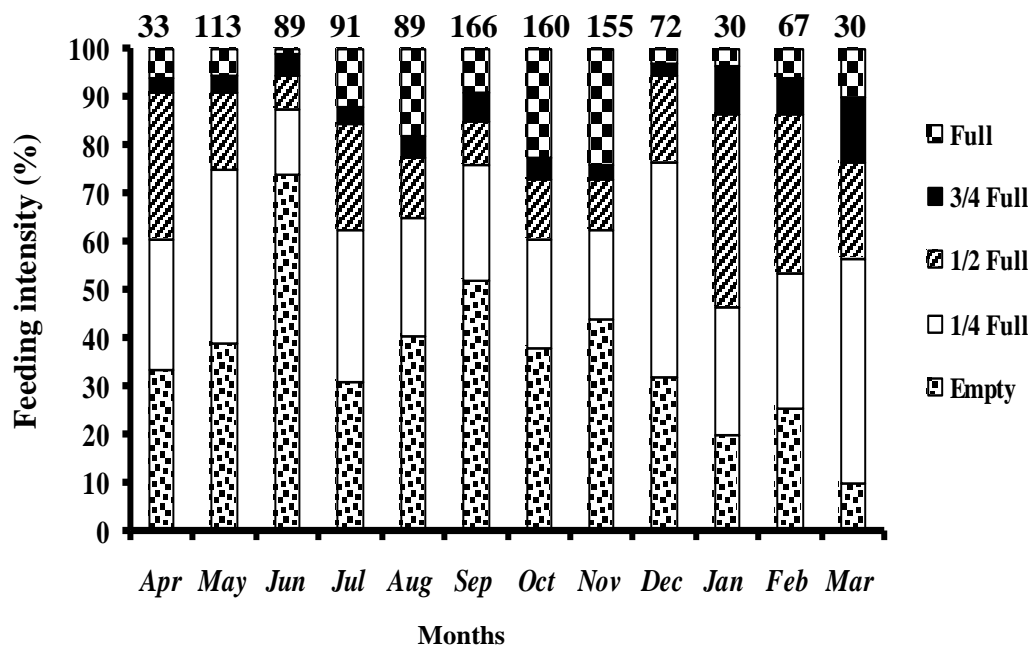


Figure 4.3 Feeding intensity of *P. affinis* during different months 2005–2009 (combined).

4.3.5. Food composition in relation to size of fish

In the fish, there was significant difference between the prey items and size groups ($\chi^2 = 40$, $df = 1,7$, $P < 0.001$). In small fish, the frequency of “other fish” items formed the important component of the diet (Fig. 4.4). Sardine was found very frequently in large fish (Fig. 4.4). The frequency of shrimp was similar in both small and large fishes. Squid was found to be higher (about 70.37%) in small group. The group size (<23 cm) differed significantly with groups (>23) ($F = 5.31$, $df = 8,408$, $P = 0.021$). In general, other fish and squid were found in higher frequencies and sardines in lower frequencies than the expected frequencies. In contrast, the diet of adult fish displayed higher than expected frequencies for sardine and lower observed frequencies for squid and other fish, indicating that the feeding habits differ among the body size groups.

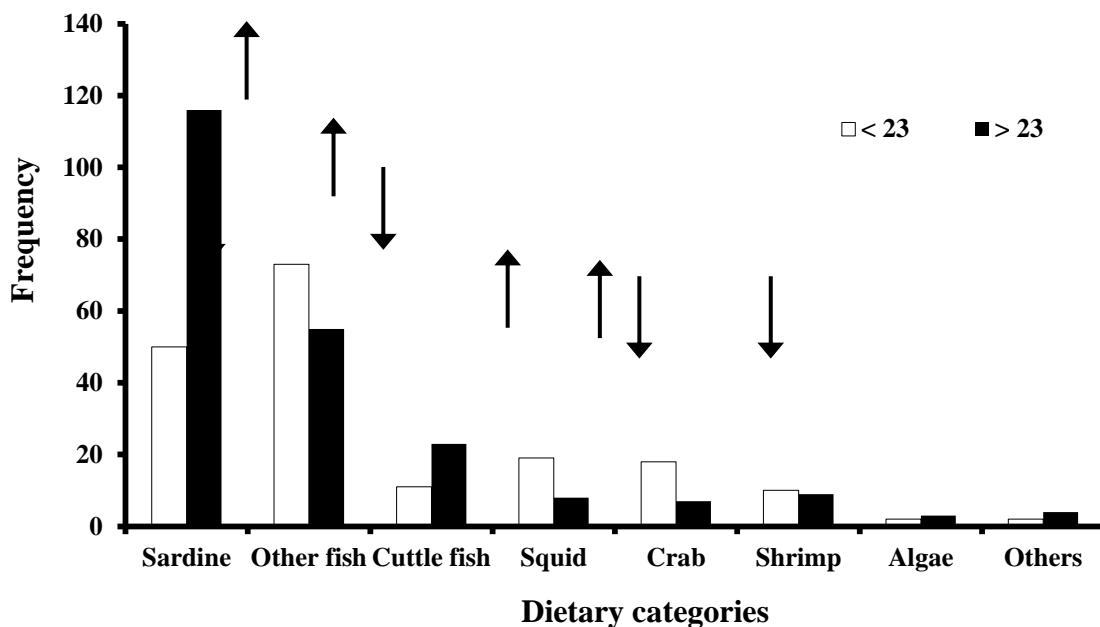


Figure 4.4 Variations in prey item frequency for juvenile and adult *P. affinis*. Data were pooled from 2005 to 2009. Arrows indicate the direction in which the observed frequencies differed from expected frequencies generated, under the assumption that a food item was impendent of size groups.

4.3.6. Feeding intensity in relation to maturity stages

Active feeding was observed in higher number of individuals in stages I (Immature), II (Maturing 1), and V (Ripe) in males ($F = 8.3$, $df = 29,537$, $P = 0.004$) and stages III (Maturing 2) and spent individuals in females ($F = 7.07$, $df = 29,532$, $P = 0.001$) (Figs. 4.5 and 4.6). Maturing fish of both sexes recorded active feeding of 12% and 20% in males and females, respectively. In stage III, 21.5% of female fed actively, in male active feeding was observed in 10.7% of individuals. Moderate feeding was noticed in more number of females than males in stages IV and V; whereas, poor feeding was common in stage IV males and females (33% and 40%, respectively). Empty stomachs occurred in all the stages with percentages ranging between 33% and 50.3% in males and 20% and 80% in females. The degree of fullness did not differ ($\chi^2 = 0.0233$, $df = 1,1072$, $P = 0.87$) between males and females throughout the period of the study except in full stomach ($\chi^2 = 7.75$, $df = 1,131$, $P = 0.0053$).

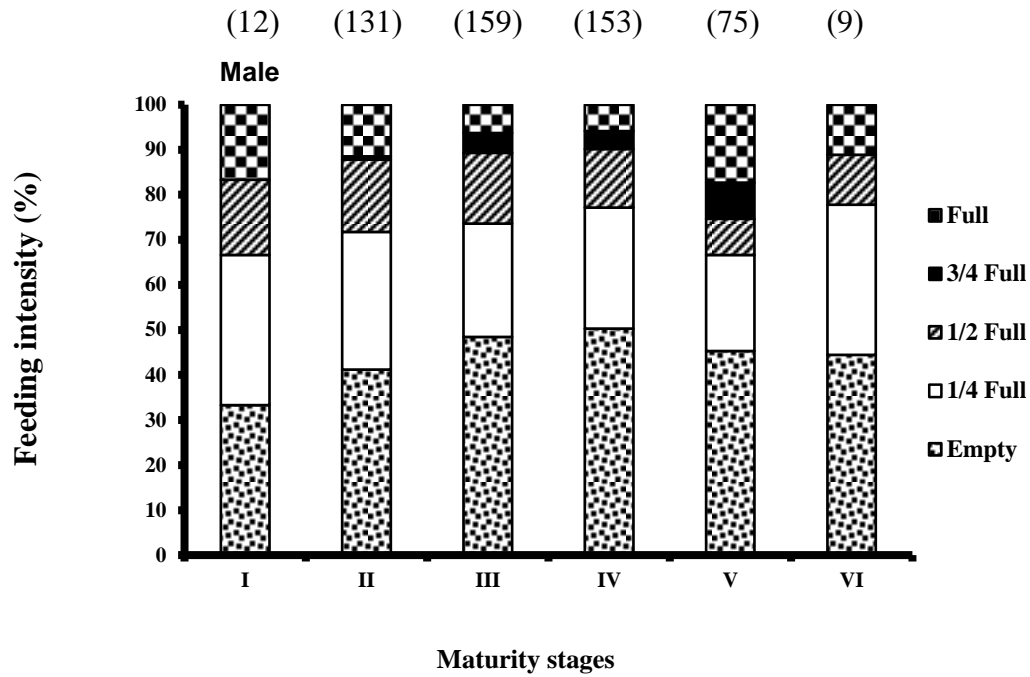


Figure 4.5 Feeding intensity in relation to different maturity stages of male *P. affinis*.

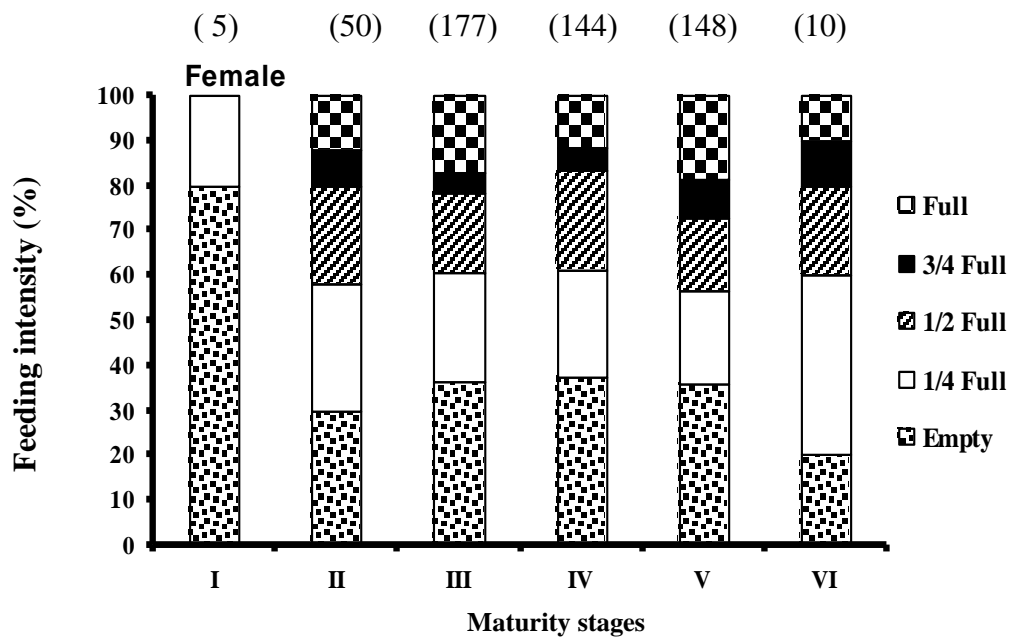


Figure 4.6 Feeding intensity in relation to different maturity stages of female *P. affinis*.

4.4. Discussion

The distribution and fluctuation of the food organisms like many other factors also affect the shoaling behavior, migration, growth, condition, and even the fishery. In view of this importance, considerable attention has been paid on the subject by various authors. Thus, the study of food and feeding habits of fish around the year would help to understand the biology and fishery of the species. It has been documented that a correlation existed between availability of food of a particular species and occurrence of the fishery for the species (Al-Marzouqi *et al.*, 2009). The dietary compositions described in this study suggest that *P. affinis* is an omnivore species with preference for carnivorous diet, which relies on fishes such as *Sardinella* spp., cephalopod, and benthic crustaceans such as shrimps and small crabs. The current study is the first investigation on the dietary composition of *P. affinis*. Though the family Sparidae includes both omnivorous and carnivorous species, the carnivores are categorized as general predators, feeding on a variety of prey organisms (Pita *et al.*, 2002). Hence, the occurrence of different types of food in the gut of fish during different months might be due to the seasonal availability of prey items.

Unidentified teleost remains were common in the stomachs of *P. affinis* in the present study. Partial digestion of prey items often made identification to species level impossible (Begg & Hopper, 1997). Occurrence of fish with empty stomach was common in all months and maturity stages for both sexes, which is probably caused by low intensity of feeding (Tolonen, 1997). The high monthly vacuity indices (%VI) observed in both sexes during June and September may be attributed to spawning (June–October) in *P. affinis* in the Arabian Sea. The intensity of feeding of *P. affinis* depends on its physiological conditions. Furthermore, the intensive feeding of adult throughout spawning months may be related to sexual maturity as reported for peacock wrasse (Ouannes-

Ghorbel & Bouain, 2006). During winter fish feed intensively to enhance energy for gonad development (Ouannes-Ghorbel *et al.*, 2002). In our study, the high proportion of empty stomachs found in fish might be attributed to the methods of fish capture. In passive fishing methods such as hook and lines, where the fish had fed to satiation have a declined response to the bait (LØkkeborg *et al.*, 1995); i.e. the fish fed with full stomachs have a tendency not to eat the bait and caught and the fish with partial fullness or empty stomachs were caught. Occurrence of large number of empty guts in eel (Serajuddin & Ali, 2005), in rays (Morato *et al.*, 2003) and in spotted mackerel (Begg & Hopper, 1997) were correlated with the methods of capture. The occurrence of empty stomachs may also be owing to digestion rates of the food eaten (Wetherbee *et al.*, 1990).

In the present study, the abundance indices of the different food items of *P. affinis* indicated that fish in particular sardines are the preferable food items for this species. Also, the high proportion of pelagic prey in the diet may owe to their preference for inshore waters. The fish belonging to sardine species formed the basic food item as observed in *Dentex genus* (Nguyen-Xuan & Wojciechowski, 1973). In general, changes in diet depend on the availability of types of food and variability of feeding activity connected with climate and breeding season (Pajuelo & Lorenzo, 1996; Lee *et al.*, 2007). The seasonal availability of certain prey items may play an important role in attracting *P. affinis* into inshore waters where they become accessible to the artisanal fisheries. Fishing may have significant influence on the trophic ecology of fish similar to the environmental and ontogenetic aspects (Tyrrell, 2007). As fishing has not only a direct impact on fish populations, but also alters communities and benthic habitats (Rijnsdorp & Vingerhoed, 2001), and accordingly change trophic relationships (Daskalov, 2002).

The quantity and quality of food varied with two sizes of fish. Larger pandora ate mostly fish and cuttlefish; whereas, smaller individuals preferred mostly crustaceans and other fish. There is evidence that size difference in fish reflects changing food preference,

as well as the ability of larger individuals to capture larger animals (Labropoulou *et al.*, 1999). Paul *et al.* (1997) observed in Pacific sandfish that non-fish items contributed to 24% in smaller sized fish compared to 5% in larger fish. Some features affect the prey variety and catching efficiency (Mérigoux & Ponton, 1998). Generally, the shift in food of fish influenced by the morphological characteristic such as body size and gape of mouth, (Winemiller, 1991; Wainwright & Richard, 1995); development of fins, swim bladder and muscles (Bone *et al.*, 1996), and shape of body (Winemiller, 1991).

In conclusion, stomach content analysis showed that the *P. affinis* is predominately a carnivorous feeder and major part of its diet being sardines and other fish (primary item). Other food items in the stomach contents were secondary prey items. The minor presence of algae may be accidental inclusion during capture of benthic prey. A higher percentage of empty stomachs were observed. The phenomenon of seasonal change in feeding *P. affinis* may be due to seasonal occurrence of food items. It would be interesting to study the alterations in digestion using time series data (Hanson & Chouinard, 2002), in relation to fishing effort.

5. Mortality, Yield and Spawning Biomass per Recruitment

5.1. Introduction

The length–weight relationship in exploited fish stocks is determined mainly to express the mathematical relationship between the two variables to enable calculation of length, if weight is known or vice-versa and to study the variation in individual weight of fish of a given length from the anticipated weight as an indication of condition and to use a & b values in the yield equation.

Acquiring knowledge of population dynamics and stock status of fish depends on reliable estimates of mortality. In an exploited fish stock, mortality occurs due to fishing (fishing mortality, F) and natural causes (natural mortality, M) such as old age, predation, disease, lack of food, and competition (Sparre & Venema, 1998; King, 1995). Usually, natural mortality rates are high in early life stages and decrease with increasing size and age (King, 1995; Lorenzen, 2006). As natural death is unobservable in fish, indirect methods are usually used to estimate natural mortality rates (Sigler, 1999) which are always subject to uncertainty (Vetter, 1988).

Natural mortality of fish is often derived from empirical equations of Pauly (1980) using the surrounding water temperature, the growth coefficient K and the asymptotic length (L_{∞}) in the von Bertalanffy growth calculation or Rikhter & Efanov (1976) using age at 50% maturity or Alagaraja (1984) based on longevity of fish (Sparre & Venema, 1998). However, natural mortality values derived from empirical techniques often vary markedly (Burton, 2001) and hence care must be taken while using these estimates in population dynamics models (Vetter, 1988).

Fishing reduces the size of the population and mortality rate caused by fishing is directly influenced by level of fishing effort (Lorenzen, 2005). Excessive fishing effort can lower recruitment by preventing fish from reproductive events. Fishing and natural

mortalities (F & M) contributing to total mortality (Z) and emigration cause losses in the fish population. The annual instantaneous total mortality (Z), can be estimated by length- (Gayanilo & Pauly, 1997) or age- based assessments (Ricker, 1975).

For effective fisheries managements knowledge of resilience of population and estimates of characteristics such as age and size at 50% maturity, spawning period, spawning frequency, fecundity, growth and mortality estimation (Quinn & Deriso, 1999). The above parameters are useful for stock assessment models to estimate maximum sustainable yield and the stock levels that remain above a selected threshold limit such as 20% virgin biomass (Mace, 1994).

Analyses of yield-per-recruit (Y/R) and spawning stock biomass-per-recruit (SSB/R) help to assess suitable yield of a species by modelling specific biological traits of the species (Thompson & Bell, 1934; Ricker, 1945, 1958, 1975; Beverton & Holt, 1957). Simple age-structured population models form the basis of numerous stock assessments, where fisheries catch data are not collected, insufficient, or questionable (Griffiths, 1997; Haddon, 2001). The models incorporate interplay between somatic growth, age-specific recruitment and vulnerability to capture, and the probability of death due to natural and fishing-related factors. Separate per-recruit models are favored for their independence of catch statistics, numerical simplicity (Chen & Gordon, 1997) and their ability to integrate age-specific gear selectivity in estimating Biological Reference Points (BRPs) (Caddy & Mahon, 1995). From the yield per-recruit perspective, F_{\max} and $F_{0.1}$ are the two commonly applied BRPs based on fishing mortality that ensure sustainable long-term yields (Clark, 1993; Punt, 1993). Unfortunately, the F_{\max} approach maximizes Y/R without taking into consideration any reproductive information to ensure sufficient future recruitment (Clark, 1993) and leads to stock decline (Hilborn & Walters, 1992), so the use of $F_{0.1}$ approach is more governor (Punt, 1993; Clark, 1993). In fish populations recruitment patterns vary considerably due to protracted age structures where mature fish spawn only during

favorable conditions for recruitment (Jones, 1991). Therefore, better understanding of the relationship between spawner abundance and subsequent recruitments is important for management of fisheries (Myers, 2001). The spawner biomass-per-recruit (SBR) model is commonly used for BRP recommendations (Butterworth *et al.*, 1989; Griffiths, 1997). In a spawner biomass BRP ($F_{SB(x)}$), the fishing mortality at which spawner biomass-per-recruit lies between 25% and 50% of the unfished level (Booth & Buxton, 1997) and overfishing may occur when the SBR drops to less than 20–30% of the unfished level (Mace, 1994).

The present study aimed to generate the input parameters required for the estimation of mortality in the *P. affinis* population based on age structure characterization and incorporating them with the biological traits of the species for age-based stock assessment. As information on catch-at-age data is lacking, per-recruit analysis was undertaken to evaluate the fishery status of *P. affinis*. The results of the study would help recommend suitable management strategy for sustainable fisheries.

5.2. Materials and methods

The parameters of length and weight relationships were calculated from randomly selected fish sample to measure the condition of the fish. The relationship between total length (TL) and total (TW) was calculated as

$$W = aL^b$$

where W is the weight (g), L the total length (cm) and a and b constants which are obtained from least-squares method. ANCOVA test was used to find out the significant difference, if any, between the slopes (b) and intercepts (a) of males and females.

Instantaneous annual total mortality rates (Z) of *P. affinis* were assessed using numbers-at-age data for males, females and sexes combined (Chapter 2) using the

semilogarithmic regression method (Ricker, 1975). By plotting age (t) against natural logarithm of the number of fish belonging to that age ($\ln N_t$), the resulting straight line has a slope equal to $-Z$ ($b = -Z$). The Z -value was evaluated from the fully recruited age group and upward. The Small fish were excluded from the calculation because they were not fully contribute to the fishery.

The instantaneous natural mortality rates (M) for males, females, and sexes combined were estimated using the following empirical formulae:

$$\text{Rikhter \& Efanov (1976): } M = (1.52/(t_{m50\%})^{0.72}) - 0.155$$

$$\text{Pauly (1980): } \ln(M) = -0.0152 - 0.279 \ln(L_{\infty}) + 0.6543 \ln(K) + 0.463 \ln(T)$$

$$\text{Hoenig (1983): } \ln(M) = 1.44 - 0.982 \ln(t_{\max})$$

$$\text{Alagaraja (1984): } M = -\ln(0.01)/t_{\max}$$

where L_{∞} is the asymptotic length, K the growth coefficient, T the mean annual seawater temperature ($^{\circ}\text{C}$), t_{\max} the maximum age, and $t_{m50\%}$ the age at 50% maturity. The mean annual seawater temperature of 23°C (Morrison *et al.*, 1998; McIlwain *et al.*, 2006 and this study) was used in Pauly's (1980) equation. The growth parameters (L_{∞} and K) were obtained from the age and growth study (Chapter 2). The parameter t_{\max} was equal to 9 years which was the maximum age recorded in this study (Chapter 2).

The instantaneous fishing mortality (F) was estimated by subtracting the natural mortality rate from the total mortality rate as:

$$F = Z - M$$

The exploitation rate (E) was analysed from the ratio F/Z (Gulland, 1971). Length at 50% capture (L_c) was estimated from the cumulative percentage length–frequency data.

Selectivity curves were fitted with a logistic function to the plot of proportion of capture against size, from which values of parameter (L_c). The logistic equation used was:

$$P = \frac{100}{1 + \exp(-r(L - L_c))}$$

where P is the proportion of capture in length class L and r the width of the ogive.

Spawning stock biomass-per-recruit (SBR) and yield per recruit (Y/R) were calculated using different values of F (0 to 4 y^{-1}). SBR (in g) was calculated using the equation:

$$SBR = \frac{SB}{R} = \sum_{t=0}^{t_{\max}} \exp(-(FS_t + M)t) a(L_t)^b G_t$$

where SB is the total spawner biomass (in g), R the number of recruits and was set to 1, F the fishing mortality rate, M the natural mortality rate, a and b the length–weight relationship constants of fish, L_t the predicted von Bertalanffy mean length-at-age t , t_{\max} the maximum observed age in the fishery (year), S_t the gear selectivity at age t which is also assumed to be knife-edge selection as

$$S_t = \begin{cases} 0, & \text{if } t < t_c \\ 1, & \text{if } t \geq t_c \end{cases} \quad \text{where } t_c = \text{the age at 50\% capture.}$$

G_t the fraction of mature fish at age t is

$$G_t = \begin{cases} 0, & \text{if } t < t_m \\ 1, & \text{if } t \geq t_m \end{cases} \quad \text{where} \quad t_m = \text{the age at 50\% maturity.}$$

Y/R was calculated from the following equation:

$$\frac{Y}{R} = \sum_{t=t_R}^{t_\lambda} \left[\frac{W_t S_t F}{S_t F + M} (1 - e^{S_t F - M}) e^{-\sum_{j=t_R}^{t-1} (S_j F + M)} (1 - D_t) \right]$$

where W_t is the total weight of fish estimated from the length–weight relationship. D_t is discarding and t_R age at recruitment

$$\text{Egg production} = \sum_{t=t_R}^{t_\lambda} N_t P_t g_t e_t$$

where P_t is the proportion of mature females of age t , g_t the proportion of females of age t , and e_t the egg production of fish of age t .

To test the sensitivity of the model to M , three different values of natural mortality (estimated $M \pm 10\%$ of this value) were used to produce three Y/R, SB/R , and egg production curves. We calculated BRPs (Thompson & Bell, 1934; Clark, 1991) for *P. affinis* based on spawning biomass-per-recruit ($F_{20\%}$ and $F_{40\%}$) and Y/R ($F_{0.1}$ and F_{Max}) to determine the current status of the *P. affinis* resource as well as to evaluate the effectiveness of the different values of natural mortality (M). F_{Max} is the fishing mortality at which maximum Y/R is obtained.

5.3. Results

The length–weight relationships of males and females are shown in Table 5.1. The values “*b*” obtained were close to 3 (Table 5.1). Arabian pandora female and male in Arabian Sea shown negative allometry growth, and when all fish individuals were combined together, negative allometry growth of weight with length was noted by applied the t-test (-0.1174). ANCOVA revealed no significant difference in the relationships between males and females ($F = 0.120$, $df = 1, 560$, $P > 0.05$).

Table 5.1 Length–weight relationship of *P. affinis*.

	<i>a</i>	<i>b</i>	<i>N</i>	<i>R</i> ²
Males	0.0174	2.953	279	0.968
Females	0.0165	2.97	283	0.966
All	0.0173	2.954	562	0.967

The minimum size caught was 13 cm and the selectivity analysis indicated that 50% of Arabian pandora were caught at a total length of 19.8 cm and the selectivity range was 8.2 cm (19.8–28 cm) (Fig. 5.1). This length is corresponding to an age of about 2.48 years using the von Bertalanffy (1934) equation. Whereas the size at which 100% of fish were fully taken on to the fishery was 28 cm (TL).

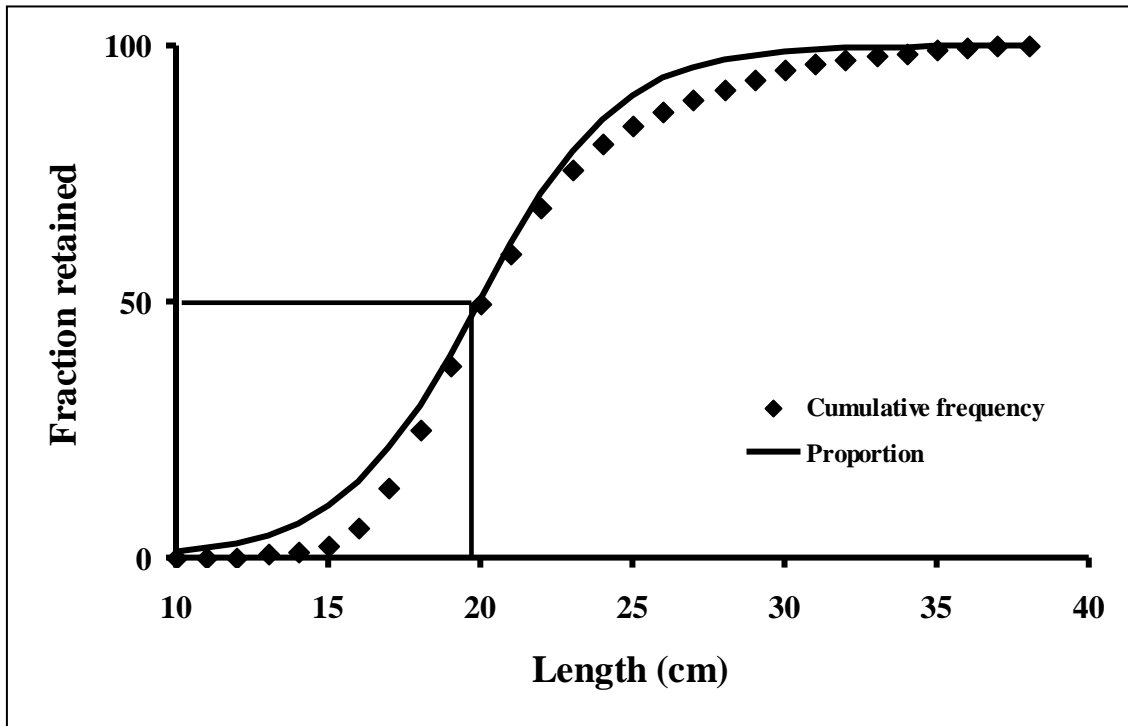


Figure 5.1 Selectivity curve for *P. affinis* in the Arabian Sea showing the mean size at 50% capture.

Total mortality rates of males, females and sexes combined *P. affinis* are shown in Fig. 5.2. The Z-value estimated for males, females and pooled sexes was found to be 0.9616, 0.9191 and 0.9363 y^{-1} , respectively. The correlation coefficient values were high indicating the good fitting of the regression (Fig. 5.2). The total mortality rate (Z) of males was higher than that of females. The difference between sexes may be due to that males were more vulnerable to the fishery than females of the same size.

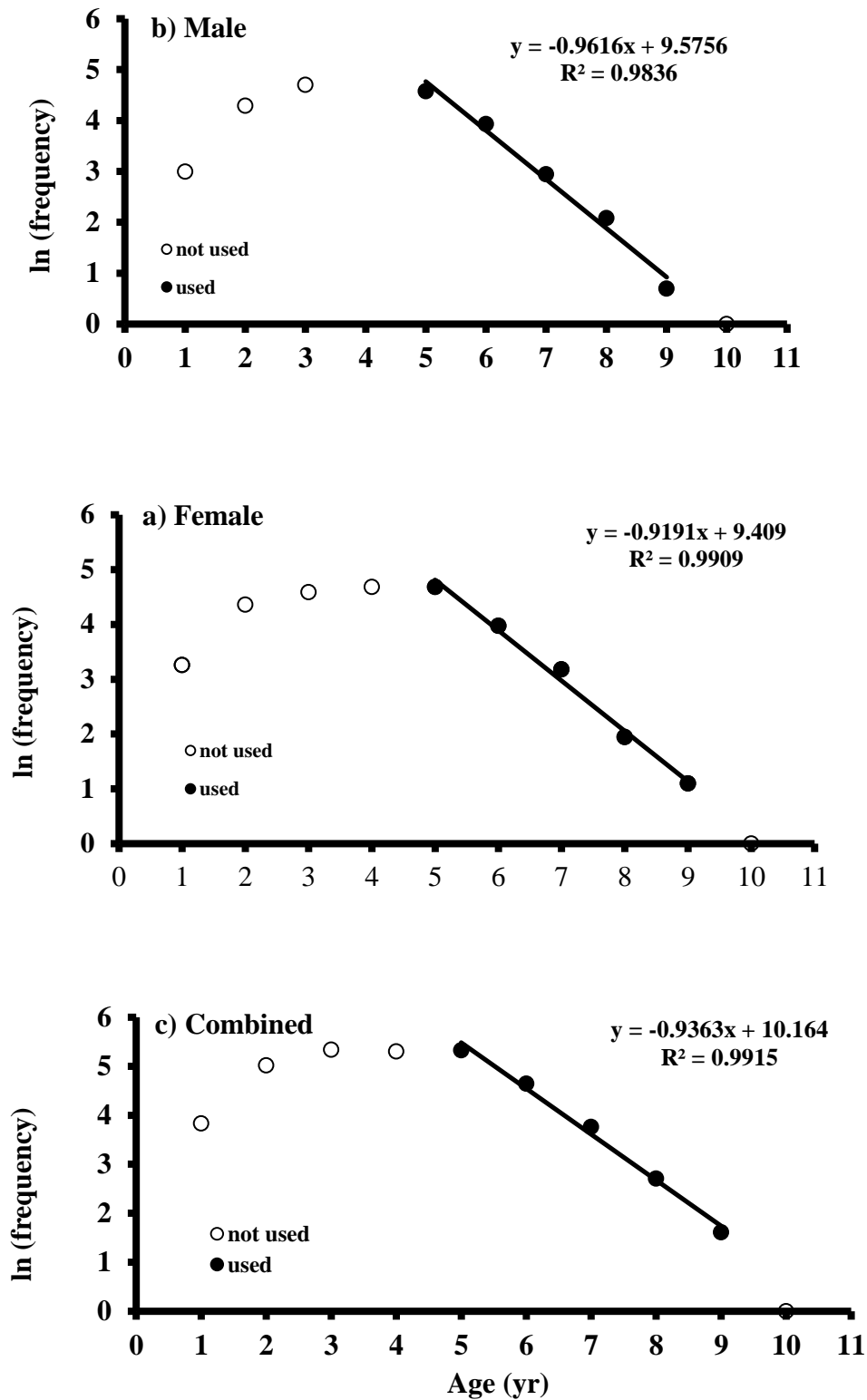


Figure 5.2 Age-based catch curves for female, male, and sexes combined for *P. affinis*. Black data points indicate the data selected for mortality estimation by linear regression analysis.

Estimates of M varied substantially and depended on the method used. Natural mortality calculated for *P. affinis* as well as the estimated longevity of sexes combined data are given in Table 5.2. Pauly's (1980) method gave the highest M -value, while the estimated M from Hoenig's (1983) and Rikhter & Efanov (1976) was the same (0.488). Although, Alagaraja's (1984) equation gave the estimate of longevity as predicted in the aging study (Chapter 2), the value estimated by Hoenig's (1983) technique was selected for molding as the value was similar to Rikhter & Efanov (1976).

Table 5.2 Different natural mortality rates (M) according to the different equations for *P. affinis* in the Arabian Sea

Method	M (y^{-1})			
	Male	Female	Combined	Te
Rikhter and Efanov (1976)	0.449	0.514	0.488	9.6
Pauly (1980) (23°C)	0.641	0.650	0.646	7.13
Hoenig (1983)	0.488	0.488	0.488	9.4
Alagaraja (1984)	0.512	0.512	0.512	8.99

Te = longevity.

Using the resultant Z and M values, the fishing mortality (F) was estimated as $0.448 y^{-1}$ and the exploitation (E) rate was computed as $0.4788 y^{-1}$.

The parameters used for a per-recruit analysis (Beverton & Holt, 1957) are given in Table 5.3. At the current fishing mortality (F_{curr}), the spawning biomass-per-recruit (SBR) was at 58.02% when correlated to a state of no fishing (Fig. 5.3). The spawner biomass and egg per recruit decreased with increasing of F , particularly at +10% of M . The precautionary reference point, when fishing mortality leaving 20% of the virgin egg per recruit, may result in recruitment as overfishing exceeded for three values of natural

mortality (M) at the current fishing mortality. BRPs ($F_{20\%} = 1.33 \text{ y}^{-1}$ and $F_{\max} = 2.6 \text{ y}^{-1}$) for *P. affinis* from spawning biomass-per-recruit and Y/R estimations were quite high due to high natural mortality and recruitment to the fishery.

The Y/R analysis was estimated to show whether the present fisheries are exploited near the optimum level of fishing mortality. This analysis (Fig. 5.4) assumed from base case and the size-at-first capture ($L_c = 19.8 \text{ cm}$) showed that the maximum Y/R at $M = 0.488 \text{ y}^{-1}$ was obtained at $F_{\max} = 2.6 \text{ y}^{-1}$, while the value of $F_{0.1}$ was 0.572 y^{-1} . For the three cases (base case, -10% and $+10\%$ of M), the Y/R curves increase to F_{\max} and the estimates for $F_{0.1}$ were quite convergent to current fishing mortality for all the three cases (0.57 , 0.51 , and 0.63 y^{-1} , respectively) (Fig. 5.4). While, the Y/R suggested a maximum yield for -10% of (M) at F_{\max} equal to 1.89 y^{-1} , for $+10\%$ of (M), the maximum Y/R was obtained at an F -value of 3.50 y^{-1} . The curves (Fig. 5.4) also show that Y/R was at about $F_{0.1}$ with present exploitation rate and size of 50% capture. Hence, further rise in the exploitation rate retaining the current size-selective features of gear (i.e., L_c constant) would not markedly alter the relative yield. Figure 5.5 shows the response of Y/R to different levels of natural mortality (M) and size-at- 50% capture (L_c). The response isopleths showed that by increasing fishing mortality higher yield could be attained. At $M = 0.4$, the peak yield-per-recruit corresponded to $L_c = 23\text{--}27 \text{ cm}$, which was higher than the current $L_c = 19.8 \text{ cm}$. At M -value of 0.5 , the yield decreased even with increased F -values.

To evaluate the suitability of length-at-first capture for *P. affinis* fishery, the size ($L = 23 \text{ cm}$) at which Y/R was maximum was used. The result showed that a higher Y/R could be obtained (Fig. 5.6), but it is understandable that the rise in Y/R related with an increase in the size-at- 50% capture was anticipated to happen at high rates of exploitation at which the outstanding biomass would be dropped to very low level. Therefore, the ($L_c =$

19.8) size of fish at first capture is optimum exploitation to maintain stock biomass. The present level of $E = 0.4788$ is close to that giving a YPR of $F_{0.1} = 0.572$.

Table 5.3 Parameters of *P. affinis* in the Arabian Sea that are used in the per-recruit analysis

Parameters	Values
(1) Growth	
L_{∞}	36.05752 cm
K	0.264 y^{-1}
t_0	-0.52528 y^{-1}
(2) $\ln(W-L)$	
a	-4.05604
b	2.95492
(3) Selectivity	
m	0.668
L_c	19.8 cm
t_c	2.48 y
(4) Discarding	
d_l	0
d_{50}	0
(4) Mortality	
F_{curr}	0.4483 y^{-1}
M	0.4879 y^{-1}
-10% M	0.4391 y^{-1}
+10% M	0.537 y^{-1}
(5) Fecundity	
a	0.0001
b	6.33
(6) Maturity	
m	0.6
L_{50}	22.1 cm
t_m	3.15 y
t_{max}	9 y

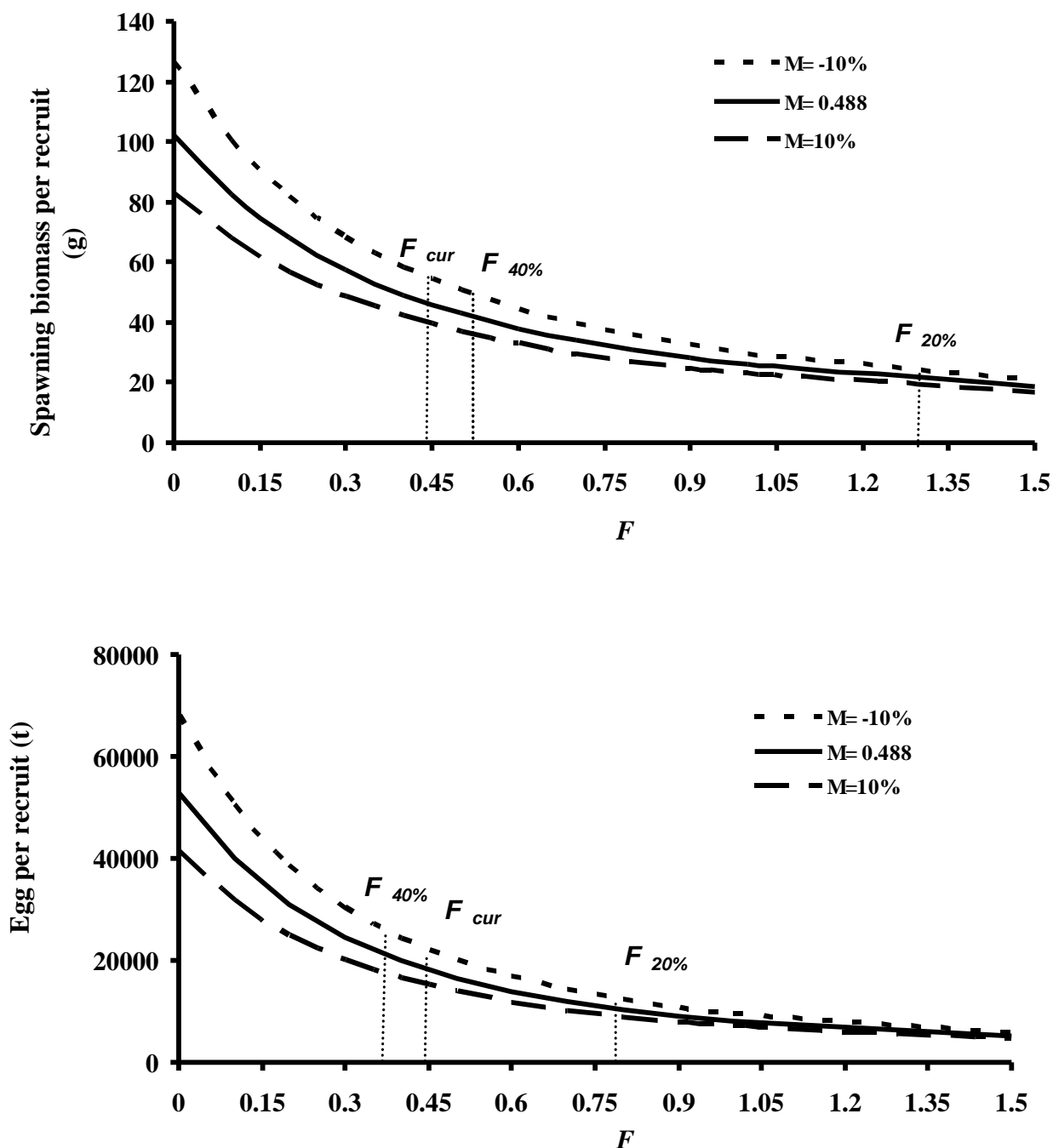


Figure 5.3 Spawning biomass-per-recruit curves for *P. affinis* in the Arabian Sea using different natural mortality rates generated from biological sampling. The dotted lines indicate F_{curr} , $F_{40\%}$ and $F_{20\%}$. Reference point; where $F_{40\%}$ and $F_{20\%}$ = the fishing mortality rate at which spawning biomass-per-recruit is reduced by 40% or 20% of unfished level.

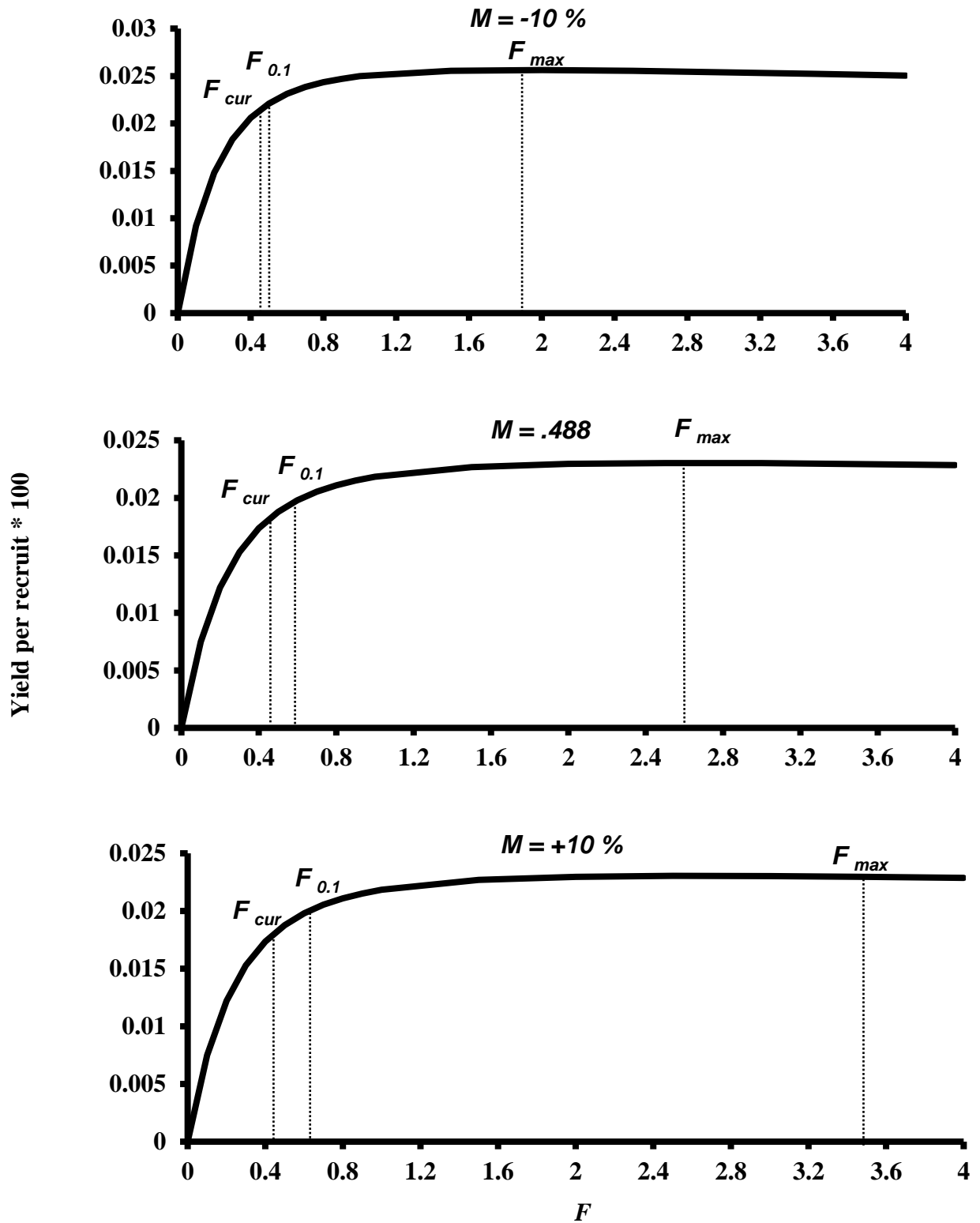


Figure 5.4 Yield-per-recruit curves for *P. affinis* in the Arabian Sea using different natural mortality rates. The dotted lines show F_{curr} , $F_{0.1}$ and F_{max} .

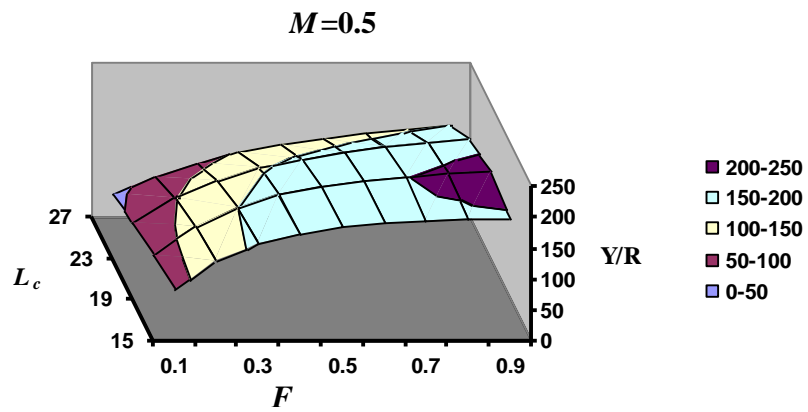
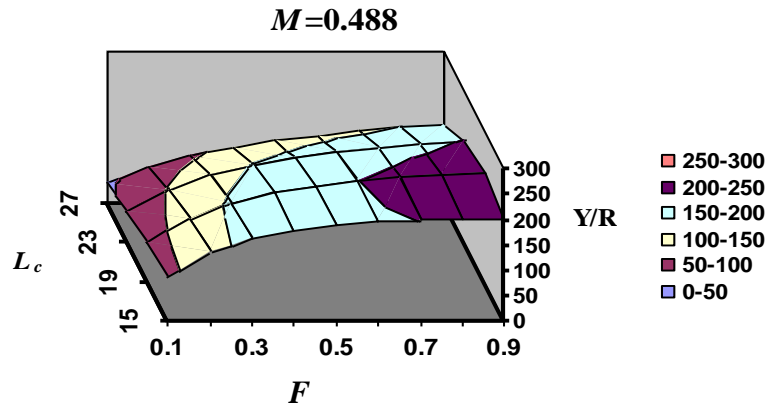
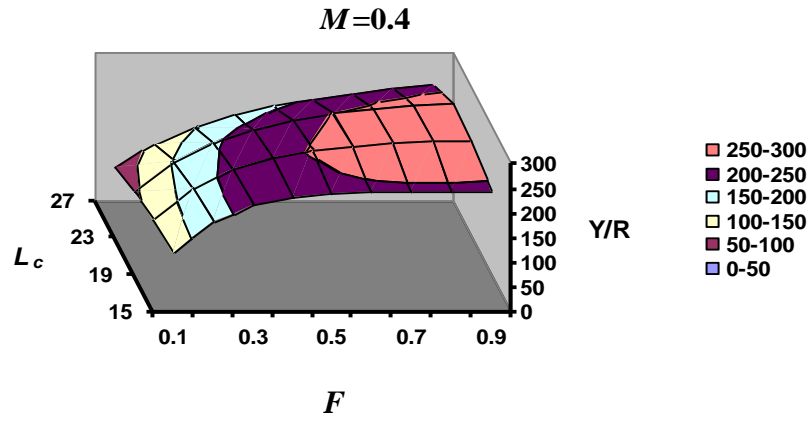


Figure 5.5 Yield-per-recruit isopleths for mean size at capture $L_c = 15\text{--}27$ cm and natural mortality $M = 0.4\text{--}0.5$ (units: Y/R in g, F in years).

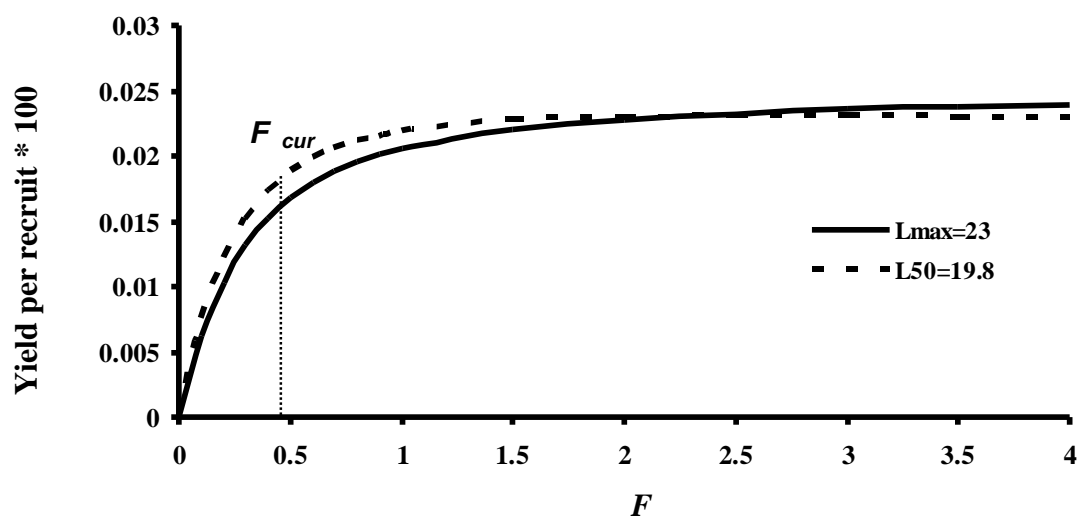


Figure 5.6 Yield-per-recruit curve for *P. affinis* in the Arabian Sea coast using different fishing mortality rates. The dotted line is F_{cur} and curves show the effect of increasing the mean size-at-first capture.

5.4 Discussion

Most fish species tend to change shape as they grow (Basimi & Grove, 1985). A fundamental tool for studying morphological variations and life history patterns in many fish species and fish population is finding the relationship between the length–weight (Gonçalves *et al.*, 1997; Santos *et al.*, 2002). The exponential b in the length–weight relationship of fish may be influenced by many factors such as sex, time of year, stage of maturity, food availability, feeding rate, and environmental conditions (Gonçalves *et al.*, 1997; Seisay, 2001; Santos *et al.*, 2002). Also, the value of the coefficient b for a species varies between stocks and between areas (Andrade & Compos, 2002). The length–weight parameters estimated in this study for males, females and combined sexes of *P. affinis* were negative allometry ($b < 3$). However, variations in length–weight relationships did not indicate the influence of season or time of the year in several species of fish, however they represented as mean annual values (Santos *et al.*, 2002). Similarly, no evidence could support that length–weight relationships are affected by reproductive activity (Andrade & Compos, 2002).

To predict the long-term impact of fishery on stocks and, relationship between the number of recruits and the abundance of spawners, the fishery models are applied (Hilborn & Walters, 1992; Quinn & Deriso, 1999; Haddon, 2001). The mortality estimates are important input parameters for applying the analytical models. In the present study, the empirical equations used for estimating M , may deviate in individual species substantially from the normal pattern (Grandcourt *et al.*, 2006). The estimate of M (0.488 y^{-1}) in *P. affinis* differs from the related species *A. spinifer* ($M = 0.374$) (Al-Mamary, 2006) and ($M = 0.573$) (Grandcourt *et al.*, 2004). Due to high water temperature in the Arabian Sea the M -value would be comparatively higher. The suggested target $F_{0.1}$ and $F_{40\%}$ values appear to be appropriate BRPs for current sustainable fisheries management. The current fishing

mortality rate ($F = 0.448 \text{ y}^{-1}$) was lower than $F_{0.1}$ (0.572 y^{-1}) and $F_{\text{SB40\%}}$ (0.537 y^{-1}). In an optimally exploited stock, fishing mortality would be equal to natural mortality, with an exploitation rate of (E) 0.5 y^{-1} (Gulland 1971).

The fish stock assessment estimates are consequently used in fisheries management for reviewing different fishing options (Lassen & Medley, 2001). The status of the *P. affinis* stock revealed that it was fully fished with the current fishing mortality proximal to the $F_{0.1}$ and $F_{40\%}$ BRPs. Several authors have suggested Target Reference Points (TRPs) of marine species based on SBR and egg-per-recruit models (Butterworth *et al.*, 1989; Booth & Buxton, 1997; Griffiths, 1997). Under data deficient situation on surplus production function and spawners–biomass–recruitment relationships, the TRPs appear to be dependable tool to determine the fishing mortality rate at which relatively high yield can be obtained with lower risks (Clark, 1991; Punt, 1993). The fish yield is a function of the annual level of recruitment and the latter is highly affected by the environmental conditions. The analysis of Y/R has the limitation in considering that there is no relation between the size of the SSB and subsequent recruitment for a range of fishing mortality rates (Buxton, 1992). Hence, this is the drawback in fast-growing tropical species where the rates natural mortality is high (Gayanilo & Pauly, 1997). Per-recruit models is advantageous to develop management strategy as it allows to evaluate the response of yield to the two fundamental management measure such as the fishing mortality and age at 50% selectivity. However, the results indicated that a rise in the size-at-first capture would increase the Y/R (L_{max}), but with little reduction in yield and a slight increase in SSB at current level of exploitation. Furthermore, the maximum yield per recruit at the current size of first capture and M value was achieved at high levels of fishing mortality. Those levels were not acceptable from the management point of view as it affect the SSB which correspondingly affect the recruitment. Generally in the present study per-recruit model

responded well to changes in size-at-first capture of *P. affinis* similar to several reef fishes and sparids (Smale & Punt, 1991; Buxton, 1992; Punt *et al.*, 1993; Grandcourt *et al.*, 2004).

The stock of *P. affinis* in the Arabian Sea is optimally exploited at present with sufficient spawning biomass for recruitment. The reproductive potential (fecundity – Chapter 3) of *P. affinis* females provides evidence of a stock effect on recruitment over long time scales. This suggests that the growth, condition and abundance of spawners act in combination for reproduction and recruitment potential of the stock. Booth & Buxton (1997) suggested that such species are vulnerable to growth overfishing and stock reduction. The current fishing mortality (0.488 y^{-1}) is close to the target fishing mortality ($F_{0.1}$), and hence the current fishing effort needs to be sustained.

In conclusion, the present study shows that the current fishing mortality is slightly lesser than the natural mortality. As the resource is optimally exploited, there is no scope for further increase in fishing effort for the fishery of *P. affinis* in the Arabian Sea. The spawning stock-recruitment relationship of this species needs be established, as well as the critical areas such as nursery and spawning grounds. Further, it is necessary to construct a data base with reliable fishery statistics enabling stock assessment of higher precision.

6. General discussion

It is acknowledged that the fishing patterns like environmental and climatic conditions, have an influence on the annual yields of different fish species. Therefore, the key issues in fisheries management are to estimate the level of fishing effort that causes optimum fishing mortality coefficient and the average size at capture at which maximum sustainable yield is obtained. Thus, the biological characteristics and population parameters of *P. affinis* estimated in the this study would help to formulate suitable strategies for effective management of that fishery in the Arabian Sea.

Use of rings on the otoliths of the fish as the seasonal marks is well known (Hyndes *et al.*, 1992; Campana, 2001; Joyeux *et al.*, 2001; Grandcourt *et al.*, 2004; Brouder, 2005). Furthermore, as there is a direct relationship between fish age and otolith weight (Metin & Ilkyaz, 2008), the weight of otolith is used as a reliable predictor of fish age (Cubillos *et al.*, 2001; Pilling & Halls, 2003; Pino *et al.*, 2004; Lou *et al.*, 2005). This phenomenon was utilized in the this study to predict the age of *P. affinis*. The reliability of age determination of *P. affinis* is presently recognized by the increase in size of fish accompanied by increase in the weight of otoliths, that is the otolith weight of larger fish is heavier than those of smaller ones. The close approximation between the calculated and observed lengths in any age group is an additional evidence of the validity of the rings as true annual marks.

The difficulty of reading rings in the otoliths, owing to in distinctive seasonality in tropical regions (Sparre & Venema, 1998) was overcome in the present study by using thin otolith sections. Fowler (1995) indicated that the evidence of validation of timing and periodicity of ring formation on otoliths have disproved the belief that no annuli are formed on the tropical fishes. The otoliths of *P. affinis* in this study were found to comprise of one opaque zone and one translucent zone that formed annually (Chapter 2) and the time of annulus formation determined by the marginal increment analysis of

otoliths indicated that low increment was recorded in September. A relationship between the type of circuli and seasonal growth was existed (Wootton, 1998), where narrow bands of circuli have been found during slow growing period and the broader bands of circuli have been observed during the period of fast growth. The formation of both translucent and opaque zones was consistent each year and highly correlated to the seasonal variations in water temperature and the monsoon season which associated upwelling in the Arabian Sea. The nutrients in the upwelled water stimulate phytoplankton growth and secondary production (Luo *et al.*, 2000). This increased food availability during the postmonsoon months triggered increased growth rate which was reflected in the opaque zone formation. The formation of these zones is also related to other factors such as, photoperiod and reproduction (Panella, 1980; Manickchand-Heileman & Phillip, 2000).

Growth rate in the first year in males and females of *P. affinis* were higher. Males attained a total length of 17.195 ± 1.8 cm, while females reached a total length of 16.82 ± 1.73 cm at the end of 1 year. However, the growth rates decreased gradually with further increase in age. Similarly, in vermilion snapper, the growth increment was very high in the first year that gradually decreased in the following years (Hood & Johnson, 1999). Besides gonadal maturity in *P. affinis*, factors like availability of prey, population biomass, etc. may also influence annual growth rate in fish (Daugherty & Sutton, 2005)].

The VBG parameters (L_{∞} , K , and t_0) are the basic input data in various models used for managing and assessing the exploited fish any resources. The values of K , L_{∞} , and t_0 obtained from different methods were close to one another (Chapter 2) and there is no significant difference for those values between sexes ($K = 0.261$ for males and $K = 0.268$ for females). The age-length key (Appendix A) indicated that the maximum age of *P. affinis* was 9 years for both sexes and age groups 3 and 4 were the most abundant ones in the commercial catch.

Investigation on reproductive biology of fish helps for assessment of its potential for harvest. From this study the reproductive dynamics of *P. affinis* in the Arabian Sea is estimated. Sex determination, sequence of variation in maturity stages, spawning period, age and size-at-50% sexual maturity, and fecundity are considered as the basic data required for knowing the general reproductive biology of an exploited fish population. The ovaries and testes increase in size and weight progressively towards the spawning season. In the present study, the ripe males and females (stage V) attained their highest percentage occurrence during August–September (16.29–21.52% for males and 28.08–31.65% for females, respectively). The monthly gonado-somatic indices (GSI) of males and females of *P. affinis* showed highest values during August–September (2.78–4.023, 2.92–3.57, 2.63–3.69 for males and 2.91–4.38, 3.49–4.32, 2.97–3.93 for females, respectively). However, the correlation between the developing of gonads in fishes and the temperature is proofed (Lambert *et al.*, 2003). This was clear in the present study where the peak of spawning activity of *P. affinis* was associated with decrease in temperature (Chapter 3). HSI values in females followed a similar trend as GSI during the spawning season. The higher HSI in females might be due to the storage of vitellogenin in the liver, that is transported to the ovary as spawning requirements. The same finding was observed for several fish species where the increase in liver size coincides with vitellogenesis (Clearwater & Pankhurst, 1994). The diameters of mature ova of *P. affinis* varied between 0.55 and 0.95 mm and the species is a fractional spawner in Oman.

Seasonal reproductive cycle is common in tropical fishes (Robertson, 1991; Montgomery & Galzin, 1993; Sadovy, 1996). In *P. affinis* spawning occurred between April and October with a peak activity during in August & September. Histological observations also corroborated that *P. affinis* is asynchronous multiple spawner, exhibiting oocyte development during a relatively long spawning period in the Arabian Sea (April–October). This might increase the possibility of recruitment in the stock for longer period

during the year. Fish typically reproduce during the period of lower water temperature and higher food availability (Shuter & Post, 1990; Scott & Pankhurst, 1992). Sadovy & Shapiro (1987) suggested that the presence of gonads containing both degenerating testicular tissue and proliferating ovarian tissue provide strong evidence of protandry. The gonads in few individuals of *P. affinis* (Chapter 3) contained predominantly the ovarian tissue besides a smaller portion of degenerating testicular tissue.

In sparids, juveniles possess both testicular and ovarian tissue (Buxton & Garratt, 1990). Therefore, when the juveniles of sparid species develop into either males or females, one type of gonadal tissue will proliferate, while the other type of gonadal tissue will be rudimentary or degenerate.

Age and size-at-50% sexual maturity of fish differ not only from one species to another, but also in same species in different localities (Trippel et al., 1997; Cardinale & Modin, 1999).

In several species of demersal fishes in the Arabian Sea, females mature earlier than males (McIlwain *et al.*, 2006). The 50% maturity of males at 23.53 cm and females at 22.1 cm indicated the age to be 3.534 and 3.145 years respectively. Hence, the stock needs protection till fourth year to spawn at least once.

Fecundity estimation has its importance in the field of fish stock assessment. It helps to evaluate the reproductive potential of an exploited fish stock. Fecundity varies not only among different species (Sadovy, 1996); but also, differs in different populations a species due to changes in environmental conditions (Cardinale & Modin, 1999). Fecundity of *P. affinis* varied from 14,460 to 757,830 eggs in females of 21.5 and 34 cm, respectively. The total length-fecundity relationship of fishes is generally curvilinear (Gunderson *et al.*, 1980). Hence, *P. affinis* exhibits a relatively protracted spawning period and a low maximum mean monthly GSI. This reduces the likelihood of all the eggs being

released during unfavorable environmental conditions and during heavy predation of eggs and larvae (Weddle & Burr, 1991; McEvoy & McEvoy, 1992).

Investigation of food and feeding habits of fish is an important aspect of fish biology. It helps to understand the prey-predator relationship and to construct trophic models of marine ecosystem (Christenen & Pauly, 1993; Walters *et al.*, 1997). Several species of demersal fishes in the Arabian sea chiefly feed on fish, crustaceans and molluscs (Al-Marzouqui *et al.*, 2009). Similarly *P. affinis* was found to feed on small teleost fishes such as sardines and benthic crustaceans such as small crabs and shrimp. Sardine and other fishes accounted for 71.53% of the diet which indicated the piscivorous nature of *P. affinis*. The low feeding intensity recorded during winter started to increase through spring to summer which was the spawning period. In the present study, occurrence of fish with empty stomachs was frequent. The occurrence of such empty stomachs or stomach with little food has been linked to the high-energy diet (Al-Marzouqi, 2012). Where fish is an main food item in the diet, the daily consumption will be less, owing to higher calorific value of the diet and as such empty stomach will be common (Sreenivasan, 1979). The rate of digestion cause frequent occurrence of empty stomach in some fishes (Wetherbee *et al.*, 1990). The information gathered on food and feeding habits of *P. affinis* will contribute to ecosystem modeling of Arabian Sea fishes.

The estimated annual total mortality coefficient (Z) of the males was lower (0.7906 y^{-1}) than that of females (0.919 y^{-1}). The high estimates of natural mortality (0.488 y^{-1}) obtained for this species by Rikhter & Efanov (1976) and Hoenig (1983) techniques may be due to the environmental conditions and/or for the method used. Also, single species might deviate significantly from the normal mortality pattern (Grandcourt *et al.*, 2006). Therefore, the estimate of M here matched favorably to that of 0.573 y^{-1} for similar species (*A. spinifer*) in the Southern Arabian Gulf (Grandcourt *et al.*, 2004).

The length–weight parameters (a & b) are essential for analytical models such as cohort or virtual population analysis (Andrade & Compos, 2002). If an individual grows isometrically, then $b \approx 3$, that is increase in weight proceeds in proportion to the cube of the length. However, when $b \neq 3$, growth in weight proceeds at a different rate (Pauly, 1984) called allometric growth pattern (positive if $b > 3$, negative if $b < 3$) and most fish species tend to change body shape as they grow (Basimi & Grove, 1985). The length–weight parameters estimated in this study for males, females and combined sexes of *P. affinis* were negative allometry ($b < 3$). However, the relation between weight and length is not fixed for whole year and due to variation in availability of food, rate of feeding, development of the gonad and spawning season (Santos *et al.*, 2002).

In the present study, analytical model (Beverton & Holt, 1957) was applied to determine the optimum level of fishing effort to obtain optimum yield of *P. affinis*.

This model estimates the yield-per-recruit for a particular set of fishing mortality coefficients was applied to regulate the catch–size composition. This model was applied because its predominant and widely use in fisheries management (Quinn & Deriso, 1999; Restrepo, 1999). The study also investigated the biological reference point ($F_{0.1}$ strategy) for the Arabian Sea pandora fishery. For management, the use of reference point $F_{0.1}$ as a target reference point is more safe than F_{\max} (Deriso, 1987; Grabowski & Chen, 2004). The results indicated that at the present level of M (0.488 y^{-1}) and L_c (19.8 cm), the current fishing mortality coefficient (0.448) is about to which gives yield per recruit at $F_{0.1}$ (0.572).

To illustrate the influence of natural mortality coefficient (M) on the yield per recruit of *P. affinis*, the yield-per-recruit was computed by using different values of M . The results indicated that the yield-per-recruit increases as the natural mortality coefficient decreases. This means habitat conservation is necessary. The identified nursery grounds

must be protected from all sources of pollutants as well as from illegal fishing. Russ *et al.* (1998) suggested that a closed season model can be introduced onto fishing grounds that have been heavily harvested or nursery grounds that need to be conserved from fishing at certain times of the year to enhance the fishery stock. Also, the closure of fishing would protect the area habitats of ground fish stocks, reduce juveniles loss and indirect influence of trawling, and also preserve potential spawning grounds and habitat complexity (Guenette *et al.*, 1998). Such habitat protection would permit individual in a stock to grow to larger size and hence, overall fecundity might increase.

Our results recommend an increase in the mesh size of trawl and gill nets to avoid growth overfishing and recruitment overfishing. Rising the size of the mesh is a technical measure of decreasing fishing mortality (Jennings *et al.*, 2001).

In unexploited fish stock, there would be high abundance of fish, low annual mortality, wide range of length-classes and age-classes and low growth rate (Goedde & Coble, 1981; Hsieh *et al.*, 2006). The stock of *P. affinis* in the Arabian Sea is exploited at the optimum level at present. As excess effort in a fishery will change age and size structure of the populations (Stauffer *et al.*, 1996; Jackson, 1999), any increase of effort for *P. affinis* fishery would affect the spawning stock biomass and recruitment.

Development of management strategy for the rational exploitation of Arabian pandora stock in the Arabian sea requires, in addition to the results obtained (age, growth, mortality, and yield and spawning biomass), information on stock-recruitment relationship, maximum sustainable yield and the corresponding level of fishing effort. As environmental conditions impact the various life-history stages of the exploited fish stock (O'brine *et al.*, 2003), information on the biotic and abiotic factors that affect the population dynamics and stock features of the Arabian pandora is necessary to delineate the factors that cause alterations in stock size, growth and condition of *P. affinis* in the Arabian Sea.

References

- Abdel-Aziz, S.H., El-Nady, F.S. 1993.** Lipid dynamics in the common torpedo, *Torpedo torpedo*, from the south eastern Mediterranean. *J. Fish Biol.* **43**, 155–162.
- Abookire, A.A. 2006.** Reproductive biology, spawning season, and growth of female rex sole (*Glyptocephalus zachirus*). *Fish. Bull.* **104**, 350–359.
- Abrams, P.A., Rowe, L. 1996.** The effects of predation on the age and size of maturity of prey. *Evolution.* **50**(3), 1052-1061.
- Abu-Hakima, R. 1984.** Some aspects of the reproductive biology of *Acanthopagrus* spp. (Family-Sparidae). *J. Fish Biol.* **25**, 515–526.
- Abu-Seedo, F.S., AL-Khatib, H.Y. 1995.** A histological and microscopic study of ovarian development in the grey mullet, *Liza carinata* (Valenciennes 1836). *J. Uni. Kuwait (Science)* **22**, 239–254.
- Al-Abdessalaam, T.Z. 1995.** Marine species of the Sultanate of Oman, identification guide. Ministry of Agriculture and Fisheries, Marine Science and Fisheries Center, Publication no. 46/95. 338 p.
- Alagaraja, K. 1984.** Simple methods for estimation of parameters for assessing exploited fish stocks. *Ind. J. Fish.* **31**(2), 177–208.
- Algamdi, F.A. 2001.** Reproductive biology, developmental stages and some biochemical characters of gonads for *Acanthopagrus bifasciatus* (Forskal, 1775) (Family: Sparidae), in Red Sea, Jeddah region, M. Sc Thesis. Faculty of Science, Soudi Arabia, Jaddah University.
- Al-Habsi, S.H., Sweeting, C.J., Polunin, N.V.C., Graham, N.A.J. 2008.** $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ elucidation of size-structured food webs in a Western Arabian Sea demersal trawl assemblage. *Mar. Ecol. Prog. Ser.* **353**, 55-63.
- Al-Mamry, J.M. 2006.** Biology and fisheries management of King soldier bream, *Argyros spinifer* and spangled emperor, *Lethrinus nebulosus* in the Arabian Sea, Oman. Unpublished PhD Thesis, University of Wales, United Kingdom. 422 p.

Al-Marzouqui, A. 2012. Food and feeding habits of Santer seabream *Cheimerius nufar* (Val.,1830) from the Arabian Sea coast of Oman. *J. Mar. Biol. Ass. India*, **54** (1), 108 - 112.

Al-Marzouqui, A., Al-Nahdi, A., Jayabalan, N., Al-Habsi, S. 2009. Stomach contents and length–weight relationship of the white-spotted rabbitfish *Siganus canaliculatus* (Park, 1797) from the Arabian Sea coast of Oman. *J. Mar. Biol. Ass. India* **51**(2), 211–216.

Al-Masroori, H., Al-Oufi, H. McIlwain J.L., Mclean E. 2004. Catch of lost fishing traps (ghost fishing) from fishing grounds near Muscat, Sultanate of Oman. *Fish. Res.* **69**, 407–414.

Andaloro, F. 1982. Resume des param &.tes biologiques sur *Pagellus acarne* de la mer Tyrrhenienne meridionale. et de la mer Ionienne septentrionale. *FAO Fish. Rep.*, No. 266, Rome, pp. 89–92.

Anderson, J.R., Morison, A.K., Ray, D.J. 1992. Age and growth of Murray cod, *Maccullochella peelii* (Perciformes: Percichthyidae), in the lower Murray-Darling basin, Australia, from thin-sectioned otoliths. *Aust. J. Mar. Freshwater Res.* **43**, 983–1013.

Andrade, H.A., Compos, R.O. 2002. Allometry coefficient variation of the length-weight relationship of skipjack tuna (*Katsuwonus pelamis*) caught in the southwest South Atlantic. *Fish. Res.* **55**, 307–312.

Anon, 2010. Annual statistics report for 2009 for the Sultanate of Oman. Department of Fisheries statistics, Directorate General of Fisheries Resources, Ministry of Agriculture & Fisheries, Muscat, Sultanate of Oman.

Araya, M., Clubillos, L.A., Guzman, M., Penailillo, J., Sepulveda, A. 2001. Evidence of a relationship between age and otoliths weight in the Chilean Jack Mackerel, *Trachurus symmetricus murphyi* (Nichols). *Fish. Res.* **51**, 17–26.

Ashjian, C.J., Smith, S.L., Flagg, C.N., Idrisi, N. 2002. Distribution, annual cycle and vertical migration of a coustically derived biomass in the Arabian Sea during 1994-1995: Deep Sea Research, Part II: Topical Studies in Oceanography, **94**(12), 2377-2402.

- Baird, J.S., Bagley, N., Devine, J., Gauthier, S., McKoy, J., Macaulay, G., Dunford, A. 2009.** Fish resources assessment survey of the Arabian Sea coast of Oman. Technical Report 5. Fishery resources of the Arabian Sea coast of Oman: Habitat, biodiversity and oceanography. Final report prepared for the Ministry of Fish Wealth, Sultanate of Oman. Bruce Shallard and Associates, 157 p.
- Baker, M.S. Jr., Wilson, C.A. 2001.** Use of bomb radiocarbon to validate otolith section ages of red snapper *Lutjanus campechanus* from the northern Gulf of Mexico. *Limnol. Oceanogr.* **46**(7), 1819–1824.
- Bani, A., Moltschaniwskyj, N.A. 2008.** Spatio-temporal variability in reproductive ecology of sand flathead, *Platycephalus bassensis*, in three Tasmanian inshore habitats: potential implications for management. *J. Appl. Ichthyol.* **24**, 555–561.
- Barbieri-Lowerre, S.K., Chittenden, M.E. Jr., Barbieri, L.R. 1996.** The multiple spawning pattern of weakfish in the Chesapeake Bay and Middle Atlantic Bight. *J. Fish Biol.* **48**, 1139–1163.
- Basimi, R.A., Grove, D.J. 1985.** Studies on feeding, growth and reproduction of a recruited inshore population of *Pleuronectes platessa*, (L.) at East Anglesey, North Wales. *J. Fish Biol.* **27**, 765–783.
- Beamish, R.J., Fournier, D.A. 1981.** A method for comparing the precision of a set of age determinations. *Can. J. Fish. Aquat. Sci.* **38**, 982–983.
- Beckman, D.W., Wilson, C.A. 1995.** Seasonal timing of opaque zone formation in fish otoliths. In: *Recent Developments in Fish Otolith Research*. Secor, D.H., Dean, J.M., Campana, S.E. (eds.). University of South Carolina Press, Columbia, S.C., pp. 27–43.
- Begg, G.A., Hopper, G.A. 1997.** Feeding patterns of school mackerel (*Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) in Queensland east-coast waters. *Mar. Freshwater Res.* **48**, 565–571.
- Ben Meriem, S., AlMarzouqi, A., Nahdi, A., Al Mamry, J., Mosharifi, N. 2003.** Current status of traditional Oman fisheries. Demersal fish project N: 5. Ministry of Agriculture and fisheries, Marine Science and Fisheries Center, Sultanate of Oman, 94 p.

Beverton, R.J.H., Holt, S.J. 1957. On the dynamics of exploited fish populations. UK. Minist. Agric. Fish. *Food. Fish. Invest. (Ser. 2)* **19**, 533 p.

Björnsson, B.Th., Stefansson, S.O., McCormick, S.D. 2011. Environmental endocrinology of salmon smoltification. *Gen Comp Endocrinol.* **170**, 290-298.

Blaxter, J.H.S., Hunter, J.R. 1982. The biology of clupeoid fishes. *Adv. Mar. Biol.* **20**, 1–223.

Bless, R. 1994. Contributions to the spawning behaviour of the spiralin- *Alburnoides bipunctatus* (Bloch) under laboratory conditions. *Fischokologie. Koln.* **7**, 1-4.

Bone, Q., Marshall, N.B., Blaxter, J.H.S. 1996. Biology of fishes, 2nd edn. Chapman & Hall, London. 332 p.

Booth, A.J., Buxton, C.D. 1997. The biology of the panga, *Pterogymnus laniarius* (Teleostei: Sparidae), on the Agulhas Bank, South Africa. *Environ. Biol. Fish* **49**, 207–226.

Bortone, S.A., Hollinsworth, C. 1980. Aging red snapper, *Lutjanus campechanus*, with otoliths, scales, and vertebrae. *Northeast Gulf Sciences* **4**(1), 60–63.

Bowker, A.H. 1948. A test for symmetry in contingency tables. *J. Am. Stat. Assoc.* **43**, 572–574.

Branstetter, S. 1987. Age and growth validation of newborn sharks held in laboratory aquaria, with comments on the life history of the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*. *Copeia*, 291–300.

Brodziak, J., Mikus, R. 2000. Variation in life history parameters of Dover sole, *Microstomus pacificus*, off the coasts of Washington, Oregon, and northern California. *Fish. Bull.* **98**, 661–673.

Bromley, P.J., Ravier, C., Witthames, P.R. 2000. The influence of feeding regime on sexual maturation, fecundity and atresia in first-time spawning turbot. *J. Fish Biol.* **56**, 264–278.

Brouder, M.J. 2005. Age and growth of Roundtail Chub in the upper Verde River, Arizona. *Trans. Am. Fish. Soc.* **134**, 866–871.

- Brouwer, S.L., Griffiths, M.H. 2005.** Reproductive biology of carpenter seabream (*Argyrozona argyrozona*) (Pisces: Sparidae) in a Marine Protected Area. *Fish. Bull.* **103**(2), 258–269.
- Brown-Peterson, N., Franks, J.S., Burke, A.M. 2000.** Preliminary observation on the reproductive biology of Wahoo, *Acanthocybium solandri*, from the northern Gulf of Mexico and Bimini, Bahamas. *Proc. Gulf Carib. Fish. Inst.* **51**, 414–427.
- Burton, M.L. 2001.** Age, growth, and mortality of gray snapper, *Lutjanus griseus*, from the east coast of Florida. *Fish. Bull.* **99**, 254–265.
- Butterworth, D.S., Punt, A.E., Borchers, D.L., Pugh, J.G., Hughes, G.S. 1989.** A manual of mathematical techniques for linefish assessment. *Report of the South African National Scientific Programmes* **160**, 1–89.
- Buxton, C.D. 1992.** The application of yield-per-recruit models to two South African sparid reef species, with special consideration to sex change. *Fish. Res.* **15**, 1–16.
- Buxton, C.D., Clarke, J.R. 1991.** The biology of the white musselcracker, *Sparodon durbanensis* (Pisces: Sparidae) on the Eastern Cape coast, South Africa. *S. Afr. J. Mar. Sci.* **10**, 285–296.
- Buxton, C.D., Clarke, J.R., 1992.** The biology of the bronze bream, *Pachymetopon grande* (Teleostei: Sparidae) from the south-east Cape coast, South Africa. *S. Afr. J. Zool.* **27**, 21–32.
- Buxton, C.D., Garratt, P.A. 1990.** Alternative reproductive styles in seabreams (Pisces: Sparidae). *Environ. Biol. Fish.* **28** (1–4), 113–124.
- Caddy, J.F., Mahon, R. 1995.** Reference points for fisheries management. FAO Fisheries Technical paper No. 347. Fisheries Department, FAO, ESSn 0429-9345. Roma, Italy, 83 p.
- Campana, S.E. 1999.** Chemistry and composition of fish otoliths: pathways, mechanisms and applications. *Mar. Ecol. Prog. Ser.* **188**, 263–297.

- Campana, S.E. 2001.** Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *J. Fish Biol.* **59**, 197–242.
- Campana, S. E., Jones, C., McFarlane, G.A., Myklevoll, S. 2006.** Bomb dating and age validation using the spines of sping dogfish (*Squalus acanthias*). *Environ. Biol. Fish.* **77**, 327–336.
- Campana, S.E., Neilson, J.D. 1985.** Microstructure of the otolith. *Can. J. Fish. Aquat. Sci.* **42**, 1014–1032.
- Cardinale, M., Arrhenius, F., Johnsson, B. 2000.** Potential use of otoliths weight for the determination of the age-structure of Baltic cod (*Gadus morhua*) and plaice (*Pleuronectes platessa*). *Fish. Res.* **45**, 239–252.
- Cardinale, M., Modin, J. 1999.** Changes in size-at-maturity of Baltic cod (*Gadus morhua*) during a period of large variations in stock size and environmental conditions. *Fish. Res.* **41**, 285–295.
- Chale-Matsau, J.R., Govender, A., Beckley, L.E. 2001.** Age, growth and retrospective stock assessment of an economically extinct sparid fish, *Polysteganus undulosus*, from South Africa. *Fish. Res.* **51**, 87–92.
- Chang, W.Y.B. 1982.** A statistical method for evaluating the reproducibility of age determination. *Can. J. Fish. Aquat. Sci.* **39**, 1208–1210.
- Chen, Y., Gordon, G.N.G. 1997.** Assessing discarding at sea using a length-structured yield-per-recruit model. *Fish. Res.* **30**, 43–55.
- Chen, Y., Jackson, D.A., Harvey, H.H., 1992.** A comparison of von Bertalanffy and polynomial functions in modeling fish growth data. *Can. J. Fish. Aquat. Sci.* **49**, 1228–1235.
- Choat, J.H., Robertson, D.R., Ackerman, J.L., Posada, J.M. 2003.** An age-based demographic analysis of the Caribbean stoplight parrotfish *Sparisoma viride*. *Mar. Ecol. Prog. Ser.* **246**, 265–277.

Christenen, V., Pauly, D. 1993. Flow characteristics of aquatic ecosystems. In: Trophic Models of Aquatic Systems. Christenen, V., Pauly, D. (eds.). ICLARM Conference Proceedings No. 26, pp. 338–352.

Chuwen, B.M., Potter, I.C., Hoeksema, S. D., Laurenson, L. J. B. 2011. Changes in catch rates and length and age at maturity, but not growth, of an estuarine plotosid (*Cnidoglanis macrocephalus*) after heavy fishing. *Fish. Bull.* **109**, 247–260.

Claramunt, G., Roa, R. 2001. An indirect approach of estimating spawning fraction as applied to *Sardinops sagax* from northern Chile. *Sci. Mar.* **65** (2), 87–94.

Clark, F.N. 1934. Maturity of the California sardine, *Sardina caerulea*, determined by ova diameter measurements. *Fish. Bull. Sacramento.* **42**, 7–49.

Clark, W.G. 1991. Groundfish exploitation rates based on life history parameters. *Can. J. Fish. Aquat. Sci.* **48**, 734–750.

Clark, W.G., 1993. The effect of recruitment variability on the choice of a target level of spawning biomass per recruit. In: Kruse, G., Eggers, D.M., Marasco, R.J., Pautzke, C., Quinn II, T.J. (Eds.), Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Alaska Sea Grant College Program Report No. 93-02. University of Alaska, Fairbanks, pp. 233–246.

Clearwater, S.J., Pankhurst, N.W. 1994. Reproductive biology and endocrinology of female red gurnard, *Chelidonichthys kumu* (Lesson and Garnot) (Family Triglidae), from the Hauraki Gulf, New Zealand. *Aust. J. Mar. Freshwater Res.* **45**, 131–139.

Collins, L.A., Johnson, A.G., Koenig, C.C., Baker, M.S. 1998. Reproductive patterns, sex ratio, and fecundity in gag, *Mycteroperca microlepis* (Serranidae), and the protogynous grouper from the northeastern Gulf of Mexico. *Fish. Bull.* **96**, 415–427.

Collins, M.R., Sedberry, G.R. 1991. Status of vermilion snapper and red porgy stocks off South Carolina. *Trans. Am. Fish. Soc.* **120**, 116–120.

Conover, D.O. 1992. Seasonality and the scheduling of life history at different latitudes. *J. Fish Biol.* **41**(suppl. B), 161–178.

- Coward, K., Bromage, N.R. 1998.** Histological classification of oocyte growth and the dynamics of ovarian recrudescence in *Tilapia zillii*. *J. Fish Biol.* **53**, 285–302.
- Crossin, G.T., Hinch, S.G., Farrell, A.P., Higgs, D.A., Lotto, A.G., Oakes, J.D., Healey, M.C. 2004.** Energetics and morphology of sockeye salmon: effects of upriver migratory distance and elevation. *J. Fish Biol.* **65**, 788–810.
- Cubillos, L.A., Arcos, D.F., Buncarey, D.A., Canales, M.T. 2001.** Seasonal growth of small pelagic fish off Talcahuano, Chile (37°S, 73°W): A consequence of their reproductive strategy to seasonal upwelling? *Aquat. Living Resour.* **14**, 115–124.
- Cuellar, N., Sedberry, G.R., Wyanski, D.M. 1996.** Reproductive seasonality, maturation, fecundity, and spawning frequency of the vermilion snapper, *Rhomboplites aurorubens*, off the southeastern United States. *Fish. Bull.* **94**, 635–653.
- Dadzie, S., Abou-Seedo, F., Al-Shallal, T. 2000.** Histological and histochemical studies of oocyte development in the silver pomfret, *Pampus argenteus* (Euphrasen) in Kuwait waters. *Arab Gulf J. Scient. Res.* **18**, 23–31.
- Dahle, R., Taranger, G.L., Karlsen, Ø., Kjesbu, O.S., Norberg, B. 2003.** Gonadal development and associated changes in liver size and sexual steroid during the reproductive cycle of captive male and female Atlantic cod (*Gadus morhua* L.). *Comp. Biochem. Physiol. Part A Mol Integr Physiol.* **136**, 641–653.
- Daskalov, G.M. 2002.** Overfishing drives a trophic cascade in the Black Sea. *Mar. Ecol. Prog. Ser.* **225**, 53–63.
- Daugherty, D.J., Sutton, T.M. 2005.** Population abundance and stock characteristics of flathead catfish in the Lower St. Joseph river, Michigan. *N. Am. J. Fish. Manage.* **25**, 1191–1201.
- Degani, G. 1990.** Effect of different diets and water quality on the growth of the larvae of *Trichogaster trichopterus* (B&S 1801). *Aquacult. Engin.* **9**, 367–9375.
- DeMartini, E.E., Fountain, R.K. 1981.** Ovarian cycling frequency and batch fecundity in the queenfish, *Seriphus politus*: attributes representative of serial spawning fishes. *Fish. Bull.* **79**(3), 547–560.

DeMartini, E.E., Lau, B.B. 1999. Morphometric criteria for estimating sexual maturity in two snappers, *Etelis carbunculus* and *Pristipomoides sieboldii*. *Fish. Bull.* **97** (3), 449–458.

Deriso, RB. 1987. Optimal $F_{0.1}$ criteria and their relationship to maximum sustainable yield. *Can. J. Fish. Aquat. Sci.* **44** (Suppl. 2), 339-348.

DeVlaming, V. 1983. Oocyte development patterns and hormonal involvements among teleosts. In: Rankin, J.C., Pitcher, T.J., Duggan, R.T. (Eds.). *Control Processes in Fish Physiology*. Croom Helm, London, pp. 176–199.

DeVlaming, V., Grossman, G., Chapman, F. 1982. On the use of the gonosomatic index. *Com. Biochem. Physiol. A*, **73**(1), 31–39.

DeVries, D.R., Frie, R.V. 1996. Determination of age and growth. In: Murphy, B.R., Willis, D.W. (eds.), *Fisheries techniques*, 2nd ed. Bethesda, MD, *Am. Fish. Soc.*, 483–512.

Dieckmann, U., Heino, M. 2007. Probabilistic maturation reaction norms: Their history, strengths, and limitations. *Mar. Ecol. Prog. Ser.* **335**, 253–269.

Domínguez-Seoane R., Pajuelo, J.G., Lorenzo, J.M., Ramos, A.G. 2006. Age and growth of the sharpsnout seabream *Diplodus puntazzo* (Cetti, 1777) inhabiting the Canarian archipelago, estimated by reading otoliths and by backcalculation. *Fish. Res.* **81**, 142-148.

Dougall, A. Mc. 2004. Assessing the use of sectioned otoliths and other methods to determine the age of the centropomid fish, barramundi (*Lates calcarifer*) (Bloch), using known-age fish. *Fish. Res.* **67**, 129-141.

Duponchelle, F., Ribbink, A.J., Msukaw, A., Mafuka, J., Mandere, D. 2000. Chapter 2: Depth distribution and breeding patterns of the demersal species most commonly caught by trawling in the southwest arm of Lake Malawi. In: *Fish Ecology Report: Lake Malawi/Nyasa/Niassa biodiversity conservation project*. Duponchelle, F., Ribbink, A.J. (eds.), pp. 29–183.

- Dwyer, K.S., Walsh, S.J., Campana, S.E. 2003.** Age determination, validation and growth of Grand Bank yellowtail flounder (*Limanda ferruginea*). *ICES, J. Mar. Sci.* **60**, 1123–1138.
- Edeyer, A., de Pontual, H., Payan, P., Troadec, H., Sévère, A., Mayer-Gostan, N. 2000.** Daily variations of the saccular endolymph and plasma compositions in the turbo *Psetta maxima*: relationship with the diurnal rhythm in otolith formation. *Mar. Ecol. Prog. Ser.* 287-294.
- Efron, B. 1981.** Non-parametric estimates of standard error: The jackknife, the bootstrap and other methods. *Biometrika* **68**(3), 589–599.
- Einum, S., Fleming, I.A., Cote, I.M., Reynolds, J.D. 2003.** Population stability in salmon species: effects of population size and female reproductive allocation. *J. Anim. Ecol.* **72**(5), 811–821.
- El-Agamy, A., Zaki, M.I., Awad, G.S., Negm, R.K. 2004.** Reproductive biology of *Boops boops* (Family Sparidae) in the Mediterranean environment. *Egyptian J. Aquat. Res.* **30** (B), 241-254.
- El-Greisy, Z. 2000.** Reproductive biology and physiology of *Diplodus sargus* (Family: Sparidae), in the Mediterranean Environment, PhD Thesis. Institute of Graduate studies and Research, Alex. Univ. Dep. Environ., Egypt.
- Elliott, M. 1989.** The pyrethroids: early discovery, recent advances and the future. *Pestic. Sci.* **27**, 337–351.
- FAO 2009.** The state of world fisheries and aquaculture 2008. Rome (Italy): FAO Fisheries Department. 162 p.
- Ferreira, B.P., Russ, G.R. 1994.** Age validation and estimation of growth rate of the coral trout, *Plectropomus leopardus*, (Lacepède, 1802) from Lizard Island, Northern Great Barrier Reef. *Fish. Bull.* **92**, 46–57.
- Figueiredo, M., Morato, T., Barreiros, J.P., Afonso, P., Santos, R.S. 2005.** Feeding ecology of the white seabream, *Diplodus sargus cadenati*, and the ballan wrasse, *Labrus bergylta*, in the Azores. *Fish. Res.* **75**(1-3), 107-119.

- Firedland, K.D., Ama- abassi, D., Manning, M., Clarke, L., Kligys, G., Chambers, R.C. 2005.** Automated egg counting and sizing from scanned images: Rapid sample processing and large data volumes for fecundity estimates. *J. Sea Res.* **54**, 307–316.
- Fletcher, W.J. 1991.** A test of the relationship between otolith weight and age for the Pilchard *Sardinops neopilchardus*. *Canad. J. Fish. Aquat. Sci.* **48**, 35–38.
- Fletcher, W.J., Blight, S.J. 1996.** Validation of using translucent zones of otoliths to age the pilchard, *Sardinops sagax neopilchardus*, from Albany, Western Australia. *Mar. Freshwater Res.* **48**, 617–624.
- Forberg, K.G. 1982.** A histological study of development of oocytes in capelin, *Mallotus villosus villosus* (Muller). *J. Fish Biol.* **20**, 143–154.
- Fossen, I., Albert, O.T., Nilssen, E.M. 2003.** Improving the precision of ageing assessments for long rough dab by using digitised pictures and otolith measurements. *Fish. Res.* **60**, 53-64.
- Fowler, A.J. 1995.** Annulus formation in the otoliths of coral reef fish—a review. In: Secor, D.H., Dean, J.M., Campana, S.E. (eds.). *Otolith Research*. University of South Carolina Press, Colombia, SC, pp. 45–63.
- Fowler, A.J., McLeay, L.J., Short, D.A. 2000.** Spatial variation in size and age structure and reproductive characteristic of the King George whiting (Percoidei: Sillaginidae) in South Australian waters. *Mar. Freshwater Res.* **51**, 11–22.
- Francis, M.P. 1997.** Spatial and temporal variation in the growth rate of elephantfish (*Callorhincus milii*). New Zealand. *J. Mar. Freshwater Res.* **31**, 9–24.
- Francis, M.P., Francis, R.I.C.C. 1992.** Growth rate estimates for New Zealand rig (*Mustelus lenticulaus*). *Aust. J. Mar. Freshwater Res.* **43**, 1157–1176.
- Francis, M.P., Mulligan, K.P., Davies, N.M., Beentjes, M.P. 1999.** Age and growth estimates for New Zealand hapuku, *Polyprion oxygeneios*. *Fish. Bull.* **97**, 227–242.

Garcia, C.B., Duarte, C.B., Altamar, J., Manjarres, L.M. 2007. Demersal fish density in the upwelling ecosystem off Colombia, Caribbean Sea: Historic outlook. *Fish. Res.* **85**(1–2), 68–73.

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T., Lasserre, G. 2003. The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. FAO Fish. Tech. Pap. 443, Rome, FAO, 71pp.

Gayanilo, F.C. Jr., Pauly, D. 1997. FAO-ICLARM stock assessment tools (FiSAT), Reference manual. FAO Computerized Information Series (Fisheries, eds.). FAO, Rome, 262 p.

Gerking, S.D. 1994. Feeding Ecology of Fish. Academic Press, San Diego, California, 415p.

Godø, O.R., Haug, T. 1999. Growth rate and sexual maturity in cod (*Gadus morhua*) and Atlantic halibut (*Hippoglossus hippoglossus*). *J. Northw. Atl. Fish. Sci.* **25**, 115–123.

Goedde, L.E., Coble, D.W. 1981. Effects of angling on previously fished and an unfished warm water fish community in two small lales in central Wisconsin. *Trans. Am. Fish. Soc.* **110**, 594–603.

Gomon, M.F., Glover, J.C.M., Kuitert, R.H. 1994. *The fishes of Australia's South Coast. Flora and Fauna of South Australia Handbooks Committee* (eds.). State Print, Adelaide. 992 p.

Gonçalves, J.M.S., Bentes, L., Lino, P.G., Ribeiro, J., Canário, A.V.M., Erzini, K. 1997. Weight-length relationships for selected fish species of the small-scale demersal fisheries of the south-west coast of Portugal. *Fish. Res.* **30**, 253–256.

Gooley, G.J., Anderson, T.A., Appleford, P. 1995. Aspects of the reproductive cycle and gonadal development of Murray cod, *Maccullochella peelii peelii* (Mitchell) (Percichthyidae), in Lake Charlegrark and adjacent farm ponds, Victoria. Australia. *Mar. Freshwater Res.* **46**, 723–728.

- Gordon, A.K., Bills, I.R. 1999.** Aspects of the feeding and reproductive biology of the Lake Tanganyikan cichlid, *Lamprologus ornatipinnis* (Pisces, Cichlidae). *Environ. Biol. Fish.* **55**, 431–441.
- Grabowski, R., Chen, Y. 2004.** Incorporating uncertainty into the estimation of the biological reference points $F_{0.1}$ and F_{max} for the Maine green sea urchin (*Strongylocentrotus droebachiensis*) fishery. *Fish. Res.* **68**, 367–371.
- Grandcourt, E.M., Al Abdessalaam, T.Z., Francis, F., Al Shamsi, A.T. 2004.** Biology and stock assessment of the Sparids, *Acanthopagrus bifasciatus* and *Argyrops spinifer* (Forsskal, 1775), in the Southern Arabian Gulf. *Fish. Res.* **69**(1), 7–20.
- Grandcourt, E.M., Al Abdessalaam, T.Z., Francis, F., Al Shamsi, A.T. 2005.** Population biology and assessment of the orange-spotted grouper, *Epinephelus coioides* (Hamilton, 1822), in the southern Arabian Gulf. *Fish. Res.* **74**(1), 55–68.
- Grandcourt, E.M., Al Abdessalaam, T.Z., Francis, F., Al Shamsi, A.T. 2006.** Population biology and assessment of the white-spotted spinefoot, *Siganus canaliculatus* (Park, 1797), in the southern Arabian Gulf. *J. Appl. Ichthyol.* 1–7.
- Griffiths, M.H. 1997.** The application of per-recruit models to *Argyrosous inodorus*, an important South African sciaenid fish. *Fish. Res.* **30**, 103–115.
- Grimes, C.B. 1987.** Reproductive biology of the Lutjanidae: a review. In: Polovina, J.J., Ralston, S. (eds.). *Tropical snappers and groupers: biology and fisheries management*. Westview Press, Boulder, CO. pp. 239–294.
- Guenette, S., Lauck, T., Clark, C. 1998.** Marine reserves: From Beverton and Holt to the Present. *Rev. Fish Biol. Fish.* **8**, 251–272.
- Gulland, J.A. 1971.** The fish resources of the ocean. West Byfleet, Surrey, Fishing News (Books), Ltd., for FAO, 255 p. Revised edition of *FAO Fish.Tech.Pap.* 97, 425 p.
- Gunderson, D.R., Callahan, P., Goiney, B. 1980.** Maturation and fecundity of four species of *Sebastes*. *Mar. Fish. Rev.* **42**(3–4), 74–79.

Haddon, M. 2001. Modelling and Quantitative Methods in Fisheries. CRC Press/Chapman & Hall, Boca Raton, FL. 406 p.

Halpern, B.S., Warner, R.R. 2002. Marine reserves have rapid and lasting effects. *Ecol. Lett.* **5**, 361–366.

Hanel, R., Sturmbauer, C. 2000. Multiple recurrent evolution of trophic types in north-eastern Atlantic and Mediterranean seabreams (Sparidae, Percoidei). *J. Mol. Evol.* **50**, 276–283.

Hansen, T., Karlsen, Ø., Taranger, G.L., Hemre, G., Holm, J.C., Kjesbu, O.S. 2001. Growth, gonadal development and spawning time of Atlantic cod (*Gadus morhua*) reared under different photoperiods. *Aquacult.* **203**, 51–67.

Hanson, J.M., Chouinard, G.A. 2002. Diet of atlantic cod in the southern Gulf of St Lawrence as an index of ecosystem change, 1959–2000. *J. Fish Biol.* **60**(4), 902–922.

Hartvig, M. 2011. Ecological processes yield complex and realistic food webs. In: Food Web Ecology - individual life-histories and ecological processes shape complex communities, pp. 75 - 126. ISBN 978-91-7473-080-7. Ph.D. thesis, Department of Biology, Lund University, Sweden.

Hassin, S., Claire, M., Holland, H., Zohar, Y. 2000. Early maturity in the male striped Bass, *Morone saxatilis*, follicle-stimulating hormone and luteinizing hormone gene expression and their regulation by gonadotropin-releasing hormone analogue and testosterone. *Biol. Reprod.* **63**, 1691–1697.

Haug, T., Huse, I., Kjørsvik, E., Rabben, H. 1989. Observations on the growth of juvenile Atlantic halibut (*Hippoglossus hippoglossus* L.) in captivity. *Aquacult.* **80**, 77–86.

Havelange, S., Lepoint, G., Dauby, P., Bouquegneau, J.M. 1997. Feeding of the sparid fish *Sarpa salpa* in a seagrass ecosystem: diet and carbon flux. *PSZNI Mar. Ecol.* **18**, 289–297.

Healey, M., Lake, R., Hinch, S. 2003. Energy expenditures during reproduction by sockeye salmon (*Oncorhynchus nerka*). *Behavior* **140**, 161–182.

Heino, M., Kaitala, V. 1999. Evolution of resource allocation between growth and reproduction in animals with indeterminate growth. *J. Evol. Biol.* **12**, 423–429.

Hesp, S.A., Potter, I.C. 2003. Reproductive biology of *Rhabdosargus sarba* (Sparidae) in Western Australian waters in which it is a rudimentary hermaphrodite. *J. Mar. Biol. Assoc. U K* **83**, 1333–1346.

Hesp, S.A., Potter, I.C., Hall, N.G. 2004. Reproductive biology and protandrous hermaphroditism in *Acanthopagrus latus*. *Environ. Biol. Fish.* **70**, 257–272.

Heupel, M.R., Williams, A.J., Welch, D.J., Davies, C.R., Penny, A., Kritzer, J.P., Marriott, R.J., Mapstone, B.D. 2010. Demographic characteristics of exploited tropical lutjanids: a comparative analysis, *Fish. Bull.* **108**, 420-432.

Hilborn, R., Walters, C.J. 1992. Quantitative fisheries stock assessment: Choice, dynamics and uncertainty. Chapman & Hall, New York.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. *Fish. Bull.* **82**, 898–902.

Hoey, J. 1991. Sex ratio data for western North Atlantic swordfish. *ICCAT Coll. Vol. Sci. Pap.* **34**(2), 429–436.

Hontela, A., Stacey, N.E. 1990. Cyprinidae. In: Reproductive Seasonality in Teleosts: Environmental Influences. Munro, A.D., Scott, A.P. Lam, T.J. (ed.). CRC Press Inc., Boca Raton, FL, pp. 53–77.

Hood, P.B., Johnson, A.K. 1999. Age, growth, mortality, and reproduction of Vermilion snapper (*Rhomboplites aurorubens*) from the eastern Gulf of Mexico. *Fish. Bull.* **97**, 828–841.

Howland, K.L., Gendron, M., Tonn, W.M., Tallman, R.F. 2004. Age determination of a long-lived coregonid from the Canadian North: Comparison of otoliths, fin rays and scales in inconnu (*Stenodus leucichthys*). *Annales Zoologici Fennici* **41**, 205–214.

Hsieh, C.H., Reiss, C.S., Hunter, J.R., Beddington, J.R., May, R.M. 2006. Fishing elevates variability in the abundance of exploited species. *Nature* **443**, 859–862.

- Htun-Han, M. 1978.** The reproductive biology of the dab *Limanda limanda* (L) in the North Sea: gonadosomatic index, hepatosomatic index and condition factor. *J. Fish Biol.* **13**, 369–378.
- Hunter, J.R., Macewicz, B.J., Lo, N.C-H., Kimbrell, C.A. 1992.** Fecundity, spawning, and maturity of female Dover sole, *Microstomus pacificus*, with an evaluation of assumptions and precision. *Fish. Bull.* **90**, 101–128.
- Hunter, J.R., Macewicz, B.J., Sibert, J.R. 1986.** The spawning frequency of skipjack tuna, *Katsuwotius pelamis*, from the South Pacific. *Fish. Bul.* **84**, 895–903.
- Hyndes, G.A., Longeragan, N.R., Potter, I.C. 1992.** Influence of sectioning otoliths on marginal increment trends and age and growth estimates for the flathead, *Platycephalus soeculator*. *Fish. Bull.* **90**, 276–284.
- Hyndes, G.A., Potter, I.C. 1996.** Comparisons between the age structures, growth and reproductive biology of two co-occurring sillaginids, *Sillago robusta* and *S. bassensis*, in temperate coastal water of Australia. *J. Fish Biol.* **49**, 14–32.
- ICES. 1991.** Report of the workshop on age determination of redfish. ICES Document, CM 1991/G: 79, 18p.
- ICES. 1996.** Report of the workshop on age reading of *Sebastes* spp. ICES Document, CM 1996/G: 1, 32p.
- Ingles, J.A., Braum, E. 1989.** Reproduction and larval ecology of the blue swimming crab *Portunus pelagicus* in Ragay Gulf, Philippines. *Internationale Revue der gesamten Hydrobiologie* **74**, 471–490.
- Irlandi, E.A., Peterson, C.H. 1991.** Modification of animal habitat by large plants: mechanisms by which seagrasses influence clam growth. *Oecologia* **87**, 307-318.
- Jackson, D.C. 1999.** Flathead catfish: biology, fisheries, and management. In: Irwin, E.R., Hubert, W.A., Rabeni, C.F., Schramm, Jr., H.L., Coon, T. (eds.) *Catfish 2000: Proceedings of the International Ictalurid Symposium* 24, Bethesda, MD. American Fisheries Society, pp. 23–35.

James, N.C., Mann, B.Q., Beckley, L.E., Govender, A. 2003. Age and growth of the estuarine-dependent sparid *Acanthopagrus berda* in northern KwaZulu-Natal, South Africa. *African Zoology* **38**(2), 265–271.

Jardas, I. 1996. Jadranska ihtiofauna. Školska knjiga: Zagreb. (In Croatian). 553p.

Jayabalan, N., Al-Marzouqui, A., Al-Nahdi, A. 2011. Reproductive biology of the soldierbream, *Argyrops filamentosus* (Valenciennes, 1830) from the Arabian Sea coast of Oman. *Indian J. Fish.* **58**(1), 9-17.

Jennings, S., Kaiser, M.J., Reynolds, J.D. 2001. Marine Fisheries Ecology. Blackwell Science Ltd., Oxford.

Jennings, S., Lock, J.M. 1996. Population and ecosystem effects of reef fishing. In: *Reef Fisheries*. Polunin, N.V.C., Roberts, C.M. (eds.). Chapman & Hall, London. pp. 193-218.

Jennings, S., Reynolds, J.D., Mills, S.C. 1998. Life history correlates of responses to fisheries exploitation. Proc. R. Soc. Lond. Ser. B, *Biol. Sci.* **265**, 333–339.

Jones, G.P. 1991. Postrecruitment processes in the ecology of coral reef fish populations: a multifactorial perspective. In: *The Ecology of Fishes in Coral Reefs*. Sale, P.F. (ed.). Academic Press, San Diego, CA, pp. 294–328.

Joyeux, J.C., Aliaume, C., Zerbi, A. 2001. An alternative to validation of otolith microincrementation. *J. Fish Biol.* **58**, 873–879.

June, F.C. 1953. Spawning of yellowfin tuna in Hawaiian waters. US Fish and Wildlife Service. *Fish. Bull.* **54**, 47–64.

Kamukuru, A.T. 2005. Using otolith weight to estimate total mortality of blackspot snapper, *Lutjanus fulvivflamma* (Lutjanidae) at Mafia Island, Tanzania. Western Indian Ocean. *J. Mar. Sci.* **4**, 211–217.

Kanyerere, G.Z. 2004. Age, growth and yield per-recruit analysis of *ndunduma* *Diplotaxodon limnothrissa* (Teleostei: Cichlidae), in the southeastern arm of Lake Malawi. Masters thesis, Rhodes University, pp.16-19.

Karlsen, Ø., Holm, J.C., Kjesbu, O.S. 1995. Effect of periodic starvation on reproductive investment in first-time spawning Atlantic cod (*Gadus morhua* L.). *Aquacult.* **133**, 159–170.

King, M. 1995. Fisheries Biology, Assessment and Management. Fishing News Books, Blackwell Science Ltd.

Kjesbu, O.S., Solemdal, P., Bratlan, P., Fonn, M. 1996. Variation in annual egg production in individual captive Atlantic cod (*Gadus morhua*). *Can. J. Fish. Aquat. Sci.* **53**, 610–620.

Kokka, H., Jennions, M.D. 2008. Parental investment, sexual selection and sex ratios. *J. Evol. Biol.* **21**, 919–948

Koslow, J.A., Bell, J., Virtue, P., Smith, D.C. 1995. Fecundity and its variability in orange roughy: Effects of population density, condition, egg size, and senescence. *J. Fish Biol.* **47**(6), 1063–1080.

Labropoulou, M., Machias, A., Tsimenides, N. 1999. Habitat selection and diet of juvenile red porgy, *Pagrus pagrus* (Linnaeus, 1758). *Fish. Bull.* **97**, 495–507.

Labropoulou, M., Papaconstantinou, C. 2000. Comparison of otolith growth and somatic growth in two macrourid fishes. *Fish. Res.* **46**, 177–188.

Lambert, Y., Dutil, J.D. 1997. Can simple condition indices be used to monitor and quantify seasonal changes in the energy reserves of Atlantic cod (*Gadus morhua*). *Can. J. Fish. Aquat. Sci.* **54**(Suppl. 1), 104–112.

Lambert, Y., Dutil, J.D. 2000. Energetic consequences of reproduction in Atlantic cod (*Gadus morhua*) in relation to spawning level of somatic energy reserves. *Can. J. Fish. Aquat. Sci.* **57**, 815–825.

Lambert, Y., Dutil, J.D., Ouellet, P. 2000. Nutritional condition and reproductive success in wild fish populations. In: Proceedings of the 6th International Symposium on the Reproductive Physiology of Fish (Norberg B., Kjesbu, O.S., Taranger, G.L., Andersson, E., Stefansson, S.O., eds), pp. 77–84. Bergen: John Grieg A/S.

Lambert, Y., Yaragina, N.A., Kraus, G., Marteinsdottir, G., Wright, P. 2003. Using environmental and biological indices as proxies of egg and larval production of marine fishes. *J. Northw. Atl. Fish. Sci.* **33**, 115–159.

Lampert, V.R., Azevedo, M.A., Fialho, C.B. 2004. Reproductive biology of *Bryconamericus iheringii* (Ostariophysi: Characidae) from rio Vacacaí, RS, Brazil. *Neotropical Ichthyol.* **2**(4), 209–215.

LaRoche, J.L., Richardson, S.L. 1980. Reproduction of northern anchovy, *Engraulis mordax*, off Oregon and Washington. *Fish.Bull.* **78**, 603–618.

Lassen, H., Medley, P. 2001. Virtual population analysis. A practical manual for stock assessment. FAO Fish. Technical Paper. No. 400. 129p.

Lee, D.E., Nur, N., Sydeman, W.J. 2007. Climate and demography of the planktivorous Cassin's auklet off northern California: implications for population change. *J. Anim. Ecol.* **76**, 337–347.

Lee, E.M., Khan, R.A. 2000. Length-weight-age relationships, food, and parasites of Atlantic cod (*Gadus morhua*) off coastal Labrador within NAFO Divisions 2H and 2J-3K. *Fish. Res.* **45**, 65–72.

Lee, Y.H., Du, J.L., Yueh, W.S., Lin, B.Y., Huang, J.D., Lee, C.Y., Lee, M.F., Lau, E.L., Lee, F.Y., Morrey, C., Nagahama, Y., Chang, C.F. 2001. Sex change in the protandrous black porgy, *Acanthopagrus schlegeli*: a review in gonadal development, estradiol, estrogen receptor, aromatase activity and gonadotropin. *J. Exp. Zool.* **290**, 715–726.

Lee, Y.H., Yueh, W.S., Du, J.L., Sun, L.T., Chang, C.F. 2002. Aromatase inhibitors block natural sex change and induce male function in the protandrous black porgy, *Acanthopagrus schlegeli* Bleeker: possible mechanism of natural sex change. *Biol. Reprod.* **66**, 1749–1754.

Lemos, J.R.G., Santos, M.Q.C., Araújo, C.S.O., Andrade, S.M.S., Viana, G.M. 2012. Parasitological evaluation and body indices of *Osteoglossum bicirrhosum* (Vandelli, 1829) traded in a fair of Manaus, Amazonas, Brazil. *J. Fish. Sci.* **6**(3), 263–270.

- Leonardo, A.F.G., Romagosa, E., Batlouni, S.R., Borella, M.I. 2006.** Occurrence and significance of ovarian and follicular regression in cachara *Pseudoplatystoma fasciatum* (Linnaeus, 1766): a histology approach, *Arq. Bras. Med. Vet. Zootec.*, **58**(5), 831-840.
- Leu, M.Y. 1994.** Natural spawning and larvae rearing of silver bream, *Rhabdosargus sarba* (Forsk.) in captivity. *Aquacult.* **120**, 115–122.
- Linde, M., Palmer, M., Gómez-Zurita, J. 2004.** Differential correlates of diet and phylogeny on the shape of the premaxilla and anterior tooth in sparid fishes (Perciformes: Sparidae). *J. Evol. Biol.* **17**, 941–952.
- Løkkeborg, S., Olla, B.L., Pearson, W.H., Davis, M.W. 1995.** Behavioural responses of sablefish, *Anoplopoma fimbria*, to bait odour. *J. Fish Biol.* **46**(1), 142–155.
- Lorenzen, K. 2005.** Population dynamics and potential of fisheries stock enhancement: practical theory for assessment and policy analysis. *Philosophical Trans. of the Royal Soci. B* **360**, 171-189.
- Lorenzen, K. 2006.** Population management in fisheries enhancement: gaining key information from release experiments through use of a size-dependent mortality model. *Fish. Res.* **80**, 19-27.
- Lou, D.C., Mapstone, B.D., Russ, G.R., Begg, G.A., Davies, C.R. 2007.** Using otolith weight-age relationships to predict age based metrics of coral reef fish population across different temporal scales. *Fish. Res.* **83**(2–3), 216–227.
- Lowe-McConnell, R.H. 1979.** Ecological aspects of seasonality in fishes of tropical waters. In: Miller, P.J. (ed.). *Fish Phenology: Anabolic Adaptiveness in Teleosts*. Symposia of the Zoological Society, London 44. Academic Press, London, pp. 219–241.
- Lowerre-Barbieri, S.K., Lowerre, J.M., Barbieri, L.R. 1998.** Multiple spawning and the dynamics of fish populations: Inferences from an individual-based simulation model. *Can. J. Fish. Aquat. Sci.* **55**, 2244–2254.
- Lucena, F.M., O'Brien, C. M. 2001.** Effects of gear selectivity and different calculation methods on estimating growth parameters of bluefish, *Pomatomus saltatrix* (Pisces: Pomatomidae), from southern Brazil. *Fish. Bull.* **99**, 432–442.

- Luo, J., Ortner, P.B., Forcucci, D., Cummings, S.R. 2000.** Diel vertical migration of zooplankton and mesopelagic fish in the Arabian Sea. *Deep-Sea Res. II* **47**, 1451–1473.
- Mace, P.M. 1994.** Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. *Can. J. Fish. Aquat. Sci.* **51**, 110–122.
- Mackie, M., Lewis, P.A.W. 2001.** Assessment of gonad staging systems and other methods used in the study of the reproductive biology of narrow-barred Spanish mackerel, *Scomberomorus commerson*, in Western Australia. Fisheries Research Report 136, Department of Fisheries, Government of Western Australia, North Beach.
- Manickchand-Heileman, S.C., Phillip, D.A.T. 2000.** Age and growth of the yellowedge grouper, *Epinephelus flavolimbatus*, and the yellowmouth grouper, *Mycteroperca interstitialis*, off Trinidad and Tobago. *Fish. Bull.* **98**(2), 290–298.
- Mann, B.Q., 2000.** South African marine linefish status reports. Mann, B. Q. (Ed.). In Oceanographic Research Institute, Special Publication. Durban, South African Association for Marine Biological Research **7**, 257p.
- Manning, A.J., Crim, L.W. 1998.** Maternal and interannual comparison of the ovulatory periodicity, egg production and egg quality of the batch-spawning yellowtail flounder. *J. Fish Biol.* **53**, 954–972.
- Mariani, S., Maccaroni, A., Massa, F., Rampacci, M., Tancioni, L. 2002.** Lack of consistency between the trophic interrelationships of five sparid species in two adjacent central Mediterranean coastal lagoons. *J. Fish Biol.* **61**, 138–147.
- Marriott, R. J., Mapstone, B. D., Begg, G. A. 2007.** Age-specific demographic parameters, and their implications for management of the red bass, *Lutjanus bohar* (Forsskal 1775): a large, long-lived reef fish. *Fish. Res.* **83**(2-3), 204–215.
- Marshall, C.T., Frank, K.T. 1999.** The effect of interannual variation in growth and condition of haddock (*Melanogrammus aeglefinus*) on recruitment. *Can. J. Fish. Aquat. Sci.* **56**, 347–355.

- Marshall, C.T., Yaragina, N.A., Ådlandsvik, B., Dolgov, A.V. 2000.** Reconstructing the stock-recruit relationship for Northeast Arctic cod using a bioenergetic index of reproductive potential. *Can. J. Fish. Aquat. Sci.* **57**, 2433–2442.
- Marteinsdottir, G., Begg, G.A. 2002.** Essential relationships incorporating the influence of age, size and condition on variables required for estimation of reproductive potential in Atlantic cod *Gadus morhua*. *Mar. Ecol. Prog. Ser.* **235**, 235–256.
- Marteinsdottir, G., Thorarinsson, K. 1998.** Improving the stock-recruitment relationship in Icelandic cod (*Gadus morhua*) by including age diversity of spawners. *Can. J. Fish. Aquat. Sci.* **55**, 1372–1377.
- Mathews, C.P., Al-Mamry, J., Al Habsy, S. 2001.** Precautionary management of Oman's demersal fishery. In: Goddard, S., Al Oufi, H., McIlwain, J., Claereboudt, M. (eds.). *Proceedings of the 1st International Conference on Fisheries, Aquaculture and Environment in the Northwest Indian Ocean, 2001*. Sultan Qaboos University, Muscat, Sultanate of Oman, pp. 29–38.
- Matic-Skoko, S., Kraljevic, M., Dulcic, J., Jardas, I. 2007.** Age, growth, maturity, mortality, and yield-per-recruit for annular sea bream (*Diplodus annularis* L.) from the eastern middle Adriatic Sea. *J. Appl. Ichthyol.* **23**, 152–157.
- Mazzoni, R., Caramaschi, E.P. 1997.** Spawning season, ovarian development and fecundity of *Hypostomus affinis* (Osteichthyes, Loricariidae). *Rev. Brasil. Biol.* **57**(3), 455–462.
- McBride, R.S., Thurman, P.E. 2003.** Reproductive biology of *Hemiramphus brasiliensis* and *H. balao* (Hemiramphidae): maturation, spawning frequency, and fecundity. *Biol. Bull.* **204**, 57–67.
- McDonough CJ, Roumillat WA, Wenner CA. 2003.** Fecundity and spawning season of striped mullet (*Mugil cephalus*) in South Carolina estuaries. *Fish Bull.* **101**(4), 822–834.
- McEvoy, L.A., McEvoy, J. 1992.** Multiple spawning in several commercial fish species and its consequences for fisheries management, cultivation and experimentation. *J. Fish. Biol.* **41**, 125–136.

- McIlwain, J., Hermosa, G.V., Claereboudt, M., Al-Oufi, H.S., Al-Awi, M. 2006.** Spawning and reproductive patterns of six exploited finfish species from the Arabian Sea, Sultanate of Oman. *J. Appl. Ichthyol.* **22**(2), 167–176.
- Mckoy, J., Bagley, N., Gauthier, S., Devine, J. 2009.** Fish resources assessment survey of the Arabian Sea coast of Oman. Technical report 1. Bruce Shallard and Associates. pp. 68.
- McPherson, G.R. 1991.** Reproductive biology of yellowfin tuna in the eastern Australian fishing zone, with special reference to the North-western Coral Sea. *Aust. J. Mar. Freshwater Res.* **42**, 465–477.
- Mejuto J., de la Serna, J.M., Garcia, B. 1995.** An overview of the sex-ratio at size of the swordfish (*Xiphias gladius*) around the world: similarity between different strata. ICCAT Coll. Vol. Sci. Pap. **44**(3), 197–205.
- Mejuto, J., Garcí'a, B., Quintans, M. 1991.** A preliminary analysis of the sex-ratio of the swordfish (*Xiphias gladius*) in the North Atlantic by size class using space-time strata. ICCAT Coll. Vol. Sci. Pap. **35**(2), 473–481.
- Melville-Smith, R. 1989.** A growth model for the deep-sea red crab (*Geryon maritae*) off South West Africa/Namibia (Decapoda, Brachyura). *Crustaceana* **56**(3), 279–292.
- Mérigoux, S., Ponton, D. 1998.** Body shape, diet and ontogenetic diet shifts in young fish of the Sinnamary River, French Guiana, South America. *J. Fish Biol.* **52**(3), 556–569.
- Metin, G., Ilkyaz, A. T. 2008.** Use of otolith length and weight in age determination of poor cod (*Trisopterus minutus* linn., 1758). *Turk. J. Zool.* **32**, 293–297.
- Micale, V., Perdichizzi, F., Basciano, G. 1996.** Aspects of the reproductive biology of the sharpsnout seabream *Diplodus puntazzo* (Cetti, 1777). 1. Gametogenesis and gonadal cycle in captivity during the third year of life. *Aquacult.* **140**(3), 281–291.
- Moghadam, H., Poissant, J., Fotherby, H., Haidle, L., Ferguson, M. 2007.** Quantitative trait loci for body weight, condition factor and age at sexual maturation in Arctic charr (*Salvelinus alpinus*): Comparative analysis with rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*). *Mol. Genet. Genomics* **277**, 647–661.

- Mohan, M.V., Sankaran, T.M. 1988.** Two new indices for stomach contents analysis of fishes. *J. Fish Biol.* **33**, 289–292.
- Montgomery, W.L., Galzin, R. 1993.** Seasonality in gonads, fat deposits and condition of tropical surgeon fishes (Teleostei: Acanthuridae). *Mar. Biol.* **115**, 529–536.
- Morales-Nin, B. 1992.** Determination of growth in bony fishes from otolith microstructure. FAO Fish. Tech. Paper (Rome) **322**, 1–51.
- Morato, T., Solà, E., Gros, M.P., Menezes, G. 2003.** Diets of Thornback Ray (*Raja clavata*) and tope shark (*Galeorhinus galeus*) in the bottom longline fishery of the Azores, northeastern Atlantic. *Fish. Bull.* **101**, 590–602.
- Morrison, J.M., Codispoti, L.A., Gaurin, S., Jones, B., Manghnani, V., Zheng, Z. 1998.** Seasonal variation of hydrographic and nutrient fields during the U.S. JGOFS Arabian Sea Process Study, Deep-Sea Research, Part-II, **45**(10-11), 2053–2101.
- Mugiya, Y., Watabe, N., Yamada, J., Dean, J.M., Dunkelberger, D.G., Shimuzu, M. 1981.** Diurnal rhythm in otoliths formation in the goldfish, *Garassius auratus*. *Comp. Biochem. Physiol.* **68A**, 659–662.
- Munro, A.D., Scott, A.P., Lam, T.J. 1995.** Reproductive Seasonality in Teleosts: Environmental Influences. CRC Press Inc., Boca Raton, FL, 264p.
- Musick, J.A. 1999.** Ecology and conservation of long-lived marine animals. In: Musick, J.A., (ed.). Life in the Slow Lane: Ecology and Conservation of Long-Lived Marine Animals. *Amer. Fish. Soc. Symp.* 23, Bethesda, MD, pp. 1–10.
- Myers, R.A. 2001.** Stock and recruitment: generalizations about maximum reproductive rate, density depenitly dependence, **and** variability. *ICES J. Mar. Sci.* **58**(5), 937–951.
- Mytilineou, C. 1987.** Preliminary study of the reproductive cycle and hermaphroditism of *Pagellus erythrinus* L., in the Patraikos and Korinthiakos Gulfs and the Ionian Sea. In: Proceedings of the 2nd Hellenic Symposium on Oceanography and Fisheries, (In Hellenic with English abstract). pp. 551-557.

- Nakai, K., Yanagisawa, Y., Sato, T., Niimura, Y., Gashagaza, M.M. 1990.** Lunar synchronization of spawning in cichlid fishes of the tribe Lamprologini in Lake Tanganyika. *J. Fish Biol.* **37**, 589–598.
- Natanson, L.J., Sulikowski, J.A., Kneebone, J.R., Tsang, P.C. 2007.** Age and growth estimates for the smooth skate, *Malacoraja senta*, in the Gulf of Maine. *Environ. Biol. Fish.* **80**, 293–308.
- Neat, F.C., Balshine-Earn, S. 1999.** A field survey of the breeding habits of *Eretmodus cyanostictus*, a biparental mouthbrooding cichlid from Lake Tanganyika. *Environ. Biol. Fish.* **55**, 333–338.
- Nedreaas, K. 1990.** Age determination of Northeast Atlantic *Sebastes* species. *J. du Conseil International pour l'Exploration*, **47**(2), 208–230.
- Neilson, J.D., Green, G.H. 1982.** Otoliths of Chinook salmon (*Onchorhynchus tshawytscha*): daily growth increments and factors influencing their production. *Can. J. Fish. Aquat. Sci.* **39**, 1340–1347.
- Newman, S.J., Dunk, I.J. 2002.** Growth, age validation, mortality, and other population characteristics of the red emperor snapper, *Lutjanus sebae* (Cuvier, 1828), off the Kimberley coast of north-western Australia. *Estuarine, Coast. Shelf Sci.* **55**, 67–80.
- Nguyen-Xuan, Loc., Wojciechowski J., 1973.** Food and feeding of fish of *Dentex* genus (*Sparidae*) from Mauritania and Senegal shelf. *Acta Ichthyol. Piscat.* **3** (1), 39-48.
- Nichol, D.G., Acuna, E.I. 2001.** Annual and batch fecundities of yellowfin sole, *Limanda aspera*, in the eastern Bering Sea. *Fish .Bull.* **99**, 108–122.
- Noble, R.L., Jones, T.W. 1993.** Managing fisheries with regulations. In: Kohler, C.C., Hubert, W.A. (eds.). *Inland Fisheries Management in North America. Amer. Fish. Soc.* Bethesda, MD, 383–404.
- Ntiba, M.J., Jaccarini, V. 1990.** Gonad maturation and spawning times of *Siganus sutor* off the Kenya coast: Evidence for definite spawning season in a tropical fish. *J. Fish. Biol.* **37**, 315–325.

O'Brien, L., Rago, P., Lough, R.G., Berrien, P. 2003. Incorporating early-life history parameters in the estimation of the stock-recruit relationship of Georges Bank Atlantic cod (*Gadus morhua*). *Northw.Atl. Fish. Sci.* **33**, 191-205.

Olaso, I., Sanchez, F., Rodriguez-Cabello, C., Velasco, F. 2002. The feeding behaviour of some demersal fish species in response to artificial discarding. *Sci. Mar. (Barc.)* **66**(3), 301–311.

Ouannes-Ghorbel, A., Bouain, A. 2006. The diet of the peacock wrasse, *Symphodus (Crenilabrus) tinca* (Labridae), in the southern coast of Tunisia. *ACTA ADRIAT* **47**(2), 175–182.

Ouannes-Ghorbel, A., Bradai, M.N., Bouain, A. 2002. Breeding period and sexual maturity of *Symphodus (Crenilabrus) tinca* (Labridae), from the coast of Sfax (Tunisia). *Cybiu* **26**(2), 1–4.

Pajuelo, J.G., Lorenzo, J.M. 1996. Life history of the red porgy *Pagrus pagrus* (Teleostei: Sparidae) off the Canary Islands, central-east Atlantic. *Fish. Res.* **28**, 163–177.

Pajuelo, J.G., Lorenzo, J.M. 1998. Population biology of the common pandora *Pagellus erythrinus* (Pisces: Sparidae) off the Canary Islands. *Fish. Res.* **36**, 75–86.

Pajuelo, J.G., Lorenzo, J.M. 1999. Life history of the black seabream, *Spondyllosoma cantharus*, off the Canary Islands, Central-east Atlantic. *Environ. Biol. Fish* **54**, 325–336.

Pajuelo, J.G. , Lorenzo, J.M. 2000. Reproduction, age, growth and mortality of axillary seabream, *Pagellus acarne* (Sparidae), from the Canarian archipelago. *J. Appl. Ichthyol.* **16**, 41–47.

Pajuelo, J.G., Lorenzo, J.M. 2001. Biology of the annular seabream *Diplodus annularis* (Sparidae), in costal waters of the Canary Island. *J. Appl. Ichthyol.* **17**, 121–125.

Pajuelo, J.G., Lorenzo, J.M., Gregoiro, M. 2003. Age and growth of bastrad grunt (*Pomadasy* *incisus* : Haemulidae) inhabiting the Canarian archipelago, *Northwest Africa*. *Fish. Bull.* **101**, 851-859.

Pajuelo, J.G., Socorro, J., González, J.A., Lorenzo, J.M., Pérez-Peñalvo, J.A., Martinz, I., Hernandez-Cruz, M. 2006. Life history of the red-banded seabream *Pagrus auriga* (Sparidae) from the coasts of the Canarian archipelago. *J. Appl. Ichthyol.* **22**(5), 430–436.

Panella, G. 1980. Growth patterns in fish sagittae. In: Rhoads, D.C., Lutz, R.A. (eds.). *Skeletal Growth of Aquatic Organisms*. Plenum Press, New York, NY, pp. 519–560.

Pankhurst, N.W. 1998. Reproduction. In: Black, K.D., Pickering, A.D. (eds.). *Biology of Farmed Fish*. Academic Press, Sheffield, pp. 1–26.

Parent, S., Schriml, L.M. 1995. A model for the determination of fish species at risk based upon life-history traits and ecological data. *Can. J. Fish. Aquat. Sci.* **52**, 1768–1781.

Paul, J.M., Paul, A.J. Vogeler, T.J., Doyle, J.P. 1997. Biological investigations on Pacific sandfish (*Trichodon trichodon*) in the northern Gulf of Alaska. In: proceedings of the international symposium on the role of forage fishes in marine ecosystems. Alaska Sea Grant College Program Rep. No. 97-01, Univ. Alaska Fairbanks, pp. 87–94.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stock. *J. Cons. Int. Explor. Mar.* **39**, 175–192.

Pauly, D. 1984. Length-converted catch curves. A powerful tool for fisheries research in the tropics. (Part II). *ICLARM Fishbyte* **2**(1), 17–19.

Pauly, D., Christensen, V., Guenette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D. 2002. Towards sustainability in world fisheries. *Nature* **418**, 689–695.

Pauly, D., David, N. 1981. ELEFAN I, a BASIC program for the objective extraction of growth parameters from length-frequency data. *Meeresforsch* **28**(4), 205–211.

Pauly, D., Munro, J.L., 1984. Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte* **2**(1), 21–22.

Pilling, G.M., Grandcourt, E.M., Kirkwood, G.P. 2003. The utility of otolith weight as a predictor of age in the emperor *Lethrinus mahsena* and other tropical fish species. *Fish. Res.* **60**(2-3), 493-506.

Pilling, G.M., Halls, A.S. 2003. Age- or length-based methods of growth estimation. What drives the choice? *NAGA* **26**(2), 4-7.

Pino, C.A., Cubillos, L.A., Araya, M., Sepúlveda, A. 2004. Otolith weight as an estimator of age in the Patagonian grenadier, *Macruronus magellanicus*, in central-south Chile. *Fish. Res.* **66**(2-3), 145-156.

Pita, C., Gamito, S., Erzini, K. 2002. Feeding habits of the gilthead seabream (*Sparus aurata*) from the Ria Formosa (southern Portugal) as compared to the black seabream (*Spondylusoma cantharus*) and the annular seabream (*Diplodus annularis*). *J. Appl. Ichthyol.* **18**, 81-86.

Plaza, G., Sakaji, H., Honda, H., Hirota, Y., Nashida, K. 2007. Spawning pattern and type of fecundity in relation to ovarian allometry in the round herring *Etrumeus teres*. *Mar. Biol.* **152**, 1051-1064.

Polis, G.A., Sears, L.W., Huxel, D.R., Strong, J.M. 2000. When is a trophic cascade a trophic cascade? *Trends Ecol. Evol.* **15**, 473-475.

Potts, J.C., Manooch III, C.S. 2002. Estimated ages of red porgy (*Pagrus pagrus*) from fishery-dependent and fishery-independent data and a comparison of growth parameters. *Fish. Bull.* **100**, 81-89.

Punt, A.E. 1993. The comparative performance of production-model and ad hoc tuned VPA based feedback-control management procedures for the stock of Cape hake off the west coast of South Africa. In: *Risk Evaluation and Biological Reference Points for Fisheries Management*. Smith, S.J., Hunt, J.J., Rivard, D. (eds.). *Can. Spec. Publ. Fish. Aquat. Sci.* **120**, 283-299.

Punt, A.E. 1994. Assessments of the stocks of Cape hakes *Merluccius* spp. off South Africa. *S. Afr. J. Mar. Sci.* **14**, 159-186.

- Punt, A.E., Garratt, P.A., Govender, A. 1993.** On an approach for applying per-recruit methods to a protogynous hermaphrodite, with an illustration for the slinger *Chrysoblephus puniceus* (Pisces: Sparidae). *S. Afr. J. Mar. Sci.* **13**, 109–119.
- Quinn II T.J., Deriso, R.B. 1999.** Quantitative Fish Dynamics. Oxford University Press, New York, 542p.
- Radebe, P.V., Mann, B.Q., Beckley, L.E., Govender, A. 2002.** Age and growth of *Rhabdosargus sarba* (Pisces: Sparidae), from KwaZulu-Natal, South Africa. *Fish. Res.* **58**, 193–201.
- Raja Prasad, R., Jaiswar, A.K., Reddy, S.B., Chakraborty, S.K., Palaniswamy, R., Parida, P. 2005.** Growth, mortality and yield per recruit of *Polynemus heptadactylus* (Cuvier) (Teleostei: Polynemidae) from Mumbai waters, India. *Fish. Res.* **76**(1), 155–161.
- Randall, J.E. 1995.** Coastal Fishes of Oman. University of Hawaii Press, Honolulu, Hawaii, 227p.
- Restrepo, V.R. (ed.), 1999.** Providing scientific advice to implement the precautionary approach under the Magnuson-Steven Fishery Conservation and Management Act. In: Proceedings of the Fifth National NMFS Stock Assessment Workshop. NOAA Technical Memo, NMFS-F/SPO-40.
- Ricker, W.E. 1945.** A method of estimating minimum size limits for obtaining maximum yield. *Copeia* **2**, 84–94.
- Ricker, W.E. 1958.** Handbook of computations for biological statistics of fish populations. Department of the Environment, Fisheries and Marine Service. Ottawa, Fish. Res.Bd. Canada, Bull. No. 119, 300p.
- Ricker, W.E. 1975.** Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.* **191**, 382p.
- Rickman, S.J., Dulvy, N.K., Jennings, S., Reynolds, J.D. 2000.** Recruitment variation related to fecundity in marine fishes. *Can. J. Fish. Aquat. Sci.* **57**, 116–124.

Rijnsdorp, A.D., Vingerhoed, B. 2001. Feeding of plaice *Pleuronectes platessa*, and sole *Solea solea* in relation to the effects of bottom trawling. *J. Sea Res.* **45**, 219–230.

Rikhter, V.A., Efanov, V.N. 1976. On one of the approaches to estimation of natural mortality of fish populations. ICNAF Res. Doc. 79/VI/8, 12p.

Roa, R., Ernst, B., Tapia, F. 1999. Estimation of size at sexual maturity: an evaluation of analytical and resampling procedures. *Fish. Bull.* **97**, 570–580.

Robertson, D.R. 1991. The role of adult biology in the timing of spawning of tropical reef fishes. In: Sale, P.F. (ed.). *The Ecology of Coral Reef fishes*. Academic Press, San Diego, CA, pp. 356–386.

Robinson, M.P., Motta, P.J. 2002. Patterns of growth and the effects of scale on the feeding kinematics of the nurse shark (*Ginglymostoma cirratum*). *J. Zool. Lond.* **256**, 449–462.

Rodríguez Mendoza, R.P. 2006. Otoliths and their applications in fishery science. *Ribarstvo*. **64**(3), 89–102.

Rundle, H.D., Jackson, D.A. 1996. Spatial and temporal variation in littoral-zone fish communities: a new statistical approach. *Can. J. Fish. Aquat. Sci.* **53**, 2167–2176.

Russ, G.R., Lou, D.C., Higgs, J.B., Ferreira, B.P. 1998. Mortality rate of a cohort of the coral trout, *Plectropomus leopardus*, in zones of the Great Barrier Reef Marine Park closed to fishing. *Aust. J. Mar. Freshwater Res.* **49**, 505–511.

Ryther, J.H., Hell, J.R., Pease, A.K., Bakun, A., Jones, M.M. 1966. Primary production in relation to the chemistry and hydrography of the western Indian Ocean. *Limnol. Oceanograph.* **11**, 371–380.

Saborido-Rey, F. 2001. Age and growth of redfish (*Sebastes marinus*, *S. mentella* and *S. fasciatus*) in Flemish Cap (Northwest Atlantic). NAFO SCR Doc. 01/109, Ser.No. N4497, 19p.

Sadovy, Y. 1996. Reproduction of reef fishery species. In: Polunin, N.V.C., Roberts, C.M. (eds.), *Reef Fisheries*. Chapman & Hall, London, pp. 15–59.

Sadovy, Y., Shapiro, D.Y. 1987. Criteria for the diagnosis of hermaphroditism in fishes. *Copeia* **1**, 136–156.

Sainsbury, K.J., Campbell, R.A., Whitelaw, A.W. 1993. Effects of trawling on the marine habitat on the North West Shelf of Australia and implications for sustainable fisheries management. In: D. A. Hancock (ed.) Sustainable Fisheries Through Sustaining Fish Habitat, Australian Society for Fish Biology Workshop. *Bureau of Resource Sciences Procee.* **17**, 137-145.

Sampson, D.B., Al-Jufaily, S.M. 1999. Geographic variation in the maturity and growth schedules of English sole along the US west coast. *J. Fish. Biol.* **54**, 1–17.

Santos, M.N., Gaspar, M.B., Vasconcelos, P., Monteiro, C.C. 2002. Short communication: Weight-length relationships for 50 selected fish species of the Algarve coast (southern Portugal). *Fish. Res.* **59**(1), 289–295.

Sarre, G.A., Platell, M.E., Potter, I.C. 2000. Do the dietary compositions of *Acanthopagrus butcheri* (Sparidae) in four estuaries and a coastal lake vary with body size and season and within and amongst these water bodies? *J. Fish Biol.* **56**, 103–122.

Sarre, G.A., Potter, I.C. 2000. Variation in age compositions and growth rates of *Acanthopagrus butcheri* (Sparidae) among estuaries: some possible contributing factors. *Fish. Bull.* **98**(4), 785–799.

Scott, S.G., Pankhurst, N.W. 1992. Interannual variation in the reproductive cycle of the New Zealand snapper *Pagrus auratus* (Bloch & Schneider) (Sparidae). *J. Fish. Biol.* **41**, 685–696.

Seifali, M., Arshad, A., Esmacili, H.R., Kiabi, B.H., Yazdani Moghaddam, F., Fardad, N. 2012. Fecundity and maturation of South Caspian spiralin, *Alburnoides* sp. (Actinopterygii: Cypriniade) from Iran. *I. J. Sci. Technol.* **A2**, 181-187.

Seisay, M.B.D. 2001. Population ecology of dab (*Limanda limanda* L.) in the eastern Irish Sea, North Wales. Unpublished PhD Thesis. School of Ocean Science. University of Wales, Bangor, 227p.

- Serajuddin, M., Ali, R. 2005.** Food and feeding habits of striped spiny eel, *Macrognathus pancalus* (Hamilton). *Ind. J. Fish.* **52**(1), 81–86.
- Shapiro, D.Y. 1992.** Plasticity of gonadal development and protandry in fishes. *J. Exp. Zool.* **261**, 194-203.
- Shears, N.T., Babcock, R.C. 2002.** Marine reserves demonstrate topdowncontrol of community structure on temperate reefs. *Oecologia* **132**, 131–142.
- Shelton, P.A., Boyd, A.J., Armstrong, M.J. 1985.** The influence of large-scale environmental processes on neritic fish population in the Benguela current system. *CalCOFI Rep.* **26**, 72-92.
- Shepherd, J.G. 1988.** Fish stock assessments and their data requirements. In: Gulland J.A. (ed.). *Fish population dynamics: the implications for management*, Chichester, John Wiley and Sons Ltd. pp. 35–62.
- Sheppard, C.R.C., Wilson, S.C., Salm, R.V., Dixon, D. 2000.** Reefs and coral communities of the Arabian Gulf and Arabian Sea. In: McClanahan, T.R., Sheppard, C.R.C., Obura, D.O. (eds.). *Coral Reefs of the Indian Ocean: Their Ecology and Conservation*. Oxford University Press, New York, USA, pp. 257–293.
- Shulman, G.E., Love, R.M. 1999.** The biochemical ecology of marine fishes. In: South Ward, A.J., Tayler, P.A., Young, C.M. (eds.). *Advances in Marine Biology*. Academic Press, London, **36**, 1-352.
- Shuter, B.J., Post, J.R. 1990.** Climate, population viability, and zoogeography of temperate fishes. *Trans. Am. Fish. Soc.* **119**, 314–336.
- Siddeek, M.S.M., Bishop, J.M., El-Musa, M., Abdul-Ghafar, A.R., Lee, J.U., Al-Yamani, F., Joseph, P.S., Almatar, S., Abdullah, M.S. 1991.** Reduction in effort and favorable environment helped to increase shrimp catch in Kuwait. *Fishbyte* **8**(3), 13–15.
- Siems, D.P., Sikes, R.S. 1998.** Tradeoffs between growth and reproduction in response to temporal variation in food supply. *Environ. Biol. Fish.* **53**, 319–329.

Sigler, M.F. 1999. Estimation of sablefish, *Anoplopoma fimbria*, abundance off Alaska with an age-structured population model. *Fish. Bull.* **97**,591–603.

Simon, K.D., Mazlan, A.G., Samat, A., Zaidi, C.C., Aziz, A. 2010. Size, growth and age of two congeneric archer fishes (*Toxotes jaculatrix* Pallas, 1767 and *Toxotes chatareus* Hamilton, 1822) inhabiting Malaysian Coastal waters. *Sains Malay.* **39**(5), 697-704.

Simpson, A.C. 1951. The fecundity of the plaice. *Fish. Invest. Minist. Agric. Fish Food* (G.B.), *Ser. II Salmon Freshwater Fish.* **17**(5), 1–27.

Sivakumaran, K.P., Brown, P., Stoessel, D., Giles, A. 2003. Maturation and reproductive biology of female wild carp, *Cyprinus carpio* in Victoria, Australia. *Environ. Biol. Fish* **68**, 321–332.

Smale, M.J., Punt, A.E. 1991. Age and growth of the red steenbras *Petrus rupestris* (Pisces: Sparidae) on the south-east coast of South Africa. *S. Afr. J. Mar. Sci.* **10**, 131–139.

Somarakis, S., Ganias, K., Tsepes, G., Koutsikopoulos 2004. Ovarian allometry and the use of gonadosomatic index: a case of study in the Mediterranean sardine, *Sardina pilchardus*. *Mar. Biol.* **146**,181–189.

Sparre, P., Venema, S. 1998. Introduction to tropical fish stock assessment. Part 1- Manual, FAO Fisheries Technical Paper, 306/1 Rev. **2**, 407p.

Sreenivasan, P.V. 1979. Feeding biology of the scad, *Decapterus dayi* Wakiya. *J. mar. biol. Ass. India*, **21**(1-2): 97-102.

Statgraphics Plus 1994: Version 7.1, Copyright STSC Inc.VITANCURT, J., LEITES, V. 1999: Cría en cautiverio de ñandúes. Bañados del Este (PROBIDES, Uruguay) **15**, 12p.

Stauffer, K.W., Binder, R.C., Chapman, B.C., Koenen, B.D. 1996. Population characteristics and sampling methods of flathead catsish *Pylodictis olivaris* in the Minnesota River. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Study IV, Job 389, St. Paul.

Stearns, SC. 1992. The evolution of Life histories. Oxford, UK: University Press, Oxford, 250p.

Stengel, H., Al Harthy, A. 2002. The traditional fishery of the Sultanate of Oman (Fishing gears and Methods). Ministry of Agriculture and Fisheries, Directorate General of Fisheries Resources. Muscat, Sultanate of Oman, 147p.

Stéquert, B., Ménard, F., Marchal, E. 2003. Reproductive biology of *Vinciguerria nimbaria* in the equatorial waters of the eastern Atlantic Ocean. *J. Fish. Biol.* **62**, 1116–1136.

Stevenson, D.K., Campana, S.E. 1992. Otolith microstructure examination and analysis. *Canadian Special Publication of Fisheries & Aquatic Sciences* 117p.

Stromme, T. 1986. Pelagic and demersal fish resources of Oman, results of the R/V Dr. Fridtjof Nansen surveys in Oman 1983-84. Institute of Marine Research, Bergen, Norway, 95p.

Sulikowski, J.A., Irvine, S.B., DaValerio, K.C., Carlson, J.K. 2007. Age, growth and maturity of the roundel skate, *Raja texana*, from the Gulf of Mexico, USA. *Mar. Freshwater Res.* **58**, 41–53.

Sun, C.L., Wang, S.P., Yeh, S.Z. 2002. Age and growth of swordfish (*Xiphias gladius* L.) in the waters around Taiwan determined from anal-fin rays. *Fish. Bull.* **100**, 822–835.

Takahashi, D. 2008. Life-history variation in relation to nest site abundance in males of the freshwater goby *Tridentiger brevispinis*. *Ecol. Freshwater Fish.* **17**(1), 71–77.

Takemura, A., Susilo, E.S., Rahman, M.S. and Morita, M. 2004. Perception and possible utilization of moonlight intensity for reproductive activities in a lunar-synchronized spawner, the golden rabbitfish. *J. Experi. Zool.* (in press).

Tancioni, L., Mariani, S., Maccaroni, A., Mariani, A., Massa, F., Scardi, M., Cataudella, S. 2003. Locality-specific variation in the feeding of *Sparus aurata* L.: evidence from two Mediterranean lagoon systems *Est., Coast. and Shelf Sci.* **57**, 469-474.

Tavares-Dias, M., Araújo, C.S.O., Gomes, A.L.S., Andrade, S.M.S. 2010. Relação peso-comprimento e fator de condição relativo (*Kn*) do pirarucu *Arapaima gigas* Schinz, 1822 (Arapaimidae) em cultivo semi-intensivo no estado do Amazonas, Brasil, *Revista Brasileira de Zoociência.*, **12**, 59-65.

Thompson, W.F., Bell, F.H. 1934. Biological statistics of the Pacific halibut fishery. 2. Effects of changes in intensity upon total yield and yield per unit of gear. *Rep. Int. Fish. (Pacific Halibut) Comm.*, **8**, 49p.

Thorpe, J.E. 2007. Maturation responses of salmonids to changing developmental opportunities. *Mar. Ecol. Prog. Ser.* **335**, 285–288.

Tolonen, A. 1997. Size-specific food partitioning and growth in benthic whitefish, *Coregonus lavaretus* (L.), in a subarctic lake. *Boreal Env. Res.* **2**, 387–399.

Tracey, S.R., Lyle, J.M. 2005. Age validation, growth modelling, and mortality estimates for striped trumpeter (*Latris lineate*) from southeastern Australia: Making the most of patchy data. *Fish. Bull.* **103**, 169–182.

Trippel, E.A. 1995. Age at maturity as a stress indicator in fisheries. *Bioscience* **45**, 759–771.

Trippel, E.A., Kjesbu, O.S., Solemdal, P. 1997. Effects of adults age and size structure on reproductive output in marine fishes. In: Chambers, R.C., Trippel, E.A. (eds.). *Early Life History and Recruitment in Fish Populations*. Chapman & Hall, London, pp. 31–62.

Tyrrell, M.C., Link, J.S., Moustahfid, H., Smith, B.E. 2007. The dynamic role of pollock (*Pollachius virens*) as a predator in the northeast US Atlantic ecosystem: a multi-decadal perspective. *J. Northwest Atl. Fish. Sci.* **38**, 53-65.

Van der Walt, B.A., Beckely, L.E. 1997. Age and growth of *Sarpa salpa* (Pisces: Sparidae) off the east coast of South Africa. *Fish. Res.* **31**, 241-248.

Vassilopoulou, V., Papaconstantinou, C. 1990. Growth by weight, condition factor and reproduction cycle of red Pandora (*Pagellus erythrinus*) in the Saronikos Gulf. In: Proceedings of the 3rd Hellenic Symposium on Oceanography and Fisheries. (In Hellenic with English abstract). pp. 584-591.

Vazzoler, A.E.A.M. 1996. Biologia da reprodução de peixes teleósteos: teoria e prática. Nupelia, Maringá-PR, 169p.

Vetter, E.F. 1988. Estimation of natural mortality in fish stocks: A review. *Fish. Bull.* **86**(1), 25–43.

von Bertalanffy, L. 1938. A quantitative theory of organic growth (inquiries of growth laws, I I.) *Human Biol.* **10**(2), 181–213.

Wainwright, P.C., Richard, B.A. 1995. Predicting patterns of prey use from morphology of fishes. *Environ. Boil. Fish* **44**, 97–113.

Walker, M.H. 1978. Food and feeding habits of *Lethrinus chrysostomus* Richardson (Pisces: Perciformes) and other lethrinids on the Great Barrier Reef. *Aust. J. Mar. Freshwater. Res.* **29**(5), 623–630.

Wallace, J.H. 1975. The estuarine fishes of the east coast of South Africa: III. Reproduction. *Invest. Rep. Oceanogr. Res. Inst.*, Durban, **41**, 1–51.

Wallace, J.H., Van der Elst., R.P. 1975. The estuarine fishes of the east coast of South Africa. Part IV. Occurrence of juveniles in estuaries. Part V. biology, estuarine dependence and status. *Invest. Rep. Oceanogr. Res. Inst.* **42**, 1–63.

Wallace, R.A., Selmen, K. 1979. Physiological aspects of oogenesis in two species sticklebacks, *Gasterosteus aculeatus* L. and *Apeltes quadracus* (Mitchill). *J. Fish Biol.* **14**, 551–564.

Wallace, R.A., Selman, K., Greeley, M.S., Jr Begovac, P.C., Lin, Y.W., McPherson, R., Petrino, T.R. 1987. Current status oocyte growth. In: Idler, D.R., Crim, L.W., Walsh, J.M. (eds.). International Symposium on Reproductive Physiology of Fish. Memorial University of Newfoundland, St. John's, pp. 167–177.

Wallace, S. 1999. Fisheries impacts on marine ecosystem and biological diversity: the role for marine protected area in British Columbia. PhD Thesis, Resource Management and Environmental Studies, University of British, Columbia.

Walters, C., Christensen, V., Pauly, D. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. *Rev. Fish Biol. Fish.* **7**, 139–172.

Watson, R., Pauly, D. 2001. Systematic distortions in world fisheries catch trends. *Nature* **414**, 534–536.

Weddle, G.K., Burr, B.M. 1991. Fecundity and the dynamics of multiple spawning in darters: An in stream study of *Etheostma refinesquei*. *Copia*, 419–433.

Welch, T.J., Van Den Avyle, M.J., Betsill, R.K., Driebe, E.M. 1993. Precision and relative accuracy of striped bass age estimates from otoliths, scales, and anal fin rays and spines. *N. Am. J. Fish. Manage.* **13**(3), 616–620.

Welcomme, R.L. 2001. Inland Fisheries: Ecology and Management. Oxford: Fishing News Books, (FAO/ Blackwell Science), 358p.

West, G. 1990. Methods of assessing ovarian development in fishes: a review. *Aust. J. Mar. Freshwater Res.* **41**, 199–222.

Wetherbee, B.M., Gruber, S.H., Cortés, E. 1990. Diet, feeding habits, digestion, and consumption in sharks, with special reference to the lemon shark, *Negaprion brevirostris*, in Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries. Pratt, H.L., Gruber, S.H., Taniuchi, T. eds., NOAA Tech. Rep. NMFS 90, U.S. Department of Commerce, Seattle, WA, pp. 29–47.

Williams, T., Bedford, B.C. 1974. The use of otoliths for age determination. In: The Ageing of Fish. Proceedings of an International Symposium (T.B. Bagenal, ed.). Unwin Brothers limited, Surrey, UK, pp. 114–123.

Wilson, C.A., Nieland, D.L. 1994. Reproductive biology of red drum, *Sciaenaps acellatus*, from the neritic waters of the northern Gulf of Mexico. *Fish. Bull.* **92**, 841–850.

Winemiller, K.O. 1991. Ecomorphological diversification in low-land freshwater fish assemblages from five biotic regions. *Ecol. Monoger.* **61**, 343–365.

Wootton, R.J. 1990. Ecology of teleost fishes. Chapman & Hall, London, 404p.

Wootton, R.J. 1998. Ecology of teleost fishes. 2nd Edition. Kluwer, Dordrecht.

Worthington, D.G., Fowler, A.J., Doherty, P.J. 1995. Variation in the relationship between otolith weight and age: implications for the estimation of age of two tropical damselfish (*Pomacentrus moluccensis* & *P. wardi*). *Can. J. Fish. Aquat. Sci.* **52**, 233–242.

Yamaguchi, A., Lee, K.H., Fujimoto, H., Kadomura, K., Yasumoto, S., Matsuyama, M. 2006. Expression of the *DMRT* gene and its roles in early gonadal development of the Japanese pufferfish *Takifugu rubripes*. *Comp. Biochem. Phys. D1*, pp. 59–68.

Yaragina, N.A., Marshall, C.T. 2000. Trophic influences on interannual and seasonal variation in the liver condition index of Northeast Arctic cod (*Gadus morhua*). *ICES J. Mar. Sci.* **57**, 42–55.

Yoneda, M., Futagawa, K., Tokimura, M., Horikawa, H., Matsuura, S., Matsuyama, M. 2002. Reproductive cycle, spawning frequency and batch fecundity of the female whitefin jack, *Kaiwarinus equula* in the East China Sea. *Fish. Res.* **57**, 297–309.

Yuen, H.S.Y. 1955. Maturity and fecundity of big-eye tuna in the Pacific. US Fish and Wildlife Service, Special Scientific Report. 150, 1–30.

Zaki, M.Z., Abdallah, M., abou-Zaid, F., Salem, S. 2004. Reproductive biology of *Diopodus vulgaris* in Egyptain water. *CIESM*.1p.

Zar, J.H. 1984. Biostatistical Analysis. 2nd ed. Prentice-Hall Inc., Englewood Cliffs, NJ, 718p.

Zar, J.H. 1996. Biostatistical Analysis, 3rd ed. Prentice-Hall Inc., Upper Saddle River, New Jersey, 662p.

Zhao, B., McGovern, J.C. 1997. Temporal variation in sexual maturity and gear-specific sex ratio of the vermilion snapper, *Rhomboplites aurorubens*, in the South Atlantic Bight. *Fish. Bull.* **95**(4), 837–848.

Appendix A

Table 2.4 Age–length key used to construct age–frequency distribution for Arabian pandora from length distributions based on transverse sections of otoliths of fish sampled from Arabian Sea (2005–2008)

All											
LF (cm)	Age Class										Total
	0	1	2	3	4	5	6	7	8	9	
12	1										
14	2										
16	3	17	11	3							
18		16	20	3							
20		5	35	23							
22		3	35	39	10	2					
24			13	66	53	5					
26			1	36	52	36	8				
28				2	51	35	18	1			
30					27	64	18	1			
32						53	34	5	2		
34						10	20	16	4	1	
36						2	5	15	6	2	
38							2	4	3	2	
40								1			
N	6	41	115	172	193	207	105	43	15	5	902
Mean LF (cm)	13.9	16.82	19.6	22.36	25.44	28.59	30.43	33.83	34.36	35.36	
SD (cm)	1.2	1.8	2.3	2.07	2.14	2.45	2.62	2.3	1.7	1.01	
Std. Err.	0.48	0.28	0.21	0.16	0.15	0.17	0.26	0.35	0.45	0.45	

Table 2.5 Age–length key used to construct age–frequency distribution for female of Arabian pandora from length distributions based on transverse sections of otoliths of fish sampled from Arabian Sea (2005–2008)

Female

LF (cm)	Age Class										Total
	0	1	2	3	4	5	6	7	8	9	
12	1										
14	1										
16	2	9	5	1							
18		9	7	2							
20		1	18	9							
22		2	24	22	3						
24			6	32	30	3					
26			1	17	29	21	4				
28				1	27	16	11	1			
30					17	37	9	1			
32						25	15	3			
34						5	12	7	1		
36						1	1	9	2		
38							1	2	2	2	
40								1	2	1	
N	2	21	61	84	106	108	53	24	7	3	469
Mean LF (cm)	13.97	16.64	19.81	22.41	25.57	28.61	30.24	33.71	34.4	35.4	
SD (cm)	1.39	1.83	2.2	2	2.12	2.3	2.74	2.6	2.22	0.67	
Std. Err.	0.69	0.4	0.28	0.22	0.21	0.22	0.38	0.54	0.84	0.38	

Table 2.6 Age–length key used to construct age–frequency distribution for male of Arabian pandora from length distributions based on transverse sections of otoliths of fish sampled from Arabian Sea (2005–2008)

Male											
LF (cm)	Age Class										Total
	0	1	2	3	4	5	6	7	8	9	
12											
14	1										
16		7	5	2							
18		7	12	1							
20		4	17	13							
22		1	11	16	6	2					
24			7	32	23	2					
26				19	23	15	4				
28				1	24	19	7				
30					9	27	9				
32						27	18	2	1		
34						4	8	9	2	1	
36						1	4	6	4		
38							1	2	1	1	
40											
N	1	19	52	84	85	97	51	19	8	2	418
Mean LF (cm)		17.13	19.4	22.33	25.3	28.53	30.62	33.96	34.33	35.25	
SD (cm)		1.83	2.3	2.18	2.1	2.6	2.52	1.8	1.4	1.77	
Std.Err.		0.41	0.32	0.24	0.23	0.26	0.35	0.41	0.48	1.25	