



**BIOLOGY AND STOCK DELINEATION OF RAZOR
MOONFISH, *MENE MACULATA* (BLOCH &
SCHNEIDER, 1801) ALONG THE KONKAN-
MALABAR COAST OF INDIA**

Thesis submitted in partial fulfillment
of the requirements
for the degree of

Ph.D. (Fisheries Resource Management)

by

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JULY, 2018

Dedicated
to
my loving Family



DECLARATION

I hereby declare that the thesis entitled **“BIOLOGY AND STOCK DELINEATION OF RAZOR MOONFISH, *MENE MACULATA* (BLOCH & SCHNEIDER, 1801) ALONG THE KONKAN-MALABAR COAST OF INDIA”** is an authentic record of the work done by me and that no part thereof has been presented for the award of any degree, diploma, associateship, fellowship or any other similar title.

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ACKNOWLEDGEMENT

This thesis is the zenith of my voyage of Ph.D which was just like swimming across English Channel in a slow but consistent pace, accompanied with encouragement, hardship, trust, and frustration. When I found myself at the opposite bank, experiencing the feeling of fulfillment, I realized though only my name appears on the cover of this thesis, a great many people including my family members, well-wishers, my friends and colleagues have contributed to accomplish this task. I thank all who in one way or another contributed in the completion of this thesis.

First of all, I would like to express my sincere gratitude to my guide, Dr. A. K. Jaiswar, (Principal Scientist, FHRPHMD, ICAR-CIFE) for the motivation and supervision throughout the study period. His constant support and encouragement has helped me complete the work on time. I am also extremely indebted to my co- guide, Dr. Prathibha Rohit (Principal Scientist and SIC of Mangalore Research Centre of ICAR-CMFRI) for providing necessary infrastructure and resources to accomplish my research work. Her help and support has always kept me on track during the study period. I am greatly indebted to the member of my Advisory Committee; Dr. K. K. Joshi (HOD, Marine biodiversity Division, ICAR-CMFRI), Dr. Sujitha Thomas (Principal Scientist, Demersal Fisheries Division, ICAR-CMFRI) and Dr. Latha Shenoy (Principal Scientist, FHRPHMD, ICAR-CIFE) for the guidance, support and encouragement throughout the study period.

I take this opportunity to sincerely acknowledge the Indian Council of Agricultural Research (ICAR), Government of India, New Delhi, for providing financial assistance in the form of CIFE Ph.D. Institutional Fellowship which buttressed me to perform my work comfortably. I would like to express my sincere thanks to the Director, ICAR-CIFE, Dr. Gopal Krishna, and Ex-Director, Dr. W.S. Lakra, for the constant support and encouragement given for the research activity during their period. I am thankful to Dr. Gopalakrishnan A., Director, ICAR-CMFRI, for permitting me to continue my Ph.D work in MRC of ICAR-CMFRI with my old registration at ICAR-CIFE, Mumbai.

I take this opportunity to acknowledge the immense support received from my teachers of my division. I would like to thank Dr. S.K. Chakraborty, Emeritus Scientist and former HOD (FRHPHMD, ICAR-CIFE) for the blessings and guidance he showered on me during my research period. I would like to express by profound gratitude to our HOD, Dr. B.B.Nayak for the guidance, support and encouragement throughout the research period. I would also like to extend my sincere thanks to Dr. Gethanjali Deshmukhe, Dr. Asha Langde, Dr. Z.J. Abidi, Dr. Rama Sharma for understanding my multiple commitments and help me tackle the administrative commitments at CIFE in an easy way. I would like to thank and appreciate Mr. Datta, Mr. Mukesh and Mr. Pandu for all the helps rendered during the research period.

I greatly appreciate and acknowledge the support received from Dr. Dineshbabu, Dr. Geetha Sasikumar, Dr. Bindu Sulochanan, Dr. Rajesh K.M., Dr. Purushotama G.B. and Mr. Nataraj during the research period in MRC of ICAR-CMFRI. I am indebted to the Research fellows in the centre like Shailaja, Sharath, Pallavi, Purbali, Yogesh, Suprabha, Prateek and Shubhankar for providing a stimulating and fun filled environment at Mangalore Research Centre of ICAR-CMFRI. The help rendered by Supporting Staff; Shrinath, Hakkim, Nagaraj, Bisun, Dharmaraju and Sathyavathi for sample and data collection is gratefully acknowledged. Capt. Jayprakash Mendon has helped a lot in samples collection and also in understanding the fishery of moonfish along the Coast and I greatly appreciate and acknowledge the support received.

Words are short to express my deep sense of gratitude towards my seniors, friends and juniors. The helping hands of Dr. Manjusha, Dr. Sasi Bhusan, Dr. Pavankumar, Mr. Karan Kumar Ramteke, Dr. Sreekanth, Mr. Srihari, Ms. Saritha, Ms. Jasmin, Ms. Teena, Mr. Ratheesh, Ms. Ammu, Ms. Lekshmi, Ms. Priya, Ms. Sarika, Mrs and Mr. Renjith, Mr. Ananad, Mr. Appu and Mr. Lokesh are greatly appreciated and acknowledged.

I thank my Amma, Acha, my sister, Aswathy and brother in law, Arun who encouraged me in chasing my dreams and prayed for me throughout the time of my research. My heartfelt regard goes to my Mother in law, Satyalatha and in laws, Reena and Reesa, niece Bhavya and nephew Bharat, for their love and moral

support. A special thanks to my co-brother, Rajendran, for all the effort he put for collecting the fish samples from Trivandrum. I owe thanks to a very special person, my husband, Rinu for his continued and unfailing love, support and understanding during my pursuit of Ph.D degree that made the completion of thesis possible. You were always around at times I thought that it is impossible to continue, you helped me to keep things in perspective. I appreciate my baby, my little princess, Naipunya, for abiding my absence and the patience she showed during my thesis writing. Words would never say how grateful I am to both of you. I consider myself the luckiest in the world to have such a lovely and caring family, standing beside me with their love and unconditional support.

There are some supporting people that I might have forgotten: exhaustion plays havoc on memory. My humblest apologies to those who consider having earned for themselves being cited among these lines

Last but not the least; I thank the Almighty for giving me the strength and patience to work through all these years so that today, I can stand proudly with my head held high.

20th July, 2018

Divya Viswambharan

सारांश

मीनी मैकुलेटा (ब्लोच और शनाइडर, 1801), जिसे आमतौर पर मूनफिश या रेज़र मूनफिश के रूप में जाना जाता है, जो कि युग्म ट्रौलर्स और पर्स सिनर्स आधारित लाइट मच्छीमारी की शुरुआत के बाद, कोंकण-मलबार तट पर एक उभरता हुआ मत्स्य संसाधन है। यद्यपि यह प्रजाति पूर्वी अरब सागर पर एक लघु मात्स्यकी को प्रोत्साहित करती हैं, इसकी आकारिकी, जीवविज्ञान, स्टॉक संरचना और मात्स्यकी की स्थिति पर कोई साहित्य उपलब्ध नहीं है। ये जानकारी किसी भी मत्स्य संसाधन के सतत प्रबंधन के लिए आवश्यक है। इसलिए वर्तमान अध्ययन कर्नाटक तट पर पाये जाने वाली मूनफिश की लंबाई-वजन संबंध, जीवविज्ञान और स्टॉक संरचना को समझने के लिए किया गया था। दिसंबर 2015 से नवंबर 2017 हर पखवाड़े में कर्नाटक के मैंगलोर और मालपे बंदरगाहों से मूनफिश के प्रतिदर्श एकत्र किए गए थे। लंबाई-वजन में संबंध के अध्ययन में परिपक्व मूनफिश में सकारात्मक एलोमेट्रिक वृद्धि, जबकि किशोरों में नकारात्मक एलोमेट्री देखी गयी। मूनफिश के लिए अनुमानित वार्षिक जनसंख्या मानदंड $L_{\infty} = 29.1$ सेमी, $K = 1.014$ / वर्ष, $t_0 = -0.014$ वर्ष, $M = 1.82$ / वर्ष, $F = 1.62$ / वर्ष और $Z = 3.44$ / वर्ष पाया गया। पहली परिपक्वता (L_m) की लंबाई 13.8 सेमी (TL) और मछली की औसत पूर्ण उर्वरत्व 43795 अंडे के रूप में अनुमानित किया गया था। प्रजनन कि अवधि फरवरी से जून तक पायी गयी और प्रजाति का न्यूनतम वैधिक आकार (MLS) 85 मिमी लंबाई पर निर्धारित किया गया था। मूनफिश एक मांसाहारी मछली है, किशोर मुख्य रूप से छोटे पर्पटीय प्राणिमन्दप्लवक पर संभरण करते हैं लेकिन वयस्क कपालपाद, पर्पटीय और मछली मूल के बड़े प्राणिमन्दप्लवक पर विस्थापित हो जाते हैं। गणनीय लक्षण का उपयोग करके किए गए स्टॉक निरूपण अध्ययन स्टॉक को चित्रित करने में विफल रहे, जबकि पुलिंदा आकारिकी अध्ययनों ने कोंकण-मालाबार तट में विभिन्न स्टॉक की उपस्थिति का संकेत दिया। पृथक कार्य विश्लेषण के परिणामों ने मैंगलोर और रत्नागिरी तट से स्टॉक के प्रखर मिश्रण का खुलासा किया, जबकि विज़िंजम तट की मछलियों को पूरी तरह से अलग पाया गया था।

Abstract

Mene maculata (Bloch and Schneider, 1801), commonly known as moonfish or razor moonfish, is an emerging fishery resource along the Konkan - Malabar Coast, after the introduction of pair trawlers and light based fishing by purse seiners. Though the species forms a minor fishery along the eastern Arabian Sea, no literature on the morphology, biology, stock structure and status of fishery is available from the region. These informations are essential for sustainable management of any fishery resource. Hence a study was taken up to understand the length weight relationship, biology and stock structure of moonfish along the Konkan–Malabar Coast with special emphasis on Karnataka Coast. The samples of moonfish were collected fortnightly from the mechanised fishing vessels landed at Mangalore and Malpe Harbours in Karnataka from December 2015 to November 2017. The study on the length weight relation showed positive allometric growth in adult moonfish while negative allometry in juveniles. The annual population parameters estimated for moonfish off Karnataka Coast were: L_{∞} = 29.1cm, K = 1.014/yr, t_0 = -0.014yr, M = 1.82/yr, F = 1.62/yr and Z = 3.44/yr. The length at first maturity (L_m) was estimated at 13.8cm (TL) and the average absolute fecundity of the fish was 43795eggs. The fish had protracted breeding season from February to June and the Minimum Legal Size (MLS) of the species was set at 85mm (TL). The species is a carnivorous where juvenile fed mainly on the small zooplankton crustaceans but adults shifted to cephalopods, larger zooplankton of crustacean and fish origin. The stock delineation studies conducted using meristic counts failed to delineate stocks while TRUSS morphometric studies indicated the presence of multiple stocks in the Konkan-Malabar Coast. The results of discriminant function analysis revealed high mixing of stocks from Mangalore and Ratnagiri Coast while the fishes of Vizhinjam Coast were purely distinct.



भा.कृ.अ.प. - केन्द्रीय मात्स्यिकी शिक्षा संस्थान
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(A university Established Under Sec.3 of UGC Act 1956)
Ministry of Agriculture, Govt. of India



Date: 21st July 2018

CERTIFICATE

Certified that the thesis entitled “**Biology and Stock Delineation of Razor moonfish, *Mene maculata* (Bloch & Schneider, 1801) along the Konkan-Malabar Coast of India**” is a record of independent bonafide research work carried out by **Mrs. Divya Viswambharan** during the period of study from August 2012 to June 2018 under our supervision and guidance for the degree of **Doctorate of Philosophy (Fisheries Resource Management)** and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title.

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1. INTRODUCTION

Fishing is an age old custom in India and the fisheries sector plays a pivotal role in providing food security as well as employment opportunity to the coastal communities in India. This sector is an important economic activity and a flourishing field with varied resources and potentials. Since Indian sub-continent is surrounded on the three sides with waters, it has a long coastline of 8,129 km with an exclusive economic zone of 2.02 million km² and a continental shelf area of 0.5 million km². These vast resources generate greater opportunities for fishing and allied activities (Shyam and Narayankumar, 2012).

India has shown uninterrupted and sustained increments in fish production since independence. Constituting about 6.3% of the global fish production, the fisheries sector contributes to 1.1% of the GDP and 5.15% of the agricultural GDP of the nation (NFDB, 2018). The vibrancy of the sector can be visualized by the 12-fold increase that India achieved in fish production (both marine and freshwater) in just seven decades, *i.e.* from 0.75 million t in 1950-51 to 11.41 t in 2016-17 (NFDB, 2018). Besides meeting the domestic needs and the dependence of over 14.5 million people on fisheries activities for their livelihood, the sector also earns foreign exchange to the tune of US\$ 3.467 billion (2016–17) from the export of fish and fisheries products (MOC, 2017). These contributions thoroughly justify the importance of the sector to the country's economy and livelihood security. The marine fish production contributed nearly 3.73 million t in 2016 which had shown an increase of 6.6% as compared to 2015 landings (CMFRI, 2017). Of the 1,400 exploited marine fish species from Indian waters, 263 species are commercially important (Sathianandan, 2013). Moonfish or Razor moonfish is one of the commercially important minor fisheries along the Indian Coast, especially in the eastern Arabian Sea region.

The razor moonfish, *Mene maculata* (Bloch and Schneider, 1801) is the only extant member of the genus *Mene* under the family Menidae. The genus '*Mene*' has few extinct members like *Mene purdyi*, *M. phosphatica*, *M. triangulum*, *M. rhombea*, *M. oblonga* and *M. novaehispaniae* described from different parts of

the world (Friedman and Johnson, 2005). The taxonomic hierarchy of the *Mene maculata* (Bloch and Schneider, 1801) is given below.

Kingdom: Animalia

Phylum: Chordata

Class: Actinopterygii

Order: Perciformes

Family: Menidae

Genus: *Mene* Lacepède 1803

Species: Mene maculata (Bloch & Schneider, 1801)

Mene maculata is easily identified by its highly compressed lateral and deep vertical profile. The fish has a wide geographical distribution extending from 30° S to 35° N latitude, showing its presence from the sub-tropical to tropical waters, which is spread across deeper to coastal waters near the bottom on the continental shelves as well as around the sea mount areas. It is very rarely seen in the estuarine areas (Froese and Pauly, 2018).

The moonfish has been listed as a common native marine resource in 33 different countries and islands in the Indo-west Pacific region (Froese and Pauly, 2018). The fish is mainly distributed at depths ranging from 40m to 200m in the sub-littoral zone of coastal open waters. The species is free-swimming in schools and shows diel vertical migration (Froese and Pauly, 2018).

The commercial fishery of moonfish is seen all throughout its range of occurrence with maximum fishing concentrated in the Northwest Pacific, western central Pacific and eastern Indian Ocean (except Bay of Bengal region) (Pauly and Zeller, 2015). The catch of moonfish has steadily increased from 1950's and maximum catch of 26 million t was registered in 1989. The global estimated total landings of moonfish during 2014 is 19.6 million tonnes (Pauly and Zeller, 2015) with maximum share coming from the EEZ areas of Taiwan, Philippines and Persian Gulf. Industrial level fishing operations conducted by mechanised trawlers and purse seiners contributes to the landing of moonfish.

The bottom trawling contributed nearly 90% of the moonfish landings followed by purse seining and longlining (Pauly and Zeller, 2015).

In India, the moonfish has significant distribution in the eastern Arabian Sea, especially along the Konkan-Malabar Coast. (The eastern Arabian Sea stretches the entire west coast of India from Gujarat to Kerala, including the coast of Daman and Diu, Maharashtra, Goa and Karnataka. The western coast of India, has two major coastal plains namely, Konkan Coast and Malabar Coast. Konkan Coast extends throughout the western coasts of Maharashtra, Goa and Karnataka. It extends from the Mayura River in the north and the Gangavalli River in the south. The Malabar Coast is a long, narrow coastline on the south western shoreline of the mainland of Indian subcontinent extends from southern Karnataka from Gangavalli River upto Kanyakumari Coast).

The fish was once landed as a seasonal by-catch in the trawl fishery and seldom used for domestic consumption due to small size and hence it was considered trash. However, with increased operation of bull trawls/pair trawls and adoption of light fishing by purse seine, the landings of moonfish has registered a significant increase since 2014. Since then, a fishery for moonfish along the south west coast has been significant with landings recorded all round the year. Consequent to increased landings, a good domestic and export market has emerged and the larger sized fishes fetch a good price (Viswambharan *et al.*, 2018). Though, the occurrence of moonfish has been reported along the Indian Coast (Talwar and Kacker, 1984; Kapoor *et al.*, 2002; Rajan *et al.*, 2011), no investigations have been carried out on the fishery and biology of this species. Hence the present study was taken up along the eastern Arabian Sea region, with special reference to the Konkan Malabar Coast with the following objectives.

- To study the reproductive biology, of the razor moonfish, *Mene maculata* along the Konkan- Malabar Coast
- To study the food and feeding biology of razor moonfish, *Mene maculata* along the Konkan - Malabar Coast
- To delineate the stock of the razor moonfish, *Mene maculata* along the Konkan-Malabar Coast of India



Plate: 1. *Mene maculata* (Bloch & Schneider, 1801)

2. REVIEW OF LITERATURE

Menidae is a morphologically very distinct family, easily recognized by its laterally compressed disc like body and dorsally oriented large mouth (Friedman and Johnson, 2005). *Mene maculata*, commonly known as moonfish or razor moonfish, is a single species belonging to Menidae, which is distributed in the Indo Pacific tropical waters from east Africa to southern Japan and north eastern Australia (Du *et al.*, 2012).

2.1. Distribution and occurrence

The moonfish has been listed as a common native marine resource in 33 different countries and islands in the Indo west Pacific region. The species has been described by Kuronuma (1961) from Vietnam; Smith and Smith (1963) from Seychelles; Aprieto and Villosio (1982) from Lingayen Gulf.; Villosio *et al.* (1983) from Philippines; Bianchi (1985) from Pakistan and Tanzania; Baissac (1990) from Mauritius; Arthur and Lumanlan Mayo (1997) from Philippines; Carpenter *et al.* (1997) from Kuwait, eastern Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates, and Heemstra (1984) from India.

The species has been mentioned in many publications related to biodiversity and species occurrence in seas along the Indian Coast (Murty, 1969; Jones and Kumaran, 1980; Bapat *et al.*, 1982; Talwar and Kacker, 1984; Fischer and Bianchi, 1984; Manna and Goswami, 1985; Balachandran and Nizar, 1990; Pillai and Augustine, 2000; Kapoor *et al.*, 2002; Bijukumar and Sushama, 2000; Rajaram *et al.*, 2004; Dholakia, 2004; Das *et al.*, 2007; Rajasegar and Sendhilkumar, 2009; Rajaram and Nedumaran, 2009; Bijukumar and Deepthi, 2009; Tike *et al.*, 2009; Saravanakumar *et al.*, 2009; Ramani *et al.*, 2010; Varghese *et al.*, 2011; Sabu *et al.*, 2011; and Rajan *et al.*, 2011).

Fischer *et al.* (1990) has reported the occurrence of the species in the neritic area of marine and coastal open waters. The substratum preference of the moonfish was reported by Letouneur *et al.* (2004) while strange occurrence of the moonfish in coral reef area was reported by Nguyen and Nguyen (2006). Though the species has commercial importance along its range of occurrence,

there is scarcity for literature on the biology, fishery and stock assessment. Much of the work related to the genetics and stock assessment is reported from China (Zhong *et al.*, 2017) and South East Asian Countries (Ingles and Pauly, 1984; Lavapie *et al.*, 1997; Hwang *et al.*, 2002).

2.2. Age, growth and stock assessment

Gumanao *et al.* (2016) reported the length weight relation of moonfish along with 138 other fishes occurring along the Davao Gulf in Philippines. Armada (2004) estimated the growth parameters of moonfish from Davao Gulf in Philippines. Age and growth of species, before and after heavy exploitation in south western Taiwan waters, was studied by Hwang *et al.* (2002). Ingles and Pauly (1984) reported growth, mortality and recruitment pattern of moonfish along the Philippines region. Lavapie *et al.* (1997) estimated the population parameters of moonfish in the coastal waters of Philippines. Ziegler (1979) analysed the length frequency of few fishes including moonfish and estimated growth and mortality rates for the moonfish of Manila Bay, Philippines. Du (2012) conducted studies on the fishery biology and exploitation status of *M. maculata* in the mouth of Beibu Gulf. Pangalila *et al.* (2014) conducted studies on the stock assessment for understanding the status of moonfish fishery and mapped fishing location of *M. maculata* in Buyat Bay. The studies on the morphological parameters of moonfish were conducted by Smith (1986) while study on the otolith morphometry of moonfish was done in Japan by Rivaton and Bourret (1999).

2.3. Fishery and biology

2.3.1. Fishery

The catch estimates, major gears used in fishery and status of moonfish landings by various countries are published by “Seas Around Us” (Pauly and Zeller, 2015). The estimated catch of moonfish in the world was 19.6 million tonnes in the year 2014, with maximum share coming from the EEZ areas of Taiwan, Philippines and Persian Gulf (Pauly and Zeller, 2015).

2.3.2. Food and feeding biology

Feeding level, feeding type and trophic level of moonfish has been reported by Fischer *et al.* (1990). There are no published reports on the fishery and biology of this species along the coast of Indian sub continent. However methods developed for studying the food and feeding, reproductive biology and stock delineation in other teleost fishes have been referred to in the present study.

The study on the feeding habits of fish and other animals, based on the analysis of stomach content has become a standard practice (Hyslop, 1980). Analysis of stomach content provides important insight into fish feeding patterns and quantitative assessment of food which is an important aspect of fisheries management (Hyslop, 1980). In food and feeding studies, qualitative and quantitative assessment of the diet items were conducted by methods like percentage of occurrence proposed by Rosecchi and Nouaze (1987), percentage of numerical abundance by Hyslop (1980) and weight percentage by Lauzanne (1977). Feeding Indices were used to quantify the importance of different prey items in the feeding ecology of fishes for example, vacuity index (Hureau, 1970); Index of electivity proposed (Ivlev, 1961), Index of Preponderance (Natarajan and Jhingran, 1961) and the Index of Relative Importance (IRI) (Pinkas *et al.*, 1971). For understanding the feeding strategy of fishes, graphical method proposed by Amundsen *et al.* (1996) is widely used, while diet breadth studies are done using the Shannon Wiener index as proposed by Krebs (1989). Most of these methods are used individually or in combinations by many researchers (Qasim, 1972; Keshava and Joseph, 1988; Manojkumar, 2003; Abdussamad, *et al.*, 2009; Abdurahiman *et al.*, 2010; Rohit and Bhat, 2012; Supraba *et al.*, 2013, 2014, 2016 and Rajesh *et al.*, 2016) to study the food and feeding biology of fishes along the Konkan Malabar Coast.

2.3.3. Reproductive biology

Reproduction is an important physiological activity, responsible for the existence and perpetuation of species. Studies on the reproductive biology of fishes are essential for conservation and management of fish stocks (Froese,

2004). The study on the reproductive biology of moonfish was done by Hwang (1984) who studied the maturity and fecundity of moonfish from Taiwan water. Okiyama (1993) studied the early stages of moonfish in the coastal waters, off Japan. There is no report on any aspect of reproductive biology of the species from Indian waters.

Estimations on the sex composition, size at first maturity (King, 2007), maturity stages (Lovern and Wood, 1937), Gonado somatic Index (June, 1953; Yuen, 1955), fecundity and spawning frequency (Clark, 1934; Hicklings and Rutenberg, 1936; Prabhu, 1956) are the major parameters studied in reproductive biology of fishes. Bal and Rao (1984), Annigeri (1963), Rao (1967), Balan (1963), Vasudevappa and James (1980), Zacharia and Jayabalan (2007), Abraham *et al.* (2011), Rajesh *et al.* (2015) and Ramya *et al.* (2016) are the researches who studied the reproductive biology of selected commercial fishes in the Konkan Malabar Coast.

2.4. Stock delineation

A fish population is defined as a group of individuals of the same species or subspecies that are spatially, genetically, or demographically separated from other groups (Wells and Richmond, 1995). Different methods have been in use for stock structure analysis of fishes including the use of ecological parameters (Ihhsen, *et al.*, 1981; Kumpf, *et al.*, 1987), tag based studies (Ihhsen, *et al.*, 1981) parasites based studies (Kumpf, *et al.*, 1987), physiological and behavioural aspects (Ihhsen, *et al.*, 1981, Kumpf, *et al.*, 1987), morphometrics and meristics (Ihhsen, *et al.*, 1981; Kumpf, *et al.*, 1987), calcified structures like otoliths and nucleic acid analysis (Ryman and Utter, 1987; Ovenden, 1990; Carvalho and Hauser, 1994; Ward and Grewe, 1994).

Truss network system is a landmark based procedure that uses geometric morphometrics and imposes no restrictions on the direction of variation or localization of shape changes and is extremely efficient in capturing information about the shape of an organism (Cavalcanti *et al.*, 1999). Truss network measurements are a series of distances calculated between landmarks that form a regular pattern of connected quadrilaterals or cells across the body

form (Strauss and Bookstein, 1982). Turan *et al.* (1998) gave a note on the examination of morphometric differentiation among fish populations using truss system. Pazhayamadam *et al.* (2015), Rebello *et al.* (2014), Remya *et al.* (2014) Sajina *et al.* (2011), Sen *et al.* (2011) and Sreekanth *et al.* (2016) worked on the stock structure analysis of major marine fishes along Indian coast using TRUSS network analysis.

2.5. Genetic assessments and others

Selected researches have been conducted on the genetics of *Mene maculata* around the globe. In China, the mitochondrial and nuclear database of moonfish was given by CAFS (2007; 2003). Zhong *et al.* (2017) reported for the first time the complete mitochondrial genome sequence of *M. maculata* for stock management and genetic assessment from China. DNA barcoding of moonfish using mitochondrial COI gene from India, was reported by Lakra *et al.* (2011).

Reports on proximate composition of *M. maculata* from the southwest coast of India was published by Bijukumar *et al.* (2013) while from Parangipettai, the south east coast of India, by Bharadhirajan *et al.* (2014). The genus *Mene* was also studied by palaeontologists. Friedman and Johnson (2005) proposed a new species of extinct menid fish namely *Mene purdyi*, from north western Peru.

Informations on the morphometrics, biology, stock structure and population dynamics for the species are not available from Indian waters.

3. MATERIALS AND METHODS

3.1. Sample collection

Samples of razor moon fish were collected on a fortnightly interval from the mechanised as well as motorised fishing vessels landing at Mangaluru Fishing Harbour and Malpe Fishing Harbour in Karnataka from December, 2015 to November, 2017. Samples were available during all months except June and July, 2016. The area of operation of fishing vessels involved in the moonfish capture is shown in Fig. 3.1.1.

3.2. Length- weight relationship

Objective: To study the length-weight relationship of moonfish based on gender.

3.2.1. Data collection

The total length (TL) of the specimens, *i.e.*, the length from the tip of the snout to the tip of the upper caudal lobe, was recorded to the nearest 0.1cm. The wet body weight (W) of the specimens was also recorded to the nearest 0.1g. The length- weight data of 339 moonfish (December, 2015 to May, 2016), comprised of 153 females, 105 males and 81 indeterminates, in the size range 6.1 to 25.5 cm, were subjected to statistical analysis.

3.2.2. Data analysis

The length-weight relationship was calculated following the formula suggested by Le Cren (1951): $W = a L^b$

Where, W= body weight (g), L= total length (cm); 'a' is a coefficient allied to body and 'b' is an exponent signifying isometric growth when equal to 3 (Edwards, 1976). The same can be written in the logarithmic form as:

In $W = \ln a + b \ln L$, where the constants 'a' and 'b' were derived by the method of linear least squares.

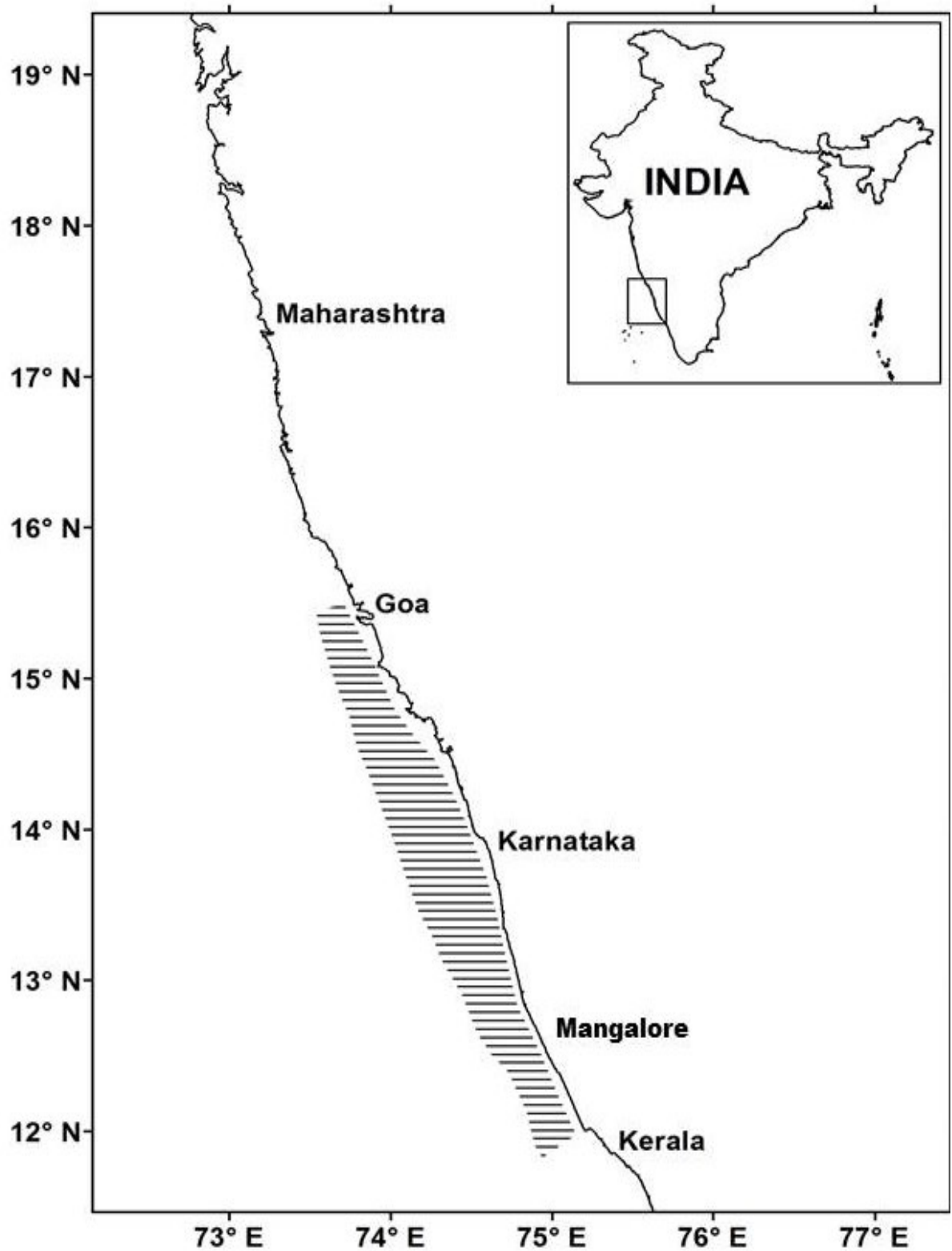


Fig. 3.1.1. The area of operation of mechanised vessels involved in the capture of moonfish along the south eastern Arabian Sea

The equations, derived separately for males, females and indeterminates, were compared for significant difference between regression coefficients (b) and intercepts (a) using Analysis of Covariance following Snedecor and Cochran (1967). The t-test (Snedecor and Cochran, 1967) was performed to check whether the regression coefficients (b) varied significantly from the isometric value '3'. The null hypothesis, Ho: The regression coefficient (b) in males, females and indeterminates; is equal to 3.

3.3. Population parameters

Objective: To give a preliminary estimate the different population parameters (L_{∞} , K, t_0 , t_{max} , Z, M, F, ϕ) of moonfish along the Karnataka Coast.

3.3.1. Data collection

For estimation of population parameters, length data of the fishes collected from trawlers and purse seiners were used. Samples (946 numbers) collected from trawlers had length ranging from 50 to 245 mm while that of purse seine (722 numbers) ranged from 61 to 255 mm. The population parameters of the moonfish population landed along the Karnataka Coast was estimated using the measurements of 1,668 specimens collected during the study period. The length measurements were distributed into 5 mm class intervals. The size-frequencies were raised to the sampling days catch and subsequently to the monthly catch.

3.3.2. Data analysis

The preliminary estimate of growth parameter, L_{∞} was estimated by the modified Wetherall plot in FiSAT software (Gayaniilo *et al.*, 1996). Automatic search routine and response surface were run to obtain the best L_{∞} and K values. However due to poor goodness of fit, size frequencies were delineated using Bhattacharya's Method (1967) and modes of each cohort were linked and growth parameters were estimated by Gulland and Holt plot (Gulland and Holt, 1959). The corrections for gear selectivity were done using the selection factor

($L_{50} = 13.90$ and $L_{75} = 14.35$ cm) and were used to reestimate the length-frequencies (Mohamed and Rao, 1997), and finally, the growth parameters were estimated using Gulland and Holt plot (1959).

The classical von Bertalanffy growth function (VBGF) (Sparre and Venema, 1998) was fitted to obtain the length of fish at different age using the following formula.

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

Where, ' L_{∞} ' is the asymptotic length, ' K ' is the von Bertalanffy growth coefficient, *i.e.*, the growth rate at which asymptotic length is attained (per year), L_t is the length of the fish at age ' t ' and t_0 is the age of the fish at zero length.

Longevity or maximal age (t_{max}) of moonfish was estimated using Pauly's equation (Pauly, 1983).

$t_{max} = t_0 + 2.996 / K$ and the ' t_0 ' was estimated using the empirical equation proposed by Pauly (1979).

$$\text{Log}_{10} (-t_0) = -0.392 - 0.275 \text{Log}_{10} L_{\infty} - 1.038K.$$

Total mortality (Z) was estimated by the methods of length converted catch curve (Gayanilo and Pauly, 1997). The length converted catch curve was obtained using the following formula:

$\ln (N_i / t_i) = a + b t_i$, where, N_i = number of specimens in length class i , t_i = relative age corresponding to length class.

Natural mortality (M) was calculated using Pauly's empirical formula (Pauly, 1980):

$$\text{Log}_{10} M = 0.0066 - 0.279 \log_{10} L_{\infty} + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

Where, M = Natural mortality, L_{∞} and K = Growth parameters of VBGF, T = Annual mean temperature ($^{\circ}$ C) of the water in which the fish lives.

In the present study, T was taken as 27 °C. Instantaneous rate of fishing mortality (F) was computed by subtracting natural mortality (M) from total mortality (Z).

$$F = Z - M.$$

The growth performance index (ϕ) was estimated using the formula given below.

$$\Phi = \log_{10}K + 2 \log_{10} L_{\infty} \text{ (Munro and Pauly, 1983)}$$

The results were compared with the population estimates and growth performance index (ϕ) values reported for this species from other parts of the world.

3.4. Reproductive biology

Objective: To study the reproductive biology of moonfish along the Karnataka Coast

3.4.1. Data collection

The 1,227 fishes, collected during the sampling period, were dissected and sex, gonad weight and maturity stage were recorded.

3.4.2. Data analysis

3.4.2.1. Gross examination of gonad

The scale recognised by the International Council for the Exploration of Sea (ICES) was used to identify and classify different gonad stages (Lovern and Wood, 1937). The gonads (ovaries and testes) were categorized into seven stages accordingly. Stage I - immature, stage II a - developing immature and stage II b - recovering spent, stage III - maturing, stage IV – mature, stage V - advanced mature, stage VI - fully ripe, stage VII a - partially spent and stage VII b - fully spent. All the fresh ovaries of 684 female fishes were examined macroscopically for understanding the general external

characteristics and microscopic examinations of the ovary were made on preserved material. In 435 males, maturity stages were classified on the basis of macroscopic examination only.

3.4.2.2. Gonado somatic Index (GSI)

The Gonado somatic Index (GSI) is used for determining the spawning season in fishes. In order to estimate GSI, the fishes were weighed individually to the nearest 'gram' and dissected gonads were carefully weighed to the nearest 'milli gram' by using an electronic balance. Of the 1227 samples, 1119 samples were used for the estimation of GSI, of which 684 were females and 435 were males. The GSI was calculated by the methods described by June (1953) and Yuen (1955):

Gonado somatic Index = (Weight of the gonad/ (Weight of the fish-gonad weight)) x 100

The variations of GSIs between months (both male and female) (independent variable) was tested using one-way ANOVA with Tukey multiple comparison test. Ho:- There is no monthly variation in the GSI in male/female.

The variation of GSIs between different lengths groups (independent variable) of both male and female were also tested using one-way ANOVA with Tukey multiple comparison test. The null hypothesis, H₀:- There is no variation in the GSI between the different length groups in male/female.

All tests were set at 5% of the significant value and performed using PAST 3.1 Software (Hammer *et al.*, 2001).

3.4.2.3. Ova diameter frequency distribution

To study the natural succession of maturity stages which an ovum pass through before becoming fully ripe egg, ova diameter measurements were taken from individual ovaries. The ovaries in different stages of maturity were preserved in customized Gilson's fluid (Bagenal and Braum, 1978) for

measurements of the ova diameter (Clark, 1934; Hicklings and Rutenberg, 1936 and Prabhu, 1956) and fecundity. Ova diameter was measured using an ocular micrometer and 1 ocular micrometer division (OMD) was found to be equal to 16 micrometer. The ova samples from anterior, middle and posterior regions of the two lobes of ovary were measured to see whether there is any size difference in ova seen in different parts of ovary. The size-frequency distribution of ova in different maturity stages was plotted. About 120 ova were measured from each ovary in various stages of maturity. About 112 ovaries in different stages of maturity (5 ovaries of Stage I, 7 ovaries of stage IIa, 15 Ovaries of stage IIb, III, IV, V, VI and VIIa, and 10 ovaries of VIIb) were used in ova diameter studies. The diameters from different ovaries of identical stage were pooled and ova diameters were converted to micrometer before plotting the graph.

3.4.2.4. Length at first maturity (L_{m50}), Minimum Size of Maturity (MSM), Minimum Size of Spent (MSS)

The length at which 50% of fish reach sexual maturity (stage III and above) is known as fish length at first maturity (L_{m50}). The length at first maturity was estimated from the logistic curve as $P = 1 / (1 + \exp[-r \times (TL - L_m)])$, where P is the proportion of mature individuals in a length class and TL is total length (0.1cm) of the fish. In the logistic model, r (intercept) and L_m (slope) are the two parameters, according to King (2007). These two parameters were estimated using the non-linear regression routine from the ratio of reproductive to non reproductive fish groups.

MSM is the Minimum Size at Maturity, which is the size of the smallest mature fish, *ie.*, the smallest fish whose gonad has been identified as in maturity stage III. Minimum Size of Spent (MSS) is defined as size of the smallest fish observed to be in spent stage (Stage VIIa).

3.4.2.5. Spawning season

The percentage occurrence of various gonad maturity stages observed in fish samples (n= 1119) in different months were plotted to find the approximate period of spawning of the fish.

3.4.2.6. Sex ratio

The sex ratio of the fishes (n=1119) caught was calculated using the method followed by Zacharia (2003) and Chi-square was used to test whether the sex ratio observed was significantly different from the expected sex ratio of 1:1.

$$X^2 = \sum (O-E)^2 / E$$

Where, O = observed number of males and females in each season/length group, E = expected number of males and females in each season/ length group. The null hypothesis, H₀: The male: female ratio is same as the expected sex ratio of 1:1 in each season/ length group.

3.4.2.7. Fecundity

Gonads, in stage V and VI, were preserved in modified Gilson's fluid. Fecundity was estimated by counting the number of ova in different preserved ovaries. A total of 33 ovaries were used for estimation of fecundity, of which 14 ovaries were from March, 2017 and 19 ovaries were from May, 2017. The excess moisture from the ovary was removed using blotting paper and weighed using an electronic balance to an accuracy of 0.1mg. As there was no dissimilarity in the ova size, in different parts of the ovary, ova were sampled from middle region of the ovary alone for fecundity studies. A small portion of the ovary (0.1mg) was removed from the middle region and the mature ova in the samples were counted in a counting chamber under a microscope. Absolute fecundity was estimated by following the method used by Zacharia (2003)

Absolute Fecundity = ((Number of ova in the sample /Weight of the sample) x Total weight of the ovary)

3.4.2.7.1. Relationship between fecundity and different variables

The relationship between fecundity and different variables like total length of the fish, fish weight and gonad weight was worked out by the least square method (Zupa *et al.*, 2013), $F = a X^b$

Where, F = fecundity, a = constant, X = variable (fish length, fish weight or ovary weight) and b = correlation coefficient. The exponential relationship was transformed into a straight line logarithmic form based on the equation,

$$\text{Log F} = \log a + b \text{ Log X}$$

3.4.2.8. Minimum Legal Size (MLS)

The length for MLS is based on the status of fishery and biology of the fish species under consideration (Hill, 1990; Sivadas *et al.*, 2017). The biological parameters considered for the determination of MLS, are the reproductive style and the growth or reproductive strategy of the fish (Mohamed *et al.*, 2014; Rohit *et al.*, 2016; Sivadas *et al.*, 2017). The status of fishery is determined by exploitation ratio and reproductive load of the fish.

Reproductive load was calculated using the formulae suggested by Tsikliras *et al.*, (2013): Reproductive Load (RL) = L_{m50}/L_{max}

Where, L_{m50} is the length at which 50% of the fish matures and L_{max} is the maximum length of the fish in the sample collected.

The Exploitation ratio (R): F/Z ,

Where, F is the Fishing Mortality and Z is the Total Mortality of the fish stock along the region (Ricker, 1975). After studying the reproductive biology and status of fishery of moonfish using the above parameters, the MLS of moonfish was finalised.

3.5. Food and feeding biology

Objective: To study the food and feeding biology of moonfish along the Karnataka Coast

3.5.1. Data collection

The fish samples (1227) were cleaned in the lab and the total length (mm) and weight (g) of fishes were recorded. The fishes were dissected

and fullness of fish stomach was recorded. The variations in the fullness of fish stomachs were classified as 'gorged', 'full', three fourth full', "half full", "quarter full', trace and 'empty', based on visual examination following the method used by Zacharia (2003). The fish stomach were removed, weighed and preserved in 5% buffered formalin for further analysis.

3.5.2. Data analysis

The food items obtained from the gut were sorted, identified, weighed and counted. The resultant values were converted to percentage in terms of weight, number and occurrence. Numerical percentages were calculated according to the method of Calver and Wooller (1982), while occurrence percentages were derived from the number of fishes feeding on a particular prey type divided by the number of fishes in the sample. The weight percentage was estimated as the proportion of the weight of each of the food items to the weight of the total gut contents expressed in percentage.

3.5.3. Food analysis indices

3.5.3.1. Empty Stomach Ratio (ESR)

The empty stomach ratio (ESR) was calculated using the method followed by Rajesh *et al.* (2016). It is estimated as the percentage of the number of specimens with an empty stomach, to the total number of specimens examined.

3.5.3.2. Index of Relative Importance (IRI)

The Index of Relative Importance (IRI) for each prey item was calculated using Pinkas *et al.*, (1971) formula: $IRI = (N + V) F$,

Where, N = numerical percentage, V = weight percentage and F = occurrence percentage.

3.5.4. Food and feeding habit

The data collected for food and feeding was classified and analysed based on the life stage. During the present study, the L_{m50} was estimated to be 138 mm. Hence, all the fishes with total length below 138mm were considered juveniles and fishes with length equal and above 138 mm were considered as adults. The length wise, month wise and season wise variation in the food composition and feeding habit of adult and juvenile moonfish were estimated.

3.5.4.1. Length wise food composition and feeding habit

To find the shift in diet from juvenile to adult, the fishes were classified into 9 groups starting from length 50 mm upto 255 mm. The nine length groups were 50-75 mm, 75.1-100 mm, 100.1-125 mm, 125.1-137.9 mm, 138-150 mm, 150.1-175 mm, 175.1-200 mm, 200.1-225 mm and >225 mm. The four groups, 50-75 mm, 75.1-100 mm, 100.1-125 mm and 125.1-137.9 mm were considered juvenile and 5 groups *i.e.*, 138-150 mm, 150.1-175 mm, 175.1-200 mm, 200.1-225 mm and >225 mm were considered adult. IRI for each prey was calculated for each length group.

3.5.4.2. Month wise food composition and feeding habit

To find the monthly variation in the diet of juvenile and adult fish, IRI for each prey was calculated for each month.

3.5.4.3. Season wise food composition and feeding habit

In order to test the seasonal variation in the diet of juveniles and adults, the samples were segregated into 3 seasons; pre monsoon, monsoon and post monsoon and IRI for each prey was calculated based on different seasons. The pre monsoon months includes: February, March, April and May; monsoon months: June, July and August and post monsoon months: September, October, November, December and January (Rajagopalan *et al.*, 1992).

3.5.5. Forage strategy of moonfish

The strategy of feeding of moonfish was explored by applying the modified Costello graphical method (Costello, 1990; Amundsen *et al.*, 1996).

Prey-specific abundance is a function of the percentage of prey items in only those fishes in which the prey occurs and is represented by the following equation:

$$P_i = (\sum S_i / \sum S_{ti}) \times 100,$$

Where, P_i is prey-specific abundance of prey type 'i', S_i is total stomach contents (number) comprised of prey 'i', and S_{ti} is total stomach content in only those moonfish with prey item 'i' in their stomach (Amundsen *et al.*, 1996). The information pertaining to the importance of prey, niche width and feeding strategy of the predator is demonstrated by the points spread along the diagonals and the axes of the graph (Fig. 3.5.5.1).

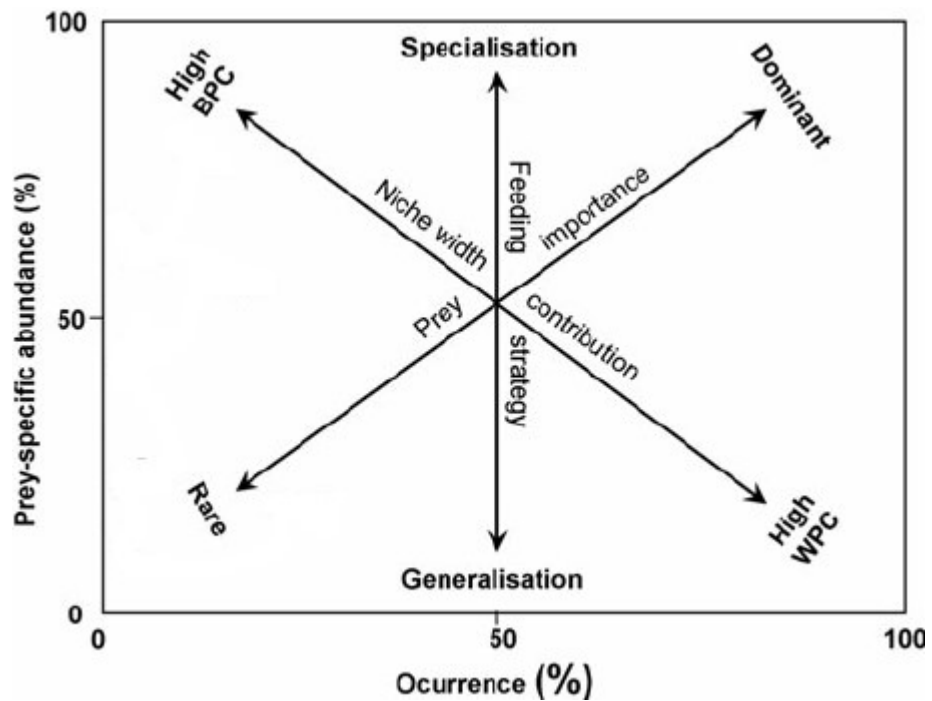


Fig. 3.5.5.1. The modified Costello Graph (1990) used to identify the feeding strategy

3.5.6. Diet breadth and dietary specialization

For investigating the trophic diet breadth and relative level of dietary specialisation of moonfish, Shannon Wiener index (H') and Evenness Index (J') were used, respectively. The IRI was used to determine trophic niche breadth for the species by means of the Shannon Wiener index (H') as used by Krebs 1989 and expressed as: $H' = - \sum p_i \log p_i$

Where, H' is the Shannon Wiener measure of trophic niche breadth and p_i is the proportion of the IRI. A high H' value indicates feeding on a higher spectrum width of prey items. The Shannon Wiener measure H' was standardized on a 0-1 scale using the evenness measure J' which is expressed as: $J' = H' / \log n$

Where, J' is the evenness measure of the Shannon Wiener function and 'n' is the total number of prey items. A high J' indicates a fish feeding on a relatively larger number of a few main prey types (Shuozeng, 1995).

3.5.7. Trophic overlap between adult and juvenile moonfish

The degree of trophic overlap was estimated by means of the simplified Morisita index (C) (Krebs, 1989). The value of C varies from 0 (for no overlap) to 1 (for complete overlap), with a value of ≥ 0.6 being considered to be significant (Hyndes *et al.*, 1997). This measure is expressed as:

$$C = 2 \sum p_{ij} p_{ik} / (\sum p_{ij} + \sum p_{ik})$$

Where, C is the simplified Morisita index of trophic niche overlap between groups j and k , and p_{ij} and p_{ik} are the proportion of prey item i consumed by group j and k , respectively.

3.5.8. TROPH and Omnivory Index (OI)

The trophic level of the moonfish was also estimated according to Pauly and Christensen (1995). The definition of TROPH for any consumer species is: $TROPH_i = 1 + \sum DC_{ij} \times TROPH_j$,

Where $TROPH_j$ is the fractional trophic level of prey 'j' and DC_j represents the fraction of 'j' in the diet of the consumer species (moonfish). The TROPH of different fish varies between 2.0, for herbivorous/ detritivorous, and 5.0, for piscivorous/ carnivorous organisms (Pauly *et al.*, 1998b, 2000; Palomares & Pauly; 1998). TROPH value was calculated using the weight contribution and the trophic level of each prey species to the diet. Trophic level values of prey were assigned according to Pauly *et al.* (2000).

A dimensionless omnivory index (OI) was calculated using the formula

$$O_i = \sum [TL_j - (TL_i - 1)]^2 \cdot DC_{ij},$$

Where, TL_j is the trophic level of prey 'j', TL_i is the trophic level of predator 'i', and DC_{ij} is the proportion that prey 'j' constitutes of the diet of predator 'i'.

3.6. Fishery

Objective: To study the fishery of moonfish along the Indian coast with special emphasis on Karnataka Coast

3.6.1. Data collection

The catch data of moonfish for Indian sub continent was obtained from the National Marine Living Resource Data Centre (NMLRDC) of ICAR-Central Marine Fisheries Research Institute. The "Stratified Multistage Random Sampling Method" was used for the gear wise catch data collection of moonfish across different landing centres of the country (Alagaraja *et al.*, 1982). The data obtained were the estimated catch of moonfish from different gears operated by the mechanised, motorised and non mechanised vessels. The data on the quantity of fishes caught by light fishing and bull trawling were recorded from Mangalore and Malpe Fishing Harbour by fortnightly field visit.

3.6.2. Data analysis

Catch and effort available for moonfish along the study area for the last one decade (2007 to 2016) was considered for analysis. Details on the landings of moonfish by different gears and craft, average landings of moonfish by different states, sector wise contribution, craft and gear wise catch of moonfish were worked out. As the Konkan Malabar Coast was the main focus of study, the gear wise and craft wise moonfish catch of the Konkan Coast, (Maharashtra, Goa and Karnataka) and the Malabar Coast, (Kerala Coast) were analysed in detail, to understand the fishery of this region. In addition, the fishery of moonfish with particular reference to Karnataka was studied in detail. District wise, sector wise and gear wise catch for the last one decade (2007-2016) was studied for the better understanding of moonfish fishery along the Karnataka Coast.

3.7. Stock delineation

Objective: To check whether the moonfish available along the Coast of Ratnagiri, Mangalore and Vizhinjam in the Konkan-Malabar region belong to a single stock using meristic counts and TRUSS morphometric measurements.

3.7.1. Sample collection

A total of 185 specimens of moonfish caught by ring seiners, purse seiners and boat seiners were collected from 3 locations along the Konkan Malabar Coast viz. Vizhinjam (60) in Kerala; Mangalore (63) in Karnataka and Ratnagiri (62) in Maharashtra (Fig. 3.7.1.1.). Samples from Ratnagiri were collected during November and May while samples from Mangalore were collected during December and April. The fish samples from Vizhinjam were collected during December and March. In Vizhinjam, the sample collection was made from motorised boat seiners which are always single day operators collecting fishes adjacent to Trivandrum Coast while in Mangalore, samples were collected from purse seiner which operated off Mangalore Coast ($12^{\circ} 43' 29''$ N $74^{\circ} 37' 46''$ E) and in Ratnagiri, samples were collected from ring seiners which are mostly single day operators. The collected fish specimens were placed in insulated box with ice packs and brought to the laboratory for further study.



Fig. 3.7.1.1. Map of India showing the sampling stations for stock delineation studies

3.7.2. Data collection

3.7.2.1. Meristic data

During the present study, data on 5 meristic counts were taken which included the number of gillrakers in the upper limb (GRC), dorsal fin spine (DFS), dorsal fin soft rays (DSR), anal fin soft rays (AFR) and pelvic fin rays (PFR). Countable data are discrete, thus facilitating statistical analysis. All counts and measurements were taken from the left lateral aspect of the fish.

3.7.2.2. Truss morphometric data

The collected fish specimens were placed on a graph paper overlaid with a plastic sheet. The fins were spread to natural position and ten significant morphological points were fixed to be measured. These 10 distinct points were significant morphological marks called 'landmarks' (Table 3.7.2.2.1.). In the current study, 21 TRUSS networks were constructed based on the 10 homologous anatomical land marks (Plate 2). The twenty one truss distances (Table 3.7.2.2.2) were measured along the entire body surface on the left side of the fish *i.e.* head, trunk and tail, using the paper and pin method (Strauss and Fuiman, 1985). The points of landmark were marked on the graph sheet through the water resistant plastic sheet, using a paper pin. The X-Y co-ordinates of these points on the graph sheet were measured. The X-Y co-ordinate data were used to calculate the truss distances between pairs of landmarks using the Pythagorean Theorem (McGlade and Boulding, 1986).

Table: 3.7.2.2.1. Land marks used for extracting truss measurements from moonfish

Sl. No.	Landmarks	Landmark position
1	A	Anterior tip of the snout
2	B	Anterior portion of the head just above the eyes
3	C	Nape above insertion of opercle
4	D	Origin of dorsal fin
5	E	Insertion of dorsal fin
6	H	Insertion of anal fin
7	I	Origin of anal fin
8	J	Origin of pelvic fin
9	K	Ventral projection of pectoral girdle
10	L	End of operculum on the ventral edge

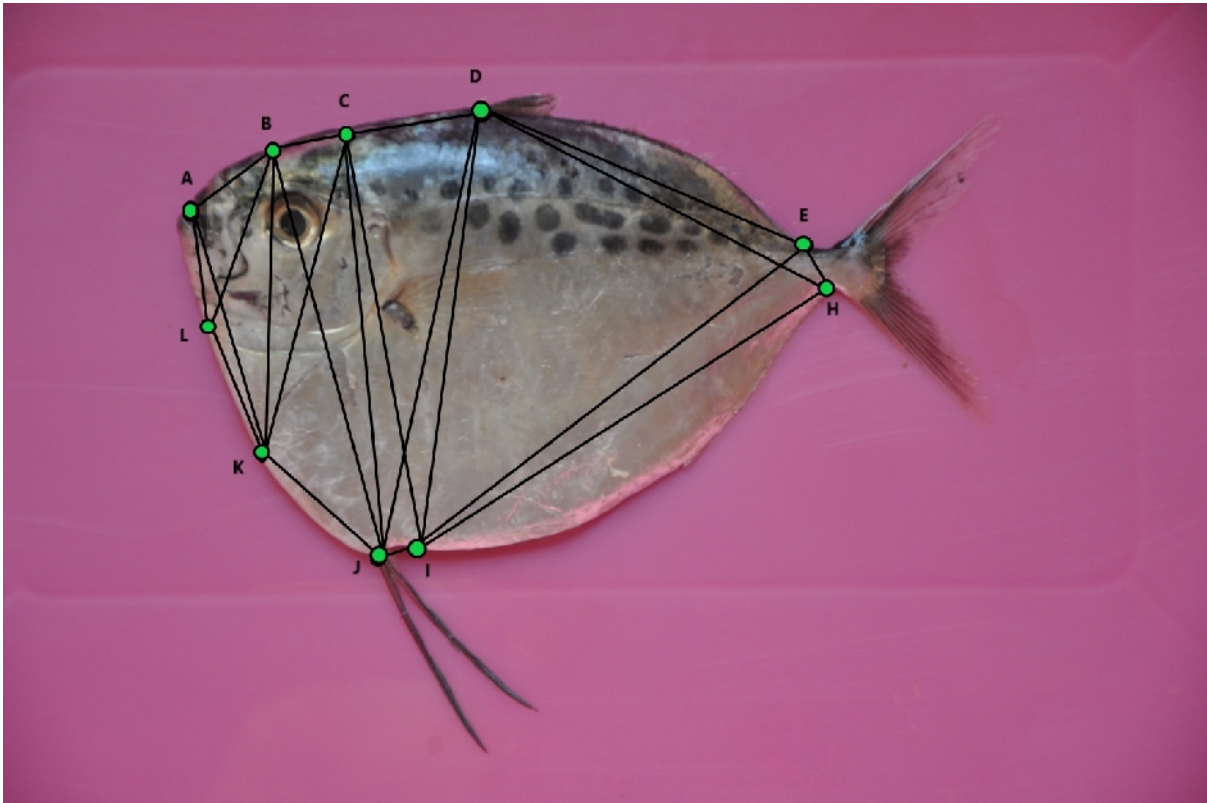


Plate: 2. Truss network of moonfish

Table: 3.7.2.2.2. Truss distance (21) obtained from the 10 morphological land marks

Sl No.	Truss Distance	Description
1	AB	Distance from anterior tip of snout to anterior portion of the head just above the eyes
2	AL	Distance from anterior tip of snout to end of operculum on the ventral edge
3	LK	Distance from end of operculum on the ventral edge to ventral projection of pectoral girdle
4	BK	Distance from anterior portion of the head just above the eyes to ventral projection of pectoral girdle
5	AK	Distance from anterior tip of the snout to ventral projection of pectoral girdle
6	BL	Distance from anterior portion of the head just above the eyes to end of operculum on the ventral edge
7	BC	Distance from anterior portion of the head just above the eyes to nape above insertion of opercle
8	KJ	Distance from ventral projection of pectoral girdle to origin of pelvic fin
9	CJ	Distance from nape above insertion of opercle to origin of pelvic fin
10	BJ	Distance from anterior portion of the head just above the eyes to origin of pelvic fin
11	CK	Distance from nape above insertion of opercle to ventral projection of pectoral girdle
12	CD	Distance from nape above insertion of opercle to origin of dorsal fin
13	IJ	Distance from origin of anal fin to origin of pelvic fin
14	DI	Distance from origin of dorsal fin to origin of anal fin
15	CI	Distance from nape above insertion of opercle to origin of anal fin
16	DJ	Distance from origin of dorsal fin to origin of pelvic fin
17	ED	Distance from insertion of dorsal fin to origin of dorsal fin
18	HI	Distance from Insertion of anal fin to origin of anal fin
19	EH	Distance from insertion of dorsal fin to insertion of anal fin
20	DH	Distance from Insertion of anal fin to origin of dorsal fin
21	EI	Distance from insertion of dorsal fin to origin of anal fin

3.7.3. Data analysis

3.7.3.1. Descriptive statistics

Minimum, maximum and mode for the meristic traits were calculated.

3.7.3.2. Removal of size dependent effects

The size dependent variation in the whole data may give false discrimination of stocks (Humphries *et al.*, 1981). Hence, the transformations of the actual truss distances were carried out and outliers were removed. The size dependent effects were removed using an allometric approach by modifying the formula provided by Ihhsen *et al.* (1981). Data were transformed using the formula:

$$M_{adj} = M (SL_{mean} / SL)^\beta$$

Where, M_{adj} : transformed morphometric measurement; M : original morphometric measurement; SL : standard length of fish; SL_{mean} : overall mean standard length of the fish and β : within group slope of the linear regression between log transformed original morphometric measurement and log transformed standard length.

3.7.3.3. Principal Component Analysis (PCA)

The 21 truss measurements and 5 meristic counts were subjected to Principal Component Analysis to extract the principal components. Only retained factors were subjected for rotation procedure by Varimax rotation.

3.7.3.4. Discriminant Function Analysis (DFA)

The discriminant function analysis was carried out to study the similarities or differences in the study sample. It was done by taking the selected principal components from the Principal Component Analysis.

3.7.3.5. Statistical package

Entry of data, editing and transformation were done in MS-Excel and all other statistical analysis were done by Statistica Version 8 (Statsoft, 2013) and PAST 3.1 Software (Hammer *et al.* 2001)

4. RESULTS

4.1. Length-weight relationship

The length-weight equations derived for males, females and indeterminates of *M. maculata* are given in the Table 4.1.1. Analysis of covariance revealed significant difference for indeterminates with male and female while there was no significant difference between male and female. Hence the length-weight data of both sexes were pooled for further analysis. Growth in fish is considered ideal when it is isometric and increase in weight is an exponential function of its length. This relationship could be expressed by the cube law, *i.e.*, $\text{weight} = a \times \text{length}^3$. The regression coefficient (*b*) of *M. maculata* was found to be 3.390 which differed significantly from the hypothetical isometric value 3, indicating positive allometric growth, hence the null hypothesis is rejected. Positive allometric growth was observed in males (3.316) and females (3.440) while the indeterminate fishes with the *b* value of 2.905 showed significant negative allometric growth. The null hypothesis is rejected in case of indeterminates too, as the *b* value of 2.905 shows significant difference from the ideal value 3. This indicates that the male and female fishes grew faster in weight than indeterminates (Fig 4.1.1 to Fig. 4.1.3.).

4.2. Estimation of population parameters

The growth parameter estimates for *M. maculata*, employing different methods in FiSAT II are given in Table 4.2.1. In order to estimate the length of fish at different age, L_{∞} value of 29.1cm, *K* value of 1.014yr^{-1} and t_0 of -0.014 were used as the 'r' values (0.38) were reasonable. The average length attained by moonfish at different age is given in Table 4.2.2. Maximum length (L_{max}) of moonfish obtained during the study was 25.5 cm (TL). This corresponds to approximately 2 years of age and could be considered as the maximum fishable life span of moonfish fished off Karnataka waters. The t_{max} for the fish was estimated at 2.97 years which were approximately 3 years of age. The natural mortality, fishing mortality and total mortality estimated were 1.82, 1.62

and 3.44, respectively, for moonfish, off Karnataka waters. The growth performance index (ϕ) of the fish in the present study was estimated at 2.934.

Table: 4.1.1. The length weight equations derived for male, females and indeterminates of *M. maculata*

Sl. No.	Group	L-W equation	R value	'b' value
1	Male(M)	$W= 0.00629L^{3.316}$	0.98	3.316
2	Female (F)	$W= 0.00465L^{3.440}$	0.99	3.440
3	Pooled data (M+F)	$W= 0.00524 L^{3.390}$	0.97	3.390
4	Indeterminates	$W=0.02330L^{2.905}$	0.98	2.905

Table: 4.2.1. Growth parameters estimated for *Mene maculata*, using different methods in FiSAT II

Sl. No.	Method used	L_{∞} (cm)	$K(\text{yr}^{-1})$
1	Modified Wetherall plot	28.14	-
2	ELEFAN I	29.10	1
3	Bhattacharya and Gulland and Holt plot (before gear selection)	28.24	1.14
4	Bhattacharya and Gulland and Holt plot (after correction for gear selection)	29.10	1.014

Table: 4.2.2. Age length key for moonfish, off Karnataka waters

Age	0.5 yr	1 yr	1.5 yr	2 yr	2.5 yr
Length (cm)	11.8	18.69	22.83	25.32	26.82

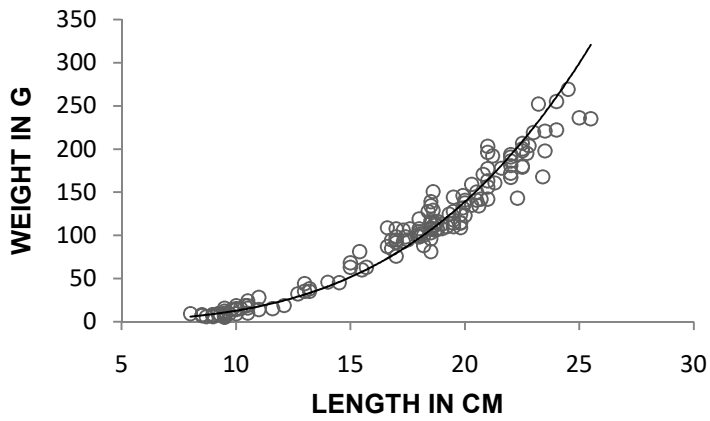


Fig. 4.1.1. Length-weight relationship of moonfish (Female)

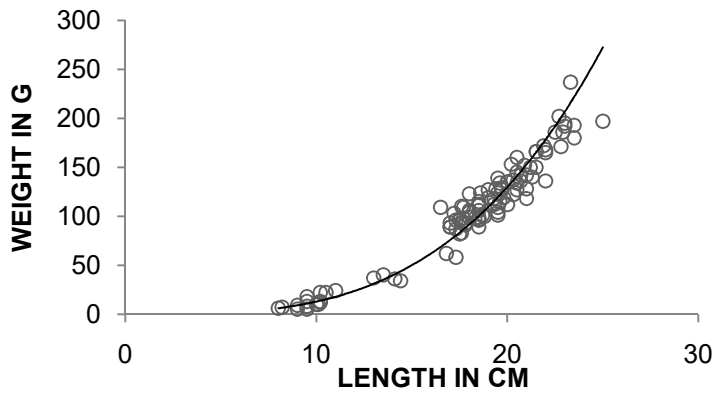


Fig. 4.1.2. Length-weight relationship of moonfish (Male)

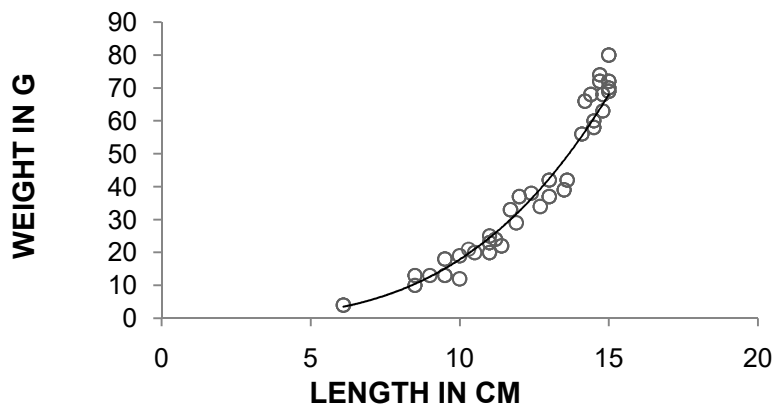


Fig. 4.1.3. Length-weight relationship of moonfish (Indeterminates)

4.3. Reproductive biology

During the investigation, 1227 samples comprising of 684 female, 435 male and 108 indeterminates were examined. No hermaphrodites were observed. The reproductive organs in moonfish consisted of paired ovaries and testes situated in the abdominal cavity of fishes (Plate 3 and Plate 4). The gonads were attached to the posterior part of lower abdominal cavity and were attached to the abdominal cavity by means of mesovarium.

Ovaries were sac like paired structures. The left and right lobes of ovaries were free at the anterior end but were attached in the middle and posterior region. The posterior portion of the ovary was connected to a common genital opening. The inner wall of gonad was lined by germinal epithelium, which developed into ova. The testes were elongated, laterally compressed paired structure and grow anteriorly with growth and maturation. The testes, initially were long thin thread like structures which were reddish to dirty white, finally developed into thick, fleshy and pinkish white on maturation.

4.3.1. Maturation stages of gonads

4.3.1.1. Maturation stages of ovary

The different stages of ovarian development are shown in Plates 5.

Stage I: Immature

Ovary was thin and short in length, transparent and occupied less than $1/10^{\text{th}}$ of body cavity. Ova irregularly shaped but all were of the similar size and fully transparent with prominent nucleus.

Stage IIa: Developing immature

Ovary slightly larger than the preceding stage, flat, transparent and occupied about almost $1/5^{\text{th}}$ of body cavity.



Plate: 3. Male moonfish with fully mature testis



Plate: 4. Female moonfish with mature ovary

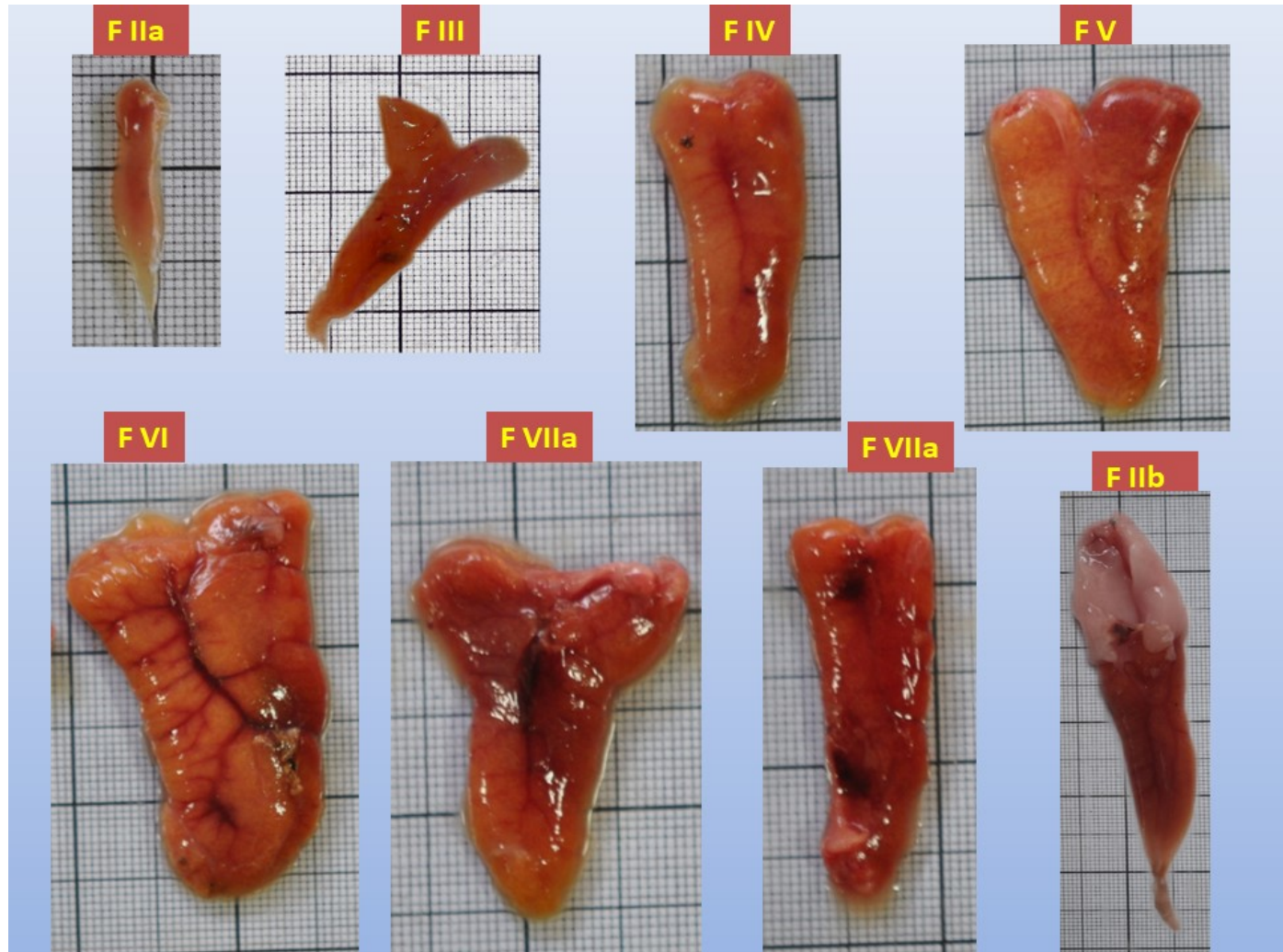


Plate: 5. The ovaries in different stages of maturation (F IIa- Developing immature, F III- Maturing, F IV- Mature, F V- Advanced mature, F VI- Fully ripe, F VIIa- Partially spent, F VIIa- Partially spent, F IIb- Recovering spent)

Stage IIb: Recovering spent

Ovaries occupied nearly 1/4th of the body cavity. Fat deposition was seen on both the anterior lobes of the ovary. Slightly reddish colour persists on the surface.

Stage III: Maturing

Ovary reddish yellowish, occupied nearly half of body cavity, ovarian wall started becoming opaque. Ova were spherical and few ova were seen as spherical granules, visible to naked eyes.

Stage IV: Mature

Ovary occupied about three-fourth of body cavity, yellowish with prominent blood vessels, fully packed with ova. The anterior portion of the ovary bent and started to grow parallel to vertebrae. Ova were spherical and seen as spherical granules, visible to naked eyes.

Stage V: Advanced mature

Ovary greatly enlarged, dark yellow to reddish orange, occupied more than three-fourth of body cavity. The anterior portion of the ovary bent and grew parallel to vertebrae; resembling a distorted 'C' shape. Ovarian wall was thin. Ova were visible as spherical, semi transparent, yolk vacuolated and yellowish.

Stage VI: Fully Ripe

Ovary reddish orange in colour, occupied the entire body cavity and ovarian wall was very thin. The anterior portion of the ovary bent and grew parallel to vertebrae; formed a distorted 'C' shape. Ova spherical in shape, separated from each other and the connective tissue, oozed out on slight pressure.

Stage VII a: Partially spent

In this stage, ovary occupied nearly 3/4 the body cavity, appeared yellowish, partly empty and in distorted shape. The anterior portion of the ovary

bent and grew parallel to vertebrae; formed a more distorted 'C' shape. Ovary appeared more of reddish colour in posterior part and become thinner.

Stage VII b: Fully spent

Ovary shrunken and flaccid, blood shot, blood vessels loosely hanging in lumen of ovaries. The anterior portion of the ovary bent and forms a thin distorted 'C' shape. Few ova were large while large majority were small and transparent.

4.3.1.2. Maturation stages of testes

Stage I: Immature

Testes were transparent thread like and occupied less than 1/5th of the body cavity. It is very difficult to distinguish from stage 1 ovary unless observed under microscope for the presence of ova.

Stage II: Developing immature

Testes increased in thickness and translucent, occupied about quarter of body cavity by length.

Stage III: Maturing

Testes whitish, enlarged in size, occupied about half of body cavity by length.

Stage IV: Late mature

Testes white or creamy in colour, occupied more than half and less than three-fourth of the length of body cavity. The anterior portion of the testes bent and started growing parallel to vertebrae and formed a distorted 'C' shape.

Stage V: Advanced mature

Testes greatly enlarged in size, convoluted in appearance and milky white, occupying about three-fourth of the length of body cavity. The anterior portion of the testes bent and grew parallel to vertebrae forming a distorted 'C' shape.

Stage VI: Fully ripe

Testes greatly enlarged, occupied full length of the body cavity, pinkish white and exude milt on slight pressure. The anterior portion of the testes bent and grew parallel to vertebrae and forms a distorted 'C' shape.

Stage VII a: Partially spent

Testes partially collapsed, reddish, transparent along the margin due to partial release of milt at spawning. The anterior portion of the testes bent and grew parallel to vertebrae and formed a distorted 'C' shape.

Stage VII b: Fully spent

Testes were reddish brown, flabby and shrunken occupied about one-fourth the length of body cavity. The anterior portion of the testes bent and formed a thin distorted 'C' shape.

4.3.2. Gonado somatic Index (GSI)

The Gonado somatic Index (GSI) estimated for different months is given in the Table 4.3.2.1 and GSI based on different length range is given in Table 4.3.2.2. The graphical representations of monthly GSI of male and females are given in Fig. 4.3.2.1 and Fig. 4.3.2.2, respectively. From the table, its clear that there is significant variation in the GSI estimates of different months (March, July, August, September, October, November and December) in both the sexes and hence the null hypothesis is rejected. The estimates of GSI based on different length showed no significant variation in case of males while significant variations were observed in case of Females. Hence the null hypothesis is accepted in case of male and rejected in case of females. The value of GSI increased rapidly from January to June and decreased from July to October. The highest GSI value, in female was observed during March while for male, during June. The lowest GSI value was observed in October for both males and females. From the GSI values, it is clear that moonfish had a protracted spawning from March to June. During the month of October, the GSI values were found to be the lowest for both sexes which signified the end of protracted breeding season. There was a small peak during November for both the sex, after which

the values decrease steeply. The low GSI value during July to October was mainly due to presence of spent gonads in fishes.

4.3.3. Length at first maturity (L_{m50}), Minimum Size of Maturity (MSM), Minimum Size of Spent (MSS)

The logistic curves for the determination of length at maturity for both sexes are provided in Fig. 4.3.3.1 and Fig. 4.3.3.2. All males, upto 82 mm, were immature. The first occurrence of maturing male were noted at 83mm (MSM) in 80-100 mm length group and the contribution of mature males continued up to 250mm. Fifty percentages of them matured at 13.5 cm length (L_{m50}). In case of females, the smallest fish with mature ovary (MSM) was seen at 85 mm, in the length group 80-100mm and the length at which first spent female was recorded at 165 mm (MSS) (Table 4.3.3.1). The length at first maturity (L_{m50}) for females was found to be 13.8 cm.

Table: 4.3.2.1. The monthly mean GSI values of males and females of moonfish

Month	Female				Male			
	Smallest Length (mm)	Largest Length (mm)	Number	Mean GSI	Smallest Length (mm)	Largest Length (mm)	Number	Mean GSI
JAN	80	246	86	2	80	247	38	2.33
FEB	60	192	92	2.97	100	188	22	3.14
MAR	140	201	55	4*	114	201	45	3.45*
APR	141	240	45	3.2	130	250	70	3.21
MAY	98	255	74	3.1	135	235	46	2.44
JUN	85	182	52	3.4	85	162	10	3.58
JUL	134	236	29	2.1*	169	226	24	1.03*
AUG	164	221	15	1.5*	118	217	25	1.24*
SEP	117	243	65	0.8*	142	241	20	0.43*
OCT	107	227	58	0.5*	108	233	38	0.56*
NOV	113	223	33	1.5*	119	228	57	1.21*
DEC	100	240	80	1.3*	95	180	40	0.66*

*p<0.01 (One way ANOVA)

Table: 4.3.2.2. The length wise mean GSI values of males and females of moonfish

Sl. No.	Length range (mm)	Female			Male		
		Smallest length (mm)	Number of Sample	Mean GSI	Smallest length (mm)	Number of Sample	Mean GSI
1	≤90	60	28	0.23*	80	7	0.44
2	90.1-120	92	128	0.695*	95	54	1.22
3	120.1-150	121	121	1.3181	125	36	1.26
4	150.1-180	151	90	1.726	152	69	1.31
5	180.1-210	181	231	2.5	182	204	1.89
6	210.1-240	212	70	2.78	211	57	1.89
7	240.1-270	241	16	3.77*	241	8	1.65

*p<0.01 (One way ANOVA)

Table: 4.3.3.1. Minimum Size at Maturity (MSM) and Minimum Size of Spent (MSS) of moonfish observed in the sample at different months

Months	Female MSM	Female MSS	Male MSM	Male MSS
Dec-15	112	180	120	160
Jan-16	105	186	96	174
Feb-16	112	184	100	168
Mar-16	140	176	133	165
Apr-16	142	165	130	144
May-16	98	175	135	164
Jun-16	nil	nil	nil	nil
Jul-16	nil	nil	nil	nil
Aug-16	nil	172	nil	164
Sep-16	119	170	142	168
Oct-16	119	175	nil	165
Nov-16	nil	168	nil	173
Dec-16	114	178	95	164
Jan-17	110	190	100	180
Feb-17	115	175	110	180
Mar-17	142	181	135	182
Apr-17	nil	187	127	196
May-17	112	173	117	168
Jun-17	85	170	83	162
Jul-17	141	172	-nil	165
Aug-17	-nil	168	nil	165
Sep-17	121	172	142	170
Oct-17	117	182	108	164
Nov-17	118	168	123	160

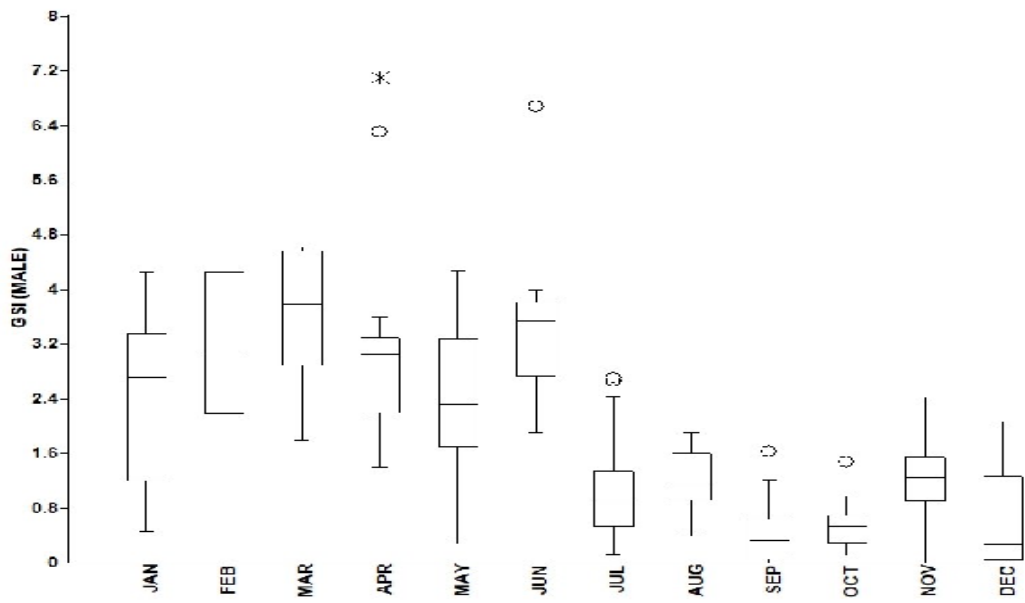


Fig. 4.3.2.1. Monthly Gonado somatic Index (GSI) of male moonfish

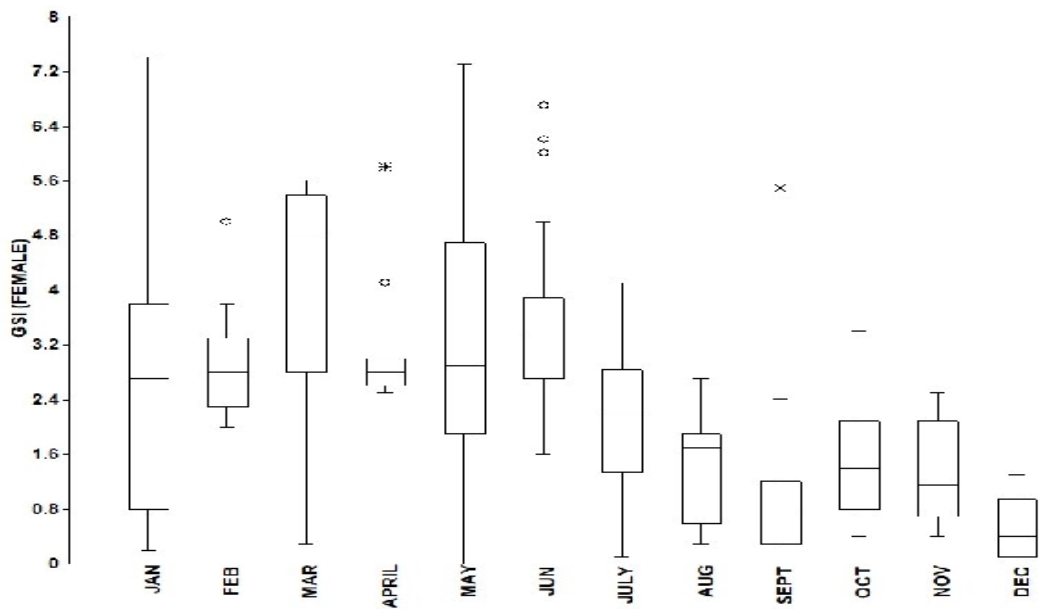


Fig. 4.3.2.2. Monthly Gonado somatic Index (GSI) of female moonfish

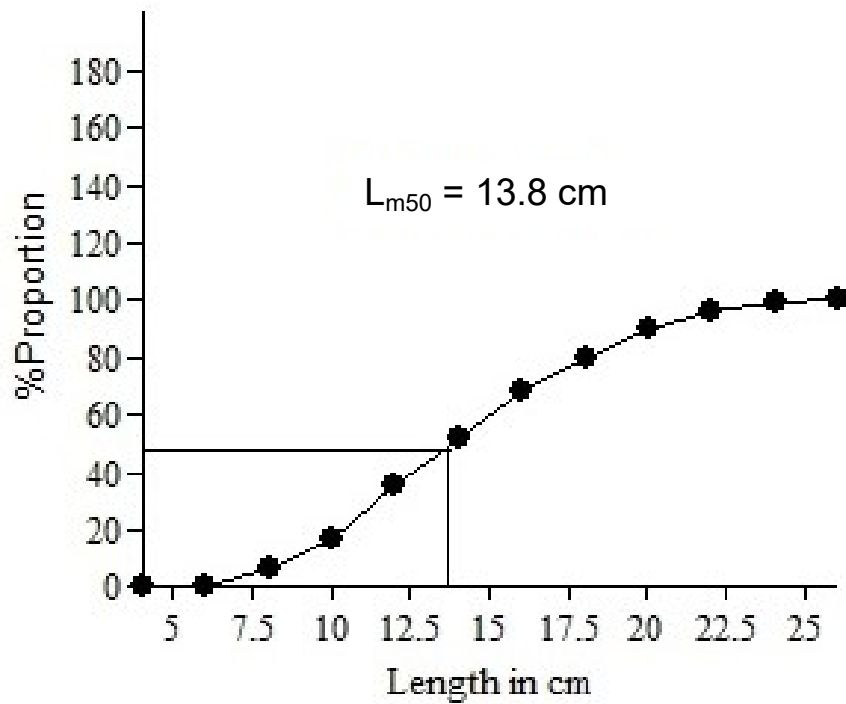


Fig. 4.3.3.1. Logistic curve for the estimation of L_{m50} in female of *M. maculata* from Karnataka Coast

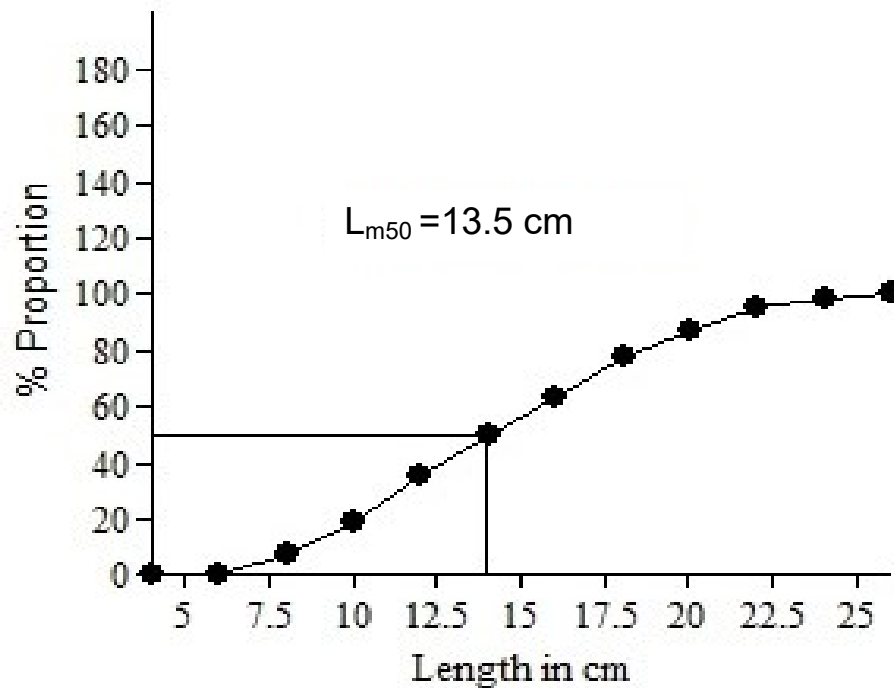


Fig. 4.3.3.2. Logistic curve for the estimation of L_{m50} in male of *M. maculata* from Karnataka Coast

4.3.4. Spawning season

The percentage occurrence of different stages of maturity of both testis and ovary during different months of the year was plotted to find out the spawning period of *M. maculata* (Fig. 4.3.4.1 and Fig. 4.3.4.2). The higher percentages of mature gonads were seen during March to August indicating peak spawning activities during this period. This was further confirmed by the presence of spent specimens in September-October and small sized (35-60 mm) fish during December and February in the commercial landings as trash in multiday trawlers. GSI also indicated similar results regarding the spawning season.

4.3.5. Spawning frequency

The ova diameter studies of the fish had shown oocytes of different sizes in the same ovary (Fig. 4.3.5.1.a & Fig. 4.3.5.1.b). The occurrence of primary oocyte was seen in all stages of ovarian development, even though the percentage of occurrence was less in stage V, VI and VIIa. The oocyte diameter of the major mode in stage I was 0.048mm which increased to 0.12 mm in stage IIa. In stage II b, in addition to the major mode of 0.12mm, few large sized ova were also seen in a minor mode with ova diameter 0.528 mm. In stage III, the mean oocyte diameter of the major mode was 0.192mm while a minor modes with an ova diameter 0.336mm was observed. In stage IV, along with the major mode with mean ova diameter of 0.288 mm, two minor modes with mean ova diameters of 0.144mm and 0.48mm were observed. In stage V, along with the major mode with mean ova diameter 0.384mm, two minor modes with mean ova diameter of 0.192mm and 0.48mm were also observed. In stage VI, along with major mode with ova diameter of 0.432 mm, four minor modes with mean ova diameter of 0.096mm, 0.24mm, 0.336mm and 0.576mm were observed. In stage VII a, along with the major mode having ova diameter of 0.576mm, three minor peaks were observed with mean ova diameter of 0.144mm, 0.24mm and 0.432mm. In stage VII b, along with the 2 minor modes of 0.144mm and 0.64mm ova diameters, a major mode with mean ova diameter 0.288mm was observed. The occurrence of ova in multiple stages of development in the same ovary was observed from ovary development stages II b onwards.

Fig. 4.3.4.1. Monthly distribution of different maturity stages in female moonfish

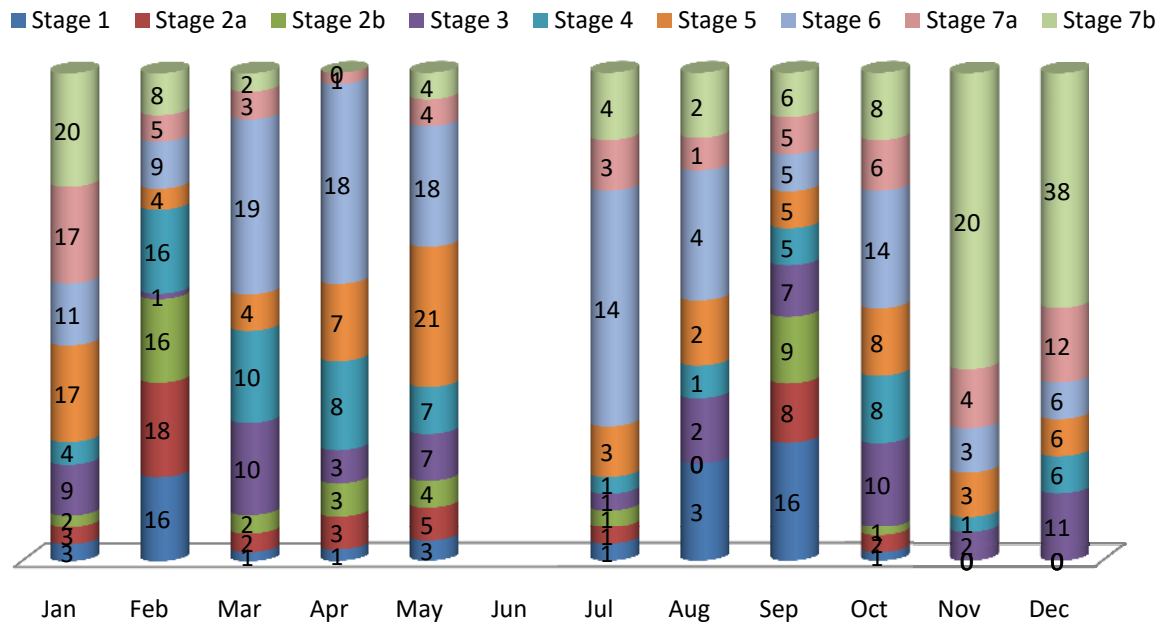
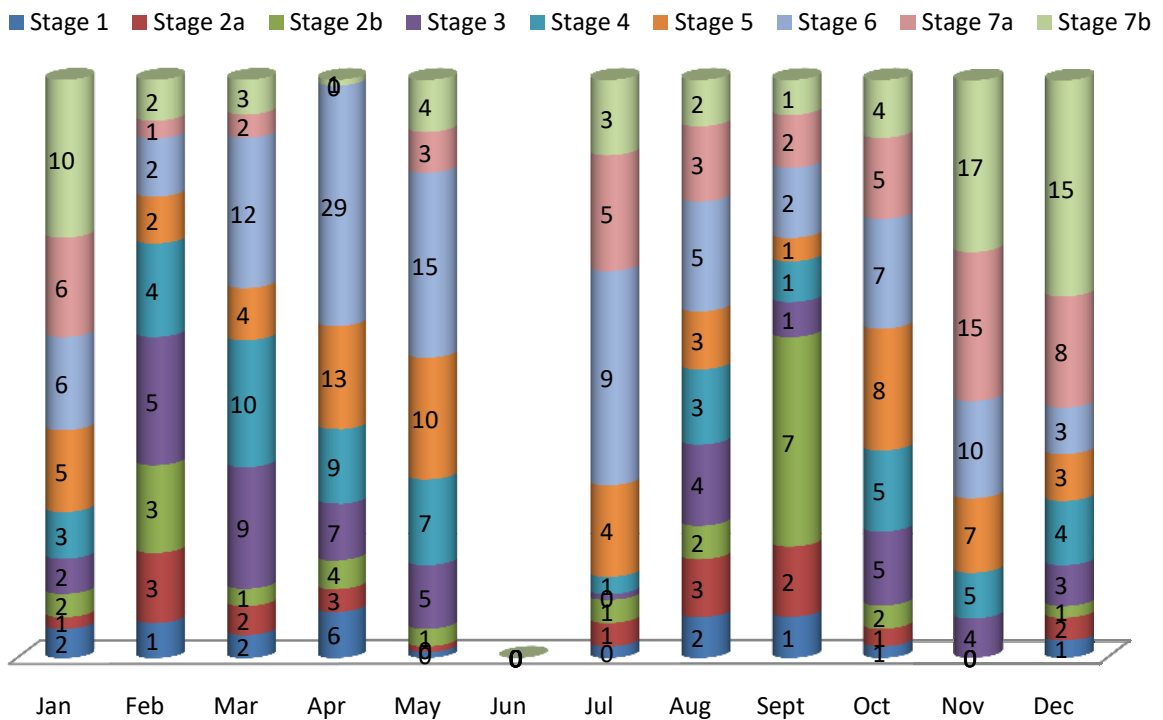


Fig. 4.3.4.2. Monthly distribution of different maturity stages in male moonfish



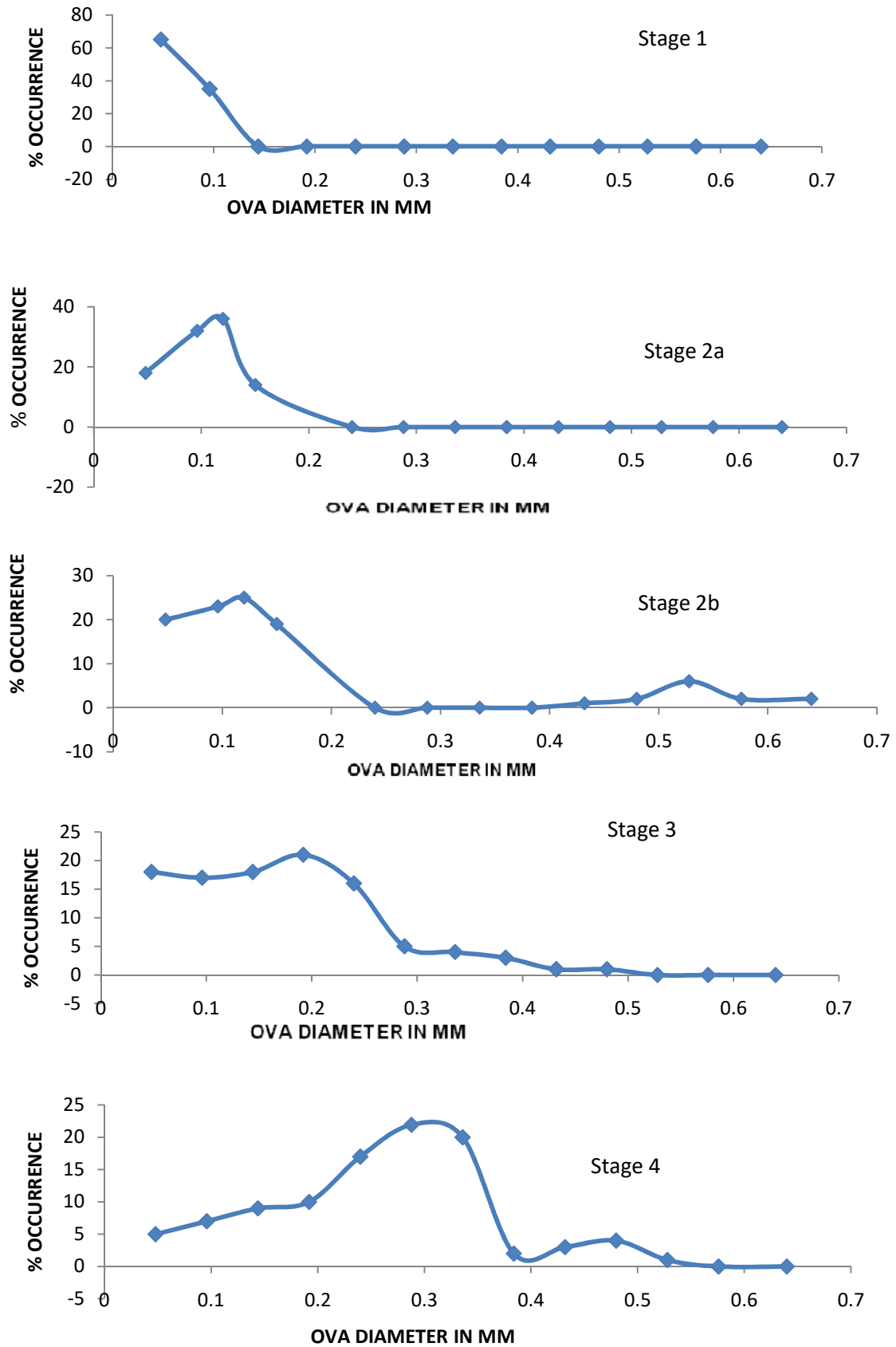


Fig. 4.3.5.1.a. Ova diameter frequency polygons of moonfish showing growth of immature ova towards maturity (stage 1 to 4)

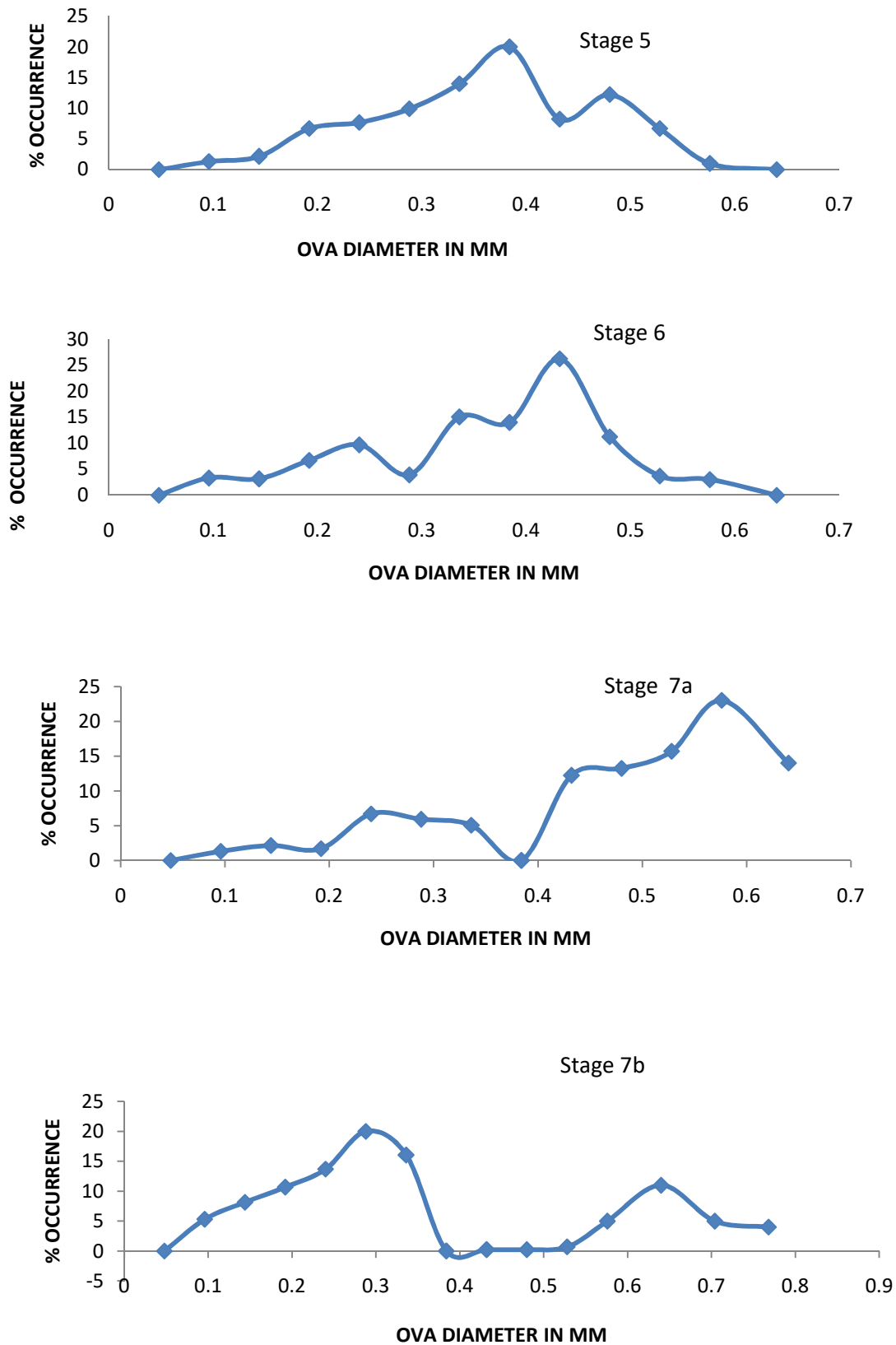


Fig. 4.3.5.1.b. Ova diameter frequency polygons of moonfish showing growth of immature ova towards maturity (stage 5 to 7b)

4.3.6. Sex ratio

Since sexual dimorphism is absent in the species, the sexes could not be distinguished externally. The null hypothesis was rejected as the females dominated significantly in catch in all seasons as well as all length range. In specimens below 70 mm, sex determination was difficult. This is because the specimens below this size were seen only in trash landings which were usually in fragile stage due to deterioration. The overall sex ratio indicated significant dominance of females. Table 4.3.6.1 and Table 4.3.6.2 summarises the sex ratio for different length groups and different seasons.

4.3.7. Fecundity

The absolute fecundity of moonfish ranged from 8,354 eggs (TL=13.9 cm, W = 164 g) to 1,08,829 eggs (TL= 23 cm; W= 215 g). The average and absolute fecundity of moonfish in different length groups is given in Table 4.3.7.1.

4.3.7.1. Relationship between fecundity and different variables

Relationship between the total length, total weight and ovary weight with absolute fecundity is shown in the Fig. 4.3.7.1.1. The relationship between the total length and fecundity was transformed into a straight line logarithmic form and expressed as: $\text{Log fecundity} = 1.924 \text{ Log (total length)} + 0.276$; Where, the correlation coefficient (r) was 0.284 indicating poor relationship ($P > 0.07$). The relationship between the total weight and fecundity was transformed into a straight line logarithmic form and expressed as: $\text{Log fecundity} = 1.325 \text{ Log (total weight)} + 1.747$; Where, the correlation coefficient (r) was 0.44 indicating that the relationship was significant ($P < 0.05$) between the two. The relationship between the ovary weight and fecundity was transformed into a straight line logarithmic form and expressed as: $\text{Log fecundity} = 0.924 \text{ log (ovary weight)} + 4.045$; Where, the correlation coefficient (r) was 0.71 indicating that the relationship was significant ($P < 0.05$).

Table: 4.3.6.1. Season wise distribution of sex ratio of moonfish

Seasons	Sex differentiated fishes	Indeterminates	No. of female	No. of male	Female: male	Chi-sq value	P-value	NS/S	Df
Pre Monsoon	114	23	92	22	4.18:1	42.04	<0.001	S	3
	100	18	55	45	1.22:1				
	115	9	45	70	0.64:1				
	120	7	74	46	1.61:1				
Monsoon	62	2	52	10	5.2:1	23.95	<0.001	S	2
	53	6	29	24	1.21:1				
	40	4	15	25	0.6:1				
Post Monsoon	85	-	65	20	3.25:1	36.26	<0.001	S	4
	96	-	58	38	1.53:1				
	90	4	33	57	0.58:1				
	120	17	80	40	2:1				
	124	18	86	38	2.26:1				
Pooled	1119	108	684	435	1.57:1	103.3	<0.001	S	11

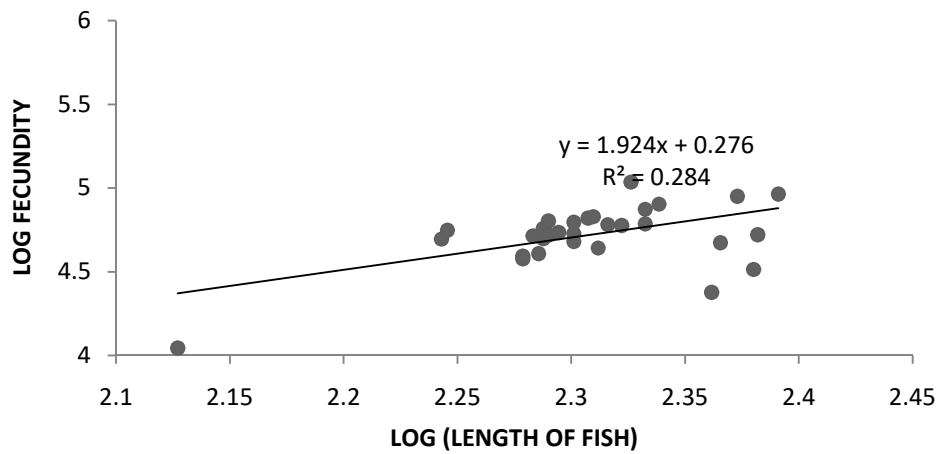
Table: 4.3.6.2. Length wise distribution of sex ratio of moonfish

Class	Length group (mm)	Sex identified	Sex ratio (female: male)	Sex unidentified	Chi- sq value	P-value	S/NS	Df
Juvenile	50-70	4	1:0	8	342.4	<0.01	S	3
	70.1-90	31	3.2:1	9				
	90.1-110	174	3.18:1	48				
	110.1-137.9	99	4.6:1	36				
Adult	138-150	67	6.25:1	2	131.09	<0.01	S	6
	150.1-170	58	1.53:1	1				
	170.1-190	222	1.64:1	2				
	190.1-210	313	1.27:1	2				
	210.1-230	117	1.21:1	0				
	230.1-250	33	2.14:1	0				
	250.1-270	1	1:0	0				

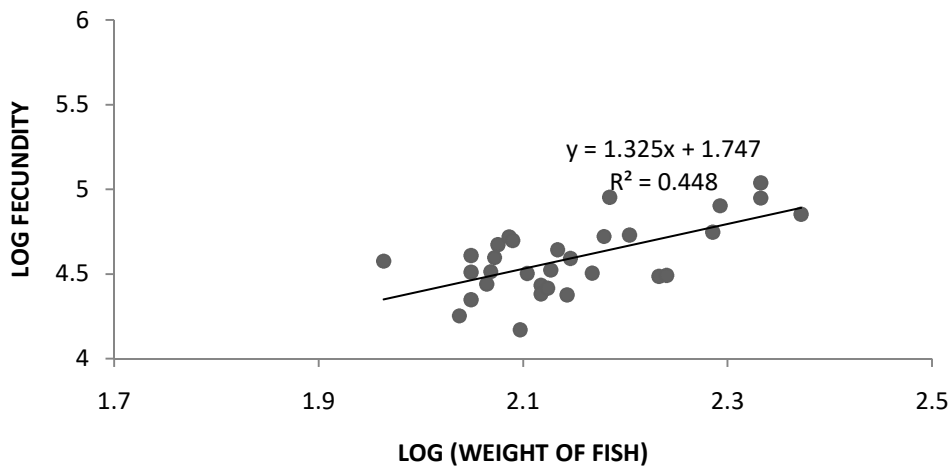
Table: 4.3.7.1. Absolute fecundity of moonfish in different length range

Sl No.	Length class (mm)	Mean length (mm)	No. of fishes counted	Absolute fecundity		Average absolute fecundity
				Minimum	Maximum	
1	<170	139	2	8354	30934	19644
2	170.1-190	181.25	4	17913	44052	30983
3	190.1-210	200.8	16	14770	89012	51891
4	210.1-230	223.3	5	23733	108829	66281
5	230.1-250	239.75	6	30568	80225	55397

a.



b.



c.

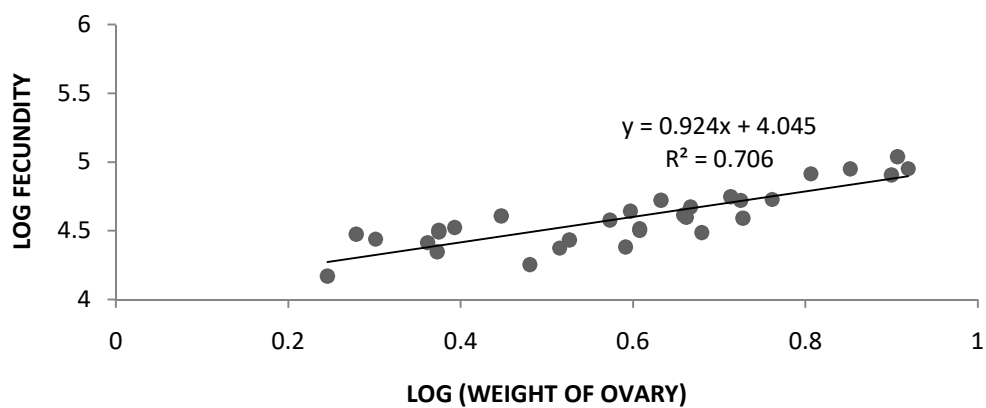


Fig. 4.3.7.1.1. Relationship of absolute fecundity with a) fish length b) fish weight and c) ovary weight

4.3.8. Minimum Legal Size (MLS)

After conducting studies on the reproductive biology of the species, it could be concluded that moonfish is a protracted spawner showing indeterminate annual fecundity with batch spawning and is iteroparous, gonochoristic, non-guarder, open pelagic spawner which possess no sexual dimorphism and exhibit external fertilization without any parental care. It is clear from the studies that the fish is showing 'r' reproductive strategy, *i.e.*, species that have high growth rates, typically exploited less and produce many offsprings, each of which has a relatively low probability of surviving to adulthood. Preliminary studies revealed that the exploitation ratio of moonfish along the Karnataka Coast is 0.47 and the reproductive load is 0.54. The initial studies reveal that the fishery is under exploited along the Karnataka waters. So the MLS can be fixed at the size at or between the length at first maturity (SFM) and minimum size of mature (MSM) fish observed in the fishery. The minimum size of mature (MSM) fish observed in the fishery was 85 mm and size at first maturity (SFM) was 138 mm. Taking into consideration the reproductive and growth characteristics of the species, the MLS of moonfish in Karnataka waters is tentatively fixed at 85 cm which is the estimated MSM. Minimum legal size is an important management option with legal binding in marine fisheries and hence could be enforced only after re-confirming results of the research on a larger scale. The MLS suggested for moonfish along the Karnataka Coast in the present study is only tentative and needs to be revalidated and reviewed after continuous studies.

4.4. Food and feeding biology

4.4.1. Diet composition of juveniles

Though 409 guts were analysed for studying the food and feeding habits of juveniles, only 62 guts had food (Fig 4.4.1.1). The Empty Stomach Ratio (ESR) was observed to be 85% for juveniles. Stomach conditions like trace, quarter, half, three fourth and full stomachs were observed in 3%, 4%, 4%, 2% and 2%, respectively, of all the juveniles studied. Monthly ESR for the fishes is given in Table 4.4.1.1. Gut conditions during the different seasons is shown in the Fig

4.4.1.2. The list of prey items observed in the gut of juvenile moonfish along with its percentage of occurrence, number and weight is given in Table 4.4.1.2.

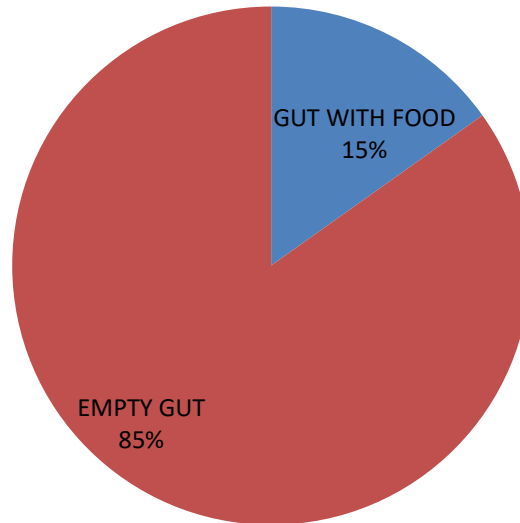


Fig. 4.4.1.1. Pie diagram showing the overall gut condition of juvenile moonfish

Table: 4.4.1.1. Monthly Empty Stomach Ratio (ESR) of juvenile moonfish

Sl. No.	Month	ESR (%)
1	January	80
2	February	84
3	March	85
4	April	80
5	May	84
6	June	92
7	July	95
8	August	85
9	September	75
10	October	86
11	November	88
12	December	85

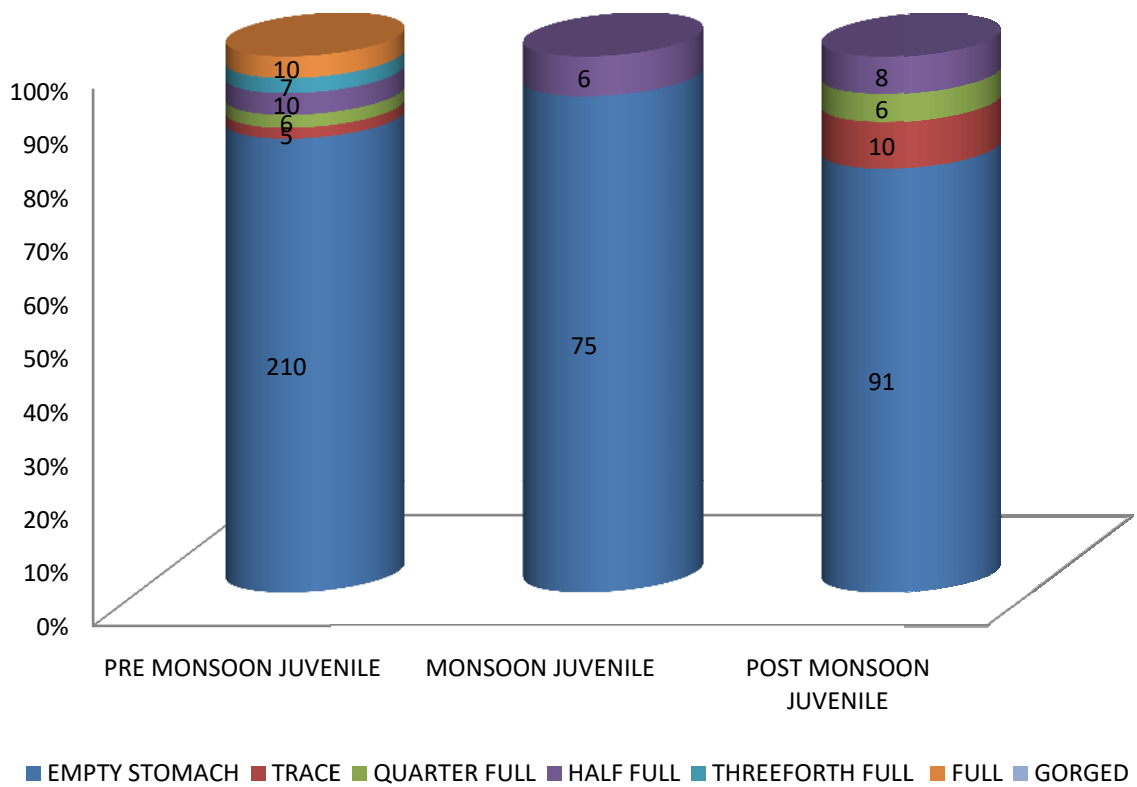


Fig. 4.4.1.2. The changes in the season wise gut condition in juvenile moonfish

Table: 4.4.1.2. The food items observed in the gut of juvenile moonfish along with its percentage of occurrence, number and weight

Sl. No.	Food item	%O	%N	%V
1	Squid juvenile	19.23	4.24	8.17
2	Amphipod	15.38	21.21	23.51
3	Copepod	23.08	46.62	15.87
4	Mysids	3.85	0.61	9.62
5	<i>Acebes</i> sp	34.62	13.94	24.04
6	Crab	0.00	0.00	0.00
7	Unicorn cod	0.01	0.01	0.01
8	Barracuda juvenile	0.01	0.01	0.01
9	Ribbonfish juvenile	3.85	1.82	2.40
10	Eel larvae	0.01	0.01	0.01
11	Anchovy	0.01	0.01	0.01
12	Unidentified fish juvenile	7.64	1.21	7.21
13	Foraminifera	0.01	0.01	0.01
14	Polychaete	15.38	2.42	5.29
15	Eggs	7.69	7.27	2.88
16	Dinoflagellates	3.85	0.61	0.96

The food items in the gut of juveniles could be classified mainly under five categories namely crustaceans, molluscs, fishes, annelids and miscellaneous group. The crustaceans included planktonic crustaceans like amphipods, copepods, mysids and *Acetes* sp. Squid juvenile alone represented molluscs. Fishes seen in the guts include anchovies (*Stolephorus* sp), unicorn cod (*Bregmaceros mccllellandi*), larvae of eels and juveniles of ribbonfish (*Trichiurus* spp) and barracuda (*Sphyraena* spp). The annelids contained polychaetes while miscellaneous item in the gut includes dinoflagellates, pelagic eggs and shells of foraminifera.

In terms of the percentage of occurrence, *Acetes* sp was followed by copepods dominated the juvenile diet. Copepods followed by amphipods dominated numerically. *Acetes* sp. and amphipods represented the maximum share gravimetrically. The contributions of the members of miscellaneous group were minimal while polychaetes was 15.38%. From these observations, it could be concluded that the juvenile moonfish fed on planktonic crustaceans like amphipods, copepods and *Acetes* sp.

4.4.1.1. Length wise diet change

The length wise changes in the diet of juvenile moonfish are shown in the Fig. 4.4.1.1.1 and Table 4.4.1.1.1. The stomachs of all fishes in the length category 50-75mm were found to be empty. The major diet item for juvenile moonfish, in length range 75.1-100 mm, was copepods and amphipods. The minor diet was comprised of eggs, *Acetes* sp, unidentified fish juvenile, shells of foraminifera and squid juvenile. For juvenile moonfish, in the length range 100.1-125 mm, the major diet included copepods, amphipods and *Acetes* sp and minor diet included squid juvenile, polychaetes, eggs, mysids and ribbonfish juvenile. For juvenile moonfish, in the length range 125.1-137.9 mm, copepods, amphipods and *Acetes* sp were the prominent diet and minor diet includes unidentified fish juvenile, anchovies (*Stolephorus* sp), unicorn cod (*Bregmaceros mccllellandi*), larvae of eels, barracuda juvenile (*Sphyraena* sp.), shells of foraminifera, squid juvenile and polychaetes.

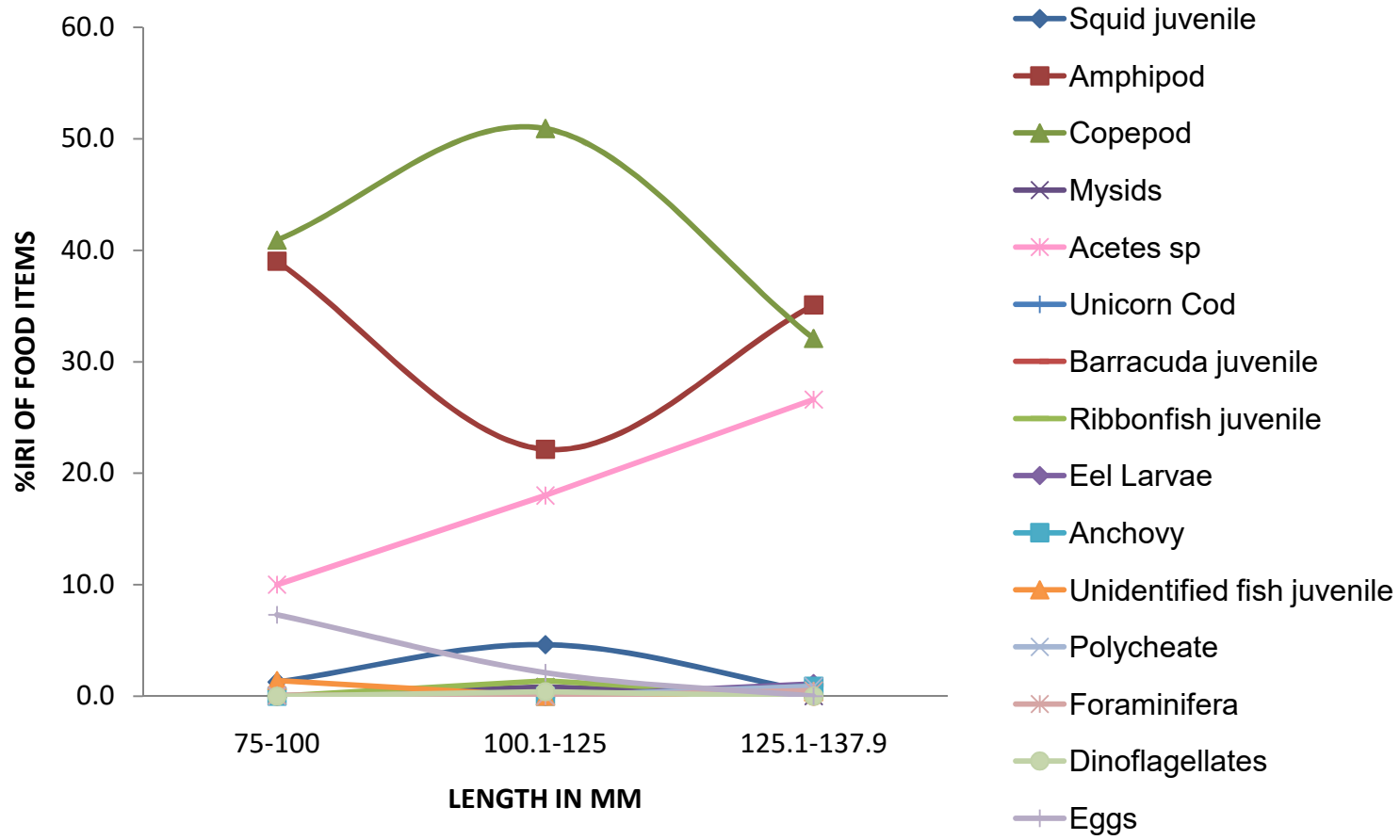


Fig. 4.4.1.1.1. The changes in the food items in the gut of juvenile moonfish of different length class

Table: 4.4.1.1.1. The IRI of food items in the gut of juvenile moonfish in different length class

Sl. No.	Food category	Food item	50-75 mm	75.1-100 mm	100.1-125 mm	125.1-137.9 mm
1.	Mollusc	Squid juvenile	0	1.3	4.6	0.4
2.	Crustacean	Amphipod	0	39.0	22.1	30.1
3.		Copepod	0	40.9	47.9	32.1
4.		Mysids	0	0.0	0.8	0.0
5.		<i>Acetes</i> sp	0	6.0	18.0	26.6
6.	Fishes	Crab	0	0.0	0.0	0.0
7.		Unicorn cod	0	0.0	0.0	1.0
8.		Barracuda juvenile	0	0.0	0.0	1.0
9.		Ribbonfish juvenile	0	0.0	1.4	0.0
10.		Eel larvae	0	0.0	0.0	1.1
11.		Anchovy	0	0.0	0.0	0.9
12.		Unidentified fish juvenile	0	1.4	0.0	0.4
13.		Annelids	Polycheate	0	4.0	3.0
14.	Miscellaneous	Foraminifera	0	0.1	0.0	0.5
15.		Dinoflagellates	0	0.0	0.4	0.0
16.		Eggs	0	7.3	2.1	0.0

4.4.1.2. Month wise diet change

The month wise diet change observed in juvenile moonfish (Table 4.4.1.2.1.) indicated that amphipods, copepods and *Acetes* sp were the major food item of juveniles throughout the year. Certain food items like *Acetes* sp, eggs, squid juvenile were seen only during certain months. Hence, season wise diet shift was also calculated to understand the diet shift.

4.4.1.3. Season wise diet changes

The major dietary items of the juvenile during the pre monsoon season were planktonic crustaceans likes *Acetes* sp followed by amphipods with %IRI of 77 and 13, respectively (Table 4.4.1.3.1). The major dietary items for the juveniles during the monsoon season were planktonic crustacean likes amphipods and copepods with IRI % of 51 and 49, respectively (Table.4.4.1.3.2). The major dietary item for the juvenile during the post monsoon season was crustacean likes copepods followed by eggs with %IRI of 65.6 and 12.4, respectively (Table 4.4.1.3.3).

4.4.1.4. Forage strategy

The information pertaining to the importance of prey, niche width and feeding strategy of the juvenile moonfish is illustrated by the points spread along the diagonals and the axes of the graph (Fig. 4.4.1.4.1). The prey importance is represented in the diagonal from lower left (rare prey) to upper right (dominant prey); the feeding strategy is represented in the vertical axis from bottom (generalisation) to top (specialisation); and the relationship between feeding strategy and the between phenotype or within phenotype contributions to the niche width is represented in the diagonal from lower right, which represents a high within phenotype component (WPC), to upper left, which means a high between phenotype component (BPC). A population with a narrow niche must necessarily be composed of individuals with narrow and specialized niches. A population with a broad niche may, on the other hand, consist of individuals with either narrow (high BPC) or wide (high WPC) niches.

From the graph, it is clear that the dominant prey of juvenile moonfish was *Acetes* sp and copepods, while the rarely represented ones are dinoflagellates, eggs and finfish juvenile (ribbonfish juvenile). The juvenile moonfish displayed specialised feeding strategy with specific affinity for amphipods and copepods. The top left portion of the graph shows that few individuals chose specific prey types; however, the specific prey selected by each individual differed. Amundsen (1996) method indicates that the feeding strategy of juvenile moonfish was specialised showing selective feeding on planktonic crustaceans. But in certain cases, they also showed opportunistic feeding because individuals mostly chose specific prey but the population was often opportunistic with regard to what prey were selected. The niche width of juvenile moonfish was found to be narrow due to high BPC (Between-Phenotype Component).

Table: 4.4.1.2.1. The month wise diet change and IRI of food item observed juvenile moonfish

Sl No.	Food category	Food item	January	February	March	April	May	June	July	August	September	October	November	December
1	Mollusc	Squid juvenile	14.9	50.0	0.0	0.0	25.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	Crustacean	Amphipod	59.3	0.0	34.5	0.0	33.3	51.6	59.2	8.3	45.8	47.2	65.0	45.8
3		Copepod	25.7	0.0	0.0	0.0	0.0	48.4	40.8	91.5	29.4	31.1	33.0	54.2
4		<i>Acetes</i> sp	0.0	0.0	65.5	0.0	39.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5		Mysids	0.0	0.0	0.0	26.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Fishes	Unicorn cod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
7		Barracuda juvenile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
8		Ribbonfish juvenile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	0.0	0.0	0.0
9		Eel larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
		Anchovy	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10		Unidentified Fish juvenile	0.0	49.8	0.0	0.0	0.0	0.0	0.0	0.0	4.4	5.9	0.0	0.0
11	Annelids	Polychaete	0.0	0.0	0.0	73.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	Miscellaneous	Eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.8	15.7	2.0	0.0
13		Foraminifera	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14		Dinoflagellates	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table: 4.4.1.3.1. The diet observed in juvenile moonfish in the pre monsoon season

Pre monsoon juvenile						
Food category	Food item	%O	%N	%V	IRI	%IRI
Mollusc	Squid juvenile	10	3.6	4.3	78.3	1.5
Crustaceans	Amphipod	10	42.9	26.6	694.5	13.0
	Mysids	5	1.8	1.2	14.8	0.3
	<i>Acetes</i> sp	45	41.1	50.2	4108.9	77.2
Annelids	Polychaete	20	7.1	11.8	379.3	7.1
Fishes	Unidentified fish juvenile	5	1.8	3.0	23.7	0.4
Phytoplanktons	Dinoflagellates	5	1.8	3.0	23.7	0.4

Table: 4.4.1.3.2. The diet observed in juvenile moonfish in the monsoon season

Monsoon juvenile						
Food category	Food item	%O	%N	%V	IRI	%IRI
Crustaceans	Amphipod	50	52.9	50	5147.1	51
	Copepod	50	47.1	50	4852.9	49

Table: 4.4.1.3.3. The diet observed in juvenile moonfish in the post monsoon season

Post monsoon juvenile						
Food category	Food item	%O	%N	%V	IRI	%IRI
Mollusc	Squid juvenile	16.7	5.4	18.9	405.0	8.9
Crustacean	Amphipod	16.7	12.0	7.5	325.1	7.1
	Copepod	33.3	65.2	24.5	2991.5	65.6
Fishes	Ribbonfish juvenile	8.3	3.3	9.4	105.8	2.3
	Unidentified fish juvenile	8.3	1.1	18.9	166.3	3.6
Miscellaneous	Eggs	16.7	13.0	20.8	563.3	12.4

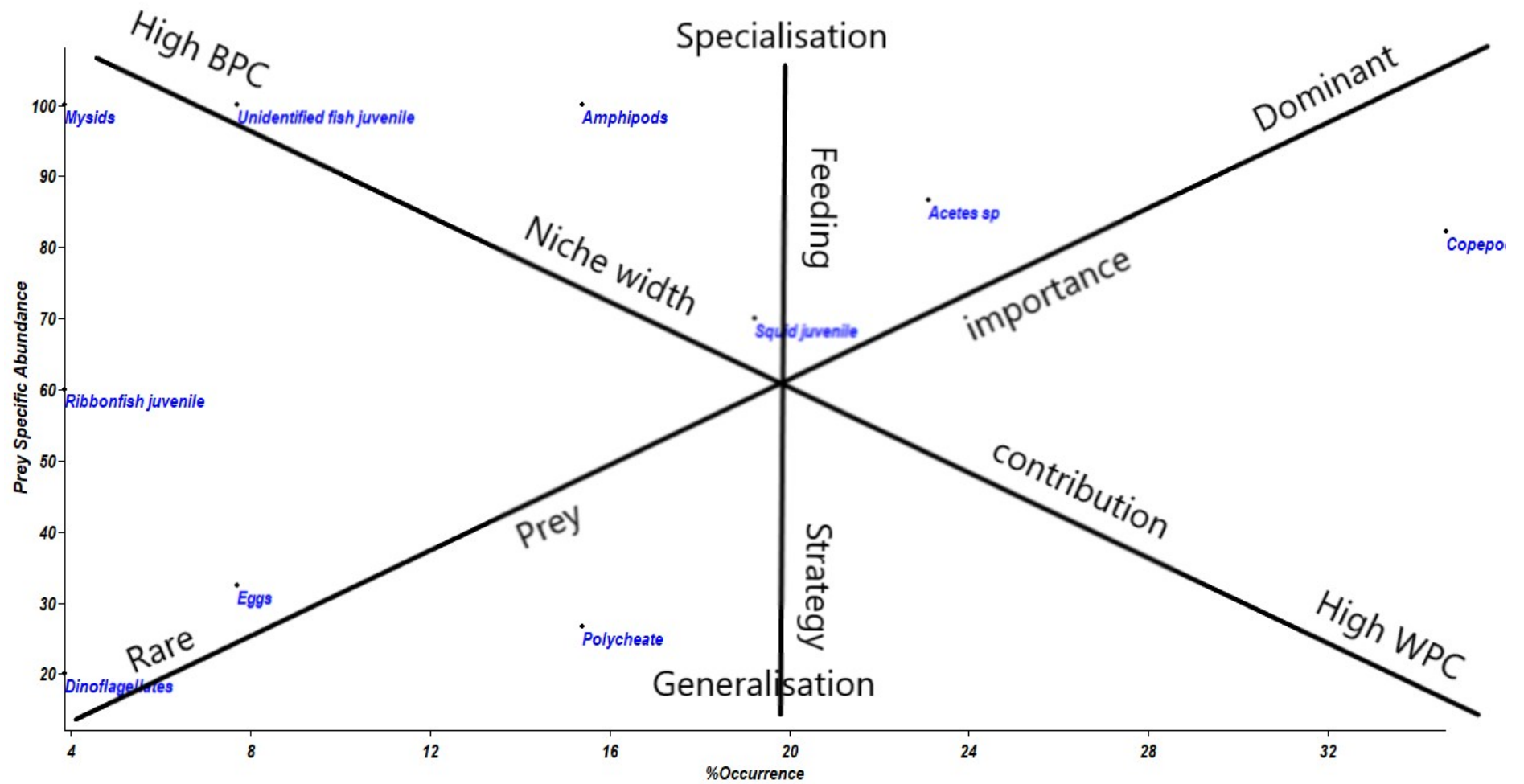


Fig. 4.4.1.4.1. Costello's modified graph (1990) illustrating the foraging strategy in juvenile moonfish

4.4.1.5. Diet breadth and dietary specialization

The Shannon Weiner index (H') and Evenness Index (J') of juveniles was estimated at 1.562344 and 0.56, respectively, which indicates low spectrum width of prey items and relatively less number of major prey types. This implies that the juvenile moonfish was a selective feeder on planktonic crustaceans.

4.4.2. Diet composition of adult moonfish

Of the 818 guts analysed, only 107 fishes had food in gut (Fig 4.4.2.1). The estimated value of Empty Stomach Ratio (ESR) was 87%. The stomach conditions like trace, quarter, half, three fourth, full and gorged were observed in 5%, 3%, 2%, 1%, 1% and 1%, respectively, for all the adults studied. Monthly ESR for the fishes showed that the maximum empty stomachs were observed in the months of June, July and February (Table 4.4.2.1). The season wise gut conditions of adults showed maximum percentage of empty stomachs during monsoon season (Fig. 4.4.2.2). The food items in the gut of adults could be classified mainly under five categories namely crustaceans, molluscs, fishes, annelids and miscellaneous group (Table 4.4.2.2). The crustaceans seen in the diet of fishes includes amphipods, copepods, *Acetes* sp, crabs and mysids. The squid juvenile was the single representative of Mollusca. Fish prey items observed in the gut included anchovies (*Stolephorus* spp), unicorn cod (*Bregmaceros mccllellandi*), larvae of eels, juveniles of ribbonfish (*Trichiurus* sp) and barracuda (*Sphyraena* sp). Annelids were represented by polychaetes. Other prey grouped as miscellaneous food item observed in the gut included eggs and shells of foraminifera. Based on the occurrence percentage of various food items, squid juvenile dominated the diet followed by unicorn cod. Based on the numerical percentage, *Acetes* sp dominated followed by squid juvenile. Squid juvenile and *Acetes* sp had the maximum share volumetrically. From these observations, it could be concluded that there was a shift in diet of moonfish after attainment of maturity. Juveniles fed mainly on the planktonic crustaceans like amphipods, copepods and *Acetes* sp while adults, retained *Acetes* sp, avoided small planktonic crustaceans but included squid juvenile and fishes in the diet. The various food item found in the gut of moonfish is shown in the Plate 6.

4.4.2.1. Length wise diet change

The changes observed in the diet of adult moonfish with different length groups are shown in the Fig. 4.4.2.1.1 and Table 4.4.2.1.1. For the fishes in length group 138-150 mm, the major food items were copepod followed by *Acetes* sp. The minor diet consisted of eggs, squid juvenile, amphipods and polychaetes. For the fishes in the length group 150.1-175 mm, the major food item were squid juvenile followed by eggs. The minor diet consisted of *Acetes* sp, copepods, amphipods, eel larvae, unidentified fish juvenile, foraminiferan shells and polychaetes. For the fishes in length group 175.1-200 mm, the major food item was squid juvenile whereas the minor diet consisted of unicorn cod, barracuda juvenile, ribbon fish, anchovy, copepods, amphipods, eel larvae, unidentified fish juvenile, foraminifera shell, eggs and polychaetes. For the fishes in length group 200.1-225 mm, the major food items were squid juvenile followed by *Acetes* sp and ribbonfish juvenile, whereas, the minor diet consisted of unicorn cod, barracuda juvenile, eel larvae, anchovy, copepods, amphipods, unidentified fish juvenile, foraminifera shells, polychaetes and eggs. For the fishes in length group >225 mm, the major food item were squid juvenile followed by ribbonfish juvenile whereas, minor diet consisted of unidentified fish juvenile, foraminiferan shells, polychaetes and *Acetes* sp.

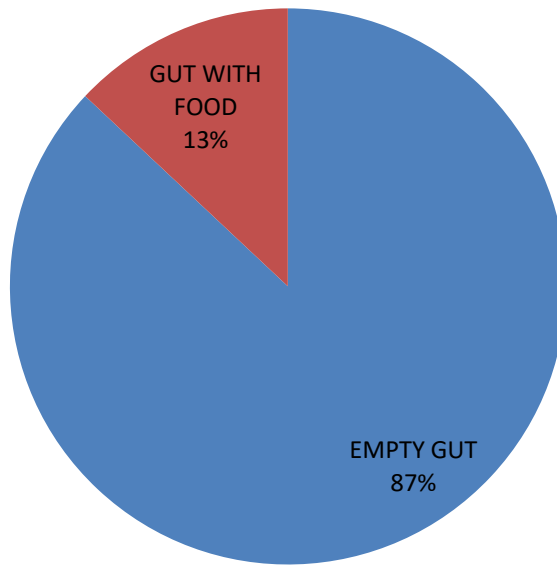


Fig. 4.4.2.1. Pie diagram showing the overall gut condition of adult moonfish

Table: 4.4.2.1. Monthly Empty Stomach Ratio (ESR) of adult moonfish

Sl. No.	Month	ESR (%)
1	January	80
2	February	92
3	March	83
4	April	85
5	May	81
6	June	95
7	July	90
8	August	78
9	September	80
10	October	79
11	November	85
12	December	84

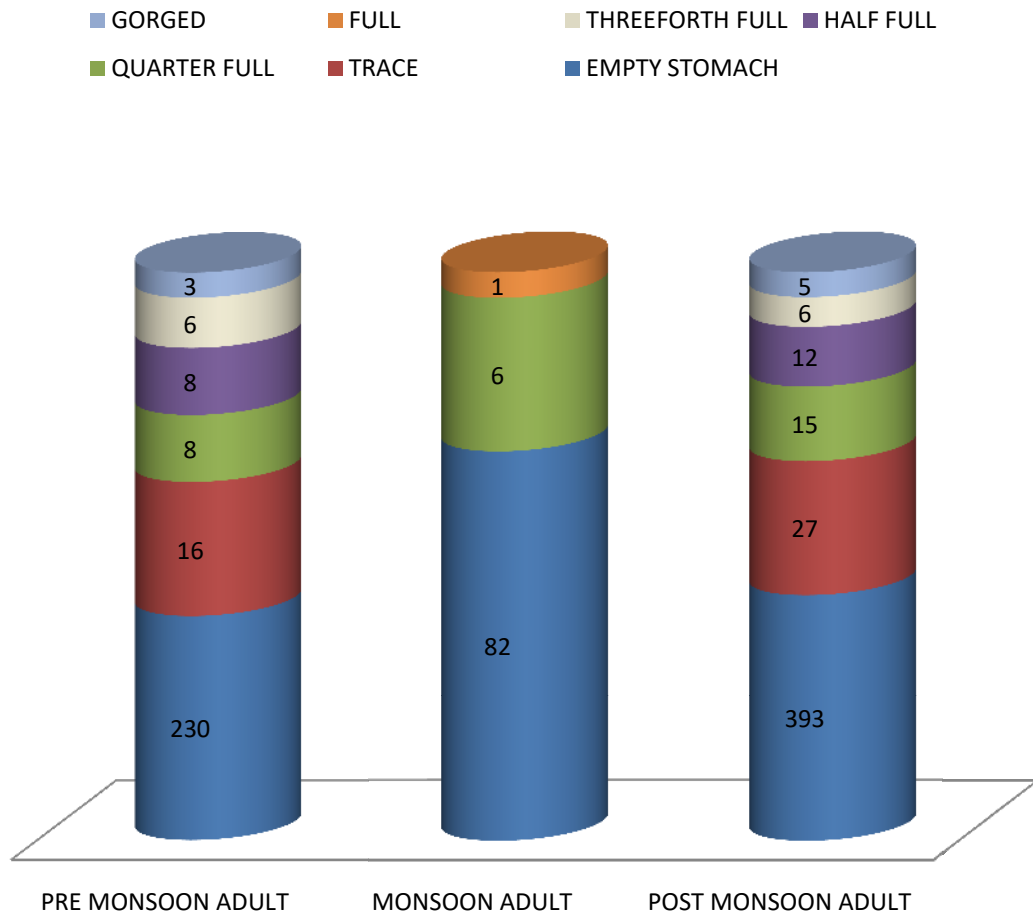


Fig. 4.4.2.2. The changes in the season wise gut condition in adult moonfish

Table: 4.4.2.2. The food items observed in the gut of adult moonfish along with its percentage of occurrence, number and weight

Sl. No.	Food item	%O	%N	%V
1	Squid juvenile	23.97	13.47	29.65
2	Amphipod	3.06	4.11	1.34
3	Copepod	4.15	8.01	1.42
4	Mysids	3.06	1.37	0.90
5	<i>Acetes</i> sp	9.80	34.58	23.67
6	Crab	0.88	0.21	0.16
7	Unicorn cod	10.95	8.14	7.18
8	Barracuda juvenile	7.52	5.49	7.20
9	Ribbonfish juvenile	8.02	5.97	9.77
10	Eel larvae	1.31	2.08	1.03
11	Anchovy	6.05	4.17	4.77
12	Unidentified fish juvenile	2.84	0.78	3.70
13	Foraminifera	3.51	2.46	1.28
14	Polychaete	5.04	1.10	2.46
15	Eggs	9.86	8.05	5.48

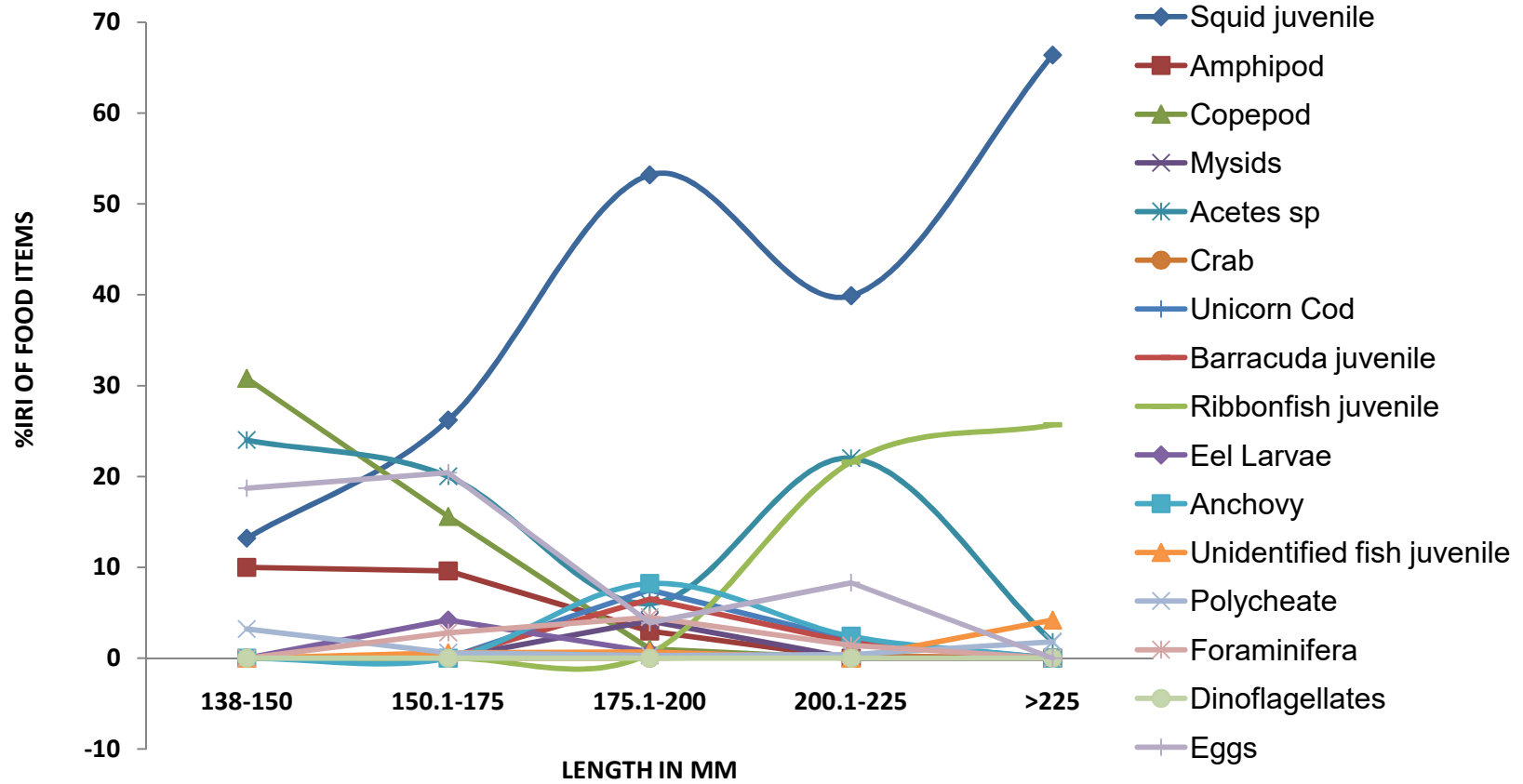


Fig. 4.4.2.1.1. Changes in the food items in the gut of adult moonfish of different length class

Table: 4.4.2.1.1. The IRI of food items in the gut of adult moonfish in different length class

Food Category	Diet item	138-150 mm	150.1- 175 mm	175.1- 200 mm	200.1- 225 mm	>225 mm
Mollusc	Squid juvenile	13.2	26.2	53.2	39.9	66.4
Crustacean	Amphipod	10	9.6	3	0	0
	Copepod	30.8	15.6	1	0	0
	Mysids	0	0	4.1	0	0
	<i>Acetes</i> sp.	24	20	6	22	1.8
	Crab	0	0	0	0.3	0
Fishes	Unicorn cod	0	0	7.5	2	0
	Barracuda juvenile	0	0	6.5	1.7	0
	Ribbonfish juvenile	0	0	0.5	21.6	25.7
	Eel larvae	0	4.2	0.7	0	0
	Anchovy	0	0	8.2	2.4	0
	Unidentified fish juvenile	0	0.6	0.7	0	4.2
	Annelids	Polycheate	3.2	0.6	0.3	0.4
Miscellaneous	Foraminifera	0	2.8	4.5	1.4	0
	Dinoflagellates	0	0	0	0	0
	Eggs	18.7	20.4	3.9	8.3	0



Plate: 6. Various food items found in the gut of moonfish

4.4.2.2. Month wise diet change

The month wise variation in the diet of adult fish is shown in the Table 4.4.2.2.1. Unlike juveniles, adult fish did not show any preference for a specific diet throughout the year. Among the diet item, squid was the most preferred diet as it had the highest IRI values in 4 months. Rest of the food items showed sporadic increase and decrease in IRI values in certain months, which completely lacked any trend which could be explained. Hence season wise diet change was also done to explore the trend in feeding habit.

4.4.2.3. Season wise diet change

The major prey items during pre monsoon season were planktonic crustaceans likes *Acetes* sp (70.9%) and eggs (19.5%) (Table.4.4.2.3.1). The major diet items during the monsoon season were squid juvenile (48.5%) followed by unicorn cod (23.1%) (Table. 4.4.2.3.2). The major food item of adults during the post monsoon season were squid juvenile (72.4%) followed by copepods (6.4%) (Table. 4.4.2.3.3).

4.4.2.4. Forage strategy

The information pertaining to the importance of prey, niche width and feeding strategy of the adult moonfish is illustrated by the points spread along the diagonals and the axes of the graph (Fig. 4.4.2.4.1). The graph indicated that unlike juveniles, adult lacks a dominant prey. There were many prey items (anchovies, copepods, unicorn cods, juvenile of ribbon fishes and barracudas) and data points scattered throughout the centre and left portion of this graph, indicated a mixed feeding strategy, suggesting opportunistic feeding in the adult population. The niche width of adult moonfish was found to be wider than juveniles even when the BPC (Between-Phenotype Component) was high.

4.4.2.5. Diet breadth and dietary specialization

The Shannon Weiner index (H') and Evenness Index (J') for the adults fishes was estimated to be 2.148 and 0.77, respectively, which indicated medium spectrum width of prey items and relatively more number of major prey

types when compared to juveniles. This implied that the adult moonfish were more of an opportunistic feeder.

Table: 4.4.2.2.1. The month wise diet change and IRI of food items observed in adult moonfish

Sl. No.	Food item	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1	Squid juvenile	0.0	0.0	0.0	6.1	1.1	69.7	4.0	83.6	75.7	0.0	60.0	0.0
2	Amphipod	0.0	0.0	31.0	0.0	0.7	0.0	0.0	0.0	0.0	27.6	0.0	11.3
3	Copepod	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	27.2	0.0	0.0
4	Mysids	0.0	0.0	34.5	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	<i>Acetes</i> sp	70.8	0.0	0.0	0.0	65.1	0.3	0.0	0.0	8.4	0.0	0.0	0.0
6	Crab	29.2	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	Unicorn cod	0.0	0.0	0.0	0.0	0.0	24.4	96.0	11.2	1.9	0.0	0.0	34.2
8	Barracuda juvenile	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	2.7	0.0	40.0	9.7
9	Ribbonfish juvenile	0.0	0.0	0.0	43.3	0.0	1.1	0.0	5.2	4.7	0.0	0.0	11.3
10	Eel larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	12.0
11	Anchovy	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	4.7	45.2	0.0	7.4
12	Unidentified fish juvenile	0.0	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0
13	Polychaete	0.0	0.0	0.0	0.0	16.9	0.0	0.0	0.0	0.0	0.0	0.0	5.1
14	Foraminifera	0.0	0.0	0.0	5.4	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	Eggs	0.0	100.0	34.5	33.0	8.8	0.0	0.0	0.0	1.2	0.0	0.0	0.0

Table: 4.4.2.3.1. The diet observed in adult moonfish in the pre monsoon season

Pre monsoon adult							
Sl.No.	Food Category		%O	%N	%V	IRI	%IRI
1	Mollusc	Squid juvenile	5.3	0.6	1.3	10.3	0.3
2	Crustaceans	Amphipod	5.3	1.0	1.5	12.8	0.4
3		Copepod	2.6	6.4	0.8	19.0	0.5
4		Mysids	5.3	1.3	1.2	13.2	0.4
5		<i>Acetes</i> sp	21.1	62.8	59.2	2568.0	70.9
6		Crab	2.6	0.6	0.5	3.0	0.1
7	Miscellaneous	Eggs	23.7	15.1	14.8	707.1	19.5
8		Foraminifera	10.5	7.4	3.8	117.9	3.3
9	Annelids	Polycheate	13.2	1.6	3.7	70.4	1.9
10	Fishes	Unidentified fish juvenile	2.6	0.6	4.9	14.7	0.4
11		Ribbonfish juvenile	7.9	2.6	8.2	85.1	2.3

Table: 4.4.2.3.2. The diet observed in adult moonfish in the monsoon season

Monsoon Adult							
Sl. No.	Food Category		%O	%N	%V	IRI	% IRI
1	Fishes	Unicorn cod	25	18.2	17.9	903.3	23.1
2		Ribbonfish juvenile	8.3	9.1	8.97	150.5	3.8
3		Anchovy	8.3	4.5	4.5	75.2	1.9
4		Barracuda juvenile	16.7	9.1	17.9	450.7	11.5
5	Mollusc	Squid juvenile	33.3	18.2	38.8	1898.7	48.5
6	Crustacean	<i>Acetes</i> sp	8.3	40.9	11.8	439.6	11.2

Table: 4.4.2.3.3. The diet observed in adult moonfish in the post monsoon season

Post monsoon adult						
Food Category		%O	%N	%V	IRI	%IRI
Mollusc	Squid juvenile	33.3	21.6	48.9	2348.3	72.4
Crustacean	Amphipod	3.9	11.4	2.5	54.5	1.7
	Copepod	9.8	17.6	3.5	206.5	6.4
	Mysids	3.9	2.8	1.5	16.8	0.5
Fishes	Unicorn cod	7.8	6.3	3.6	77.1	2.4
	Barracuda juvenile	5.9	7.4	3.6	64.8	2.0
	Ribbonfish juvenile	7.8	6.3	12.1	144.1	4.4
	Eel larvae	3.9	6.3	3.1	36.6	1.1
	Anchovy	9.8	8.0	9.8	174.2	5.4
	Unidentified fish juvenile	5.9	1.7	6.2	46.4	1.4
Annelids	Polychaete	2.0	1.7	3.6	10.5	0.3
Miscellaneous	Eggs	5.9	9.1	1.6	63.1	1.9

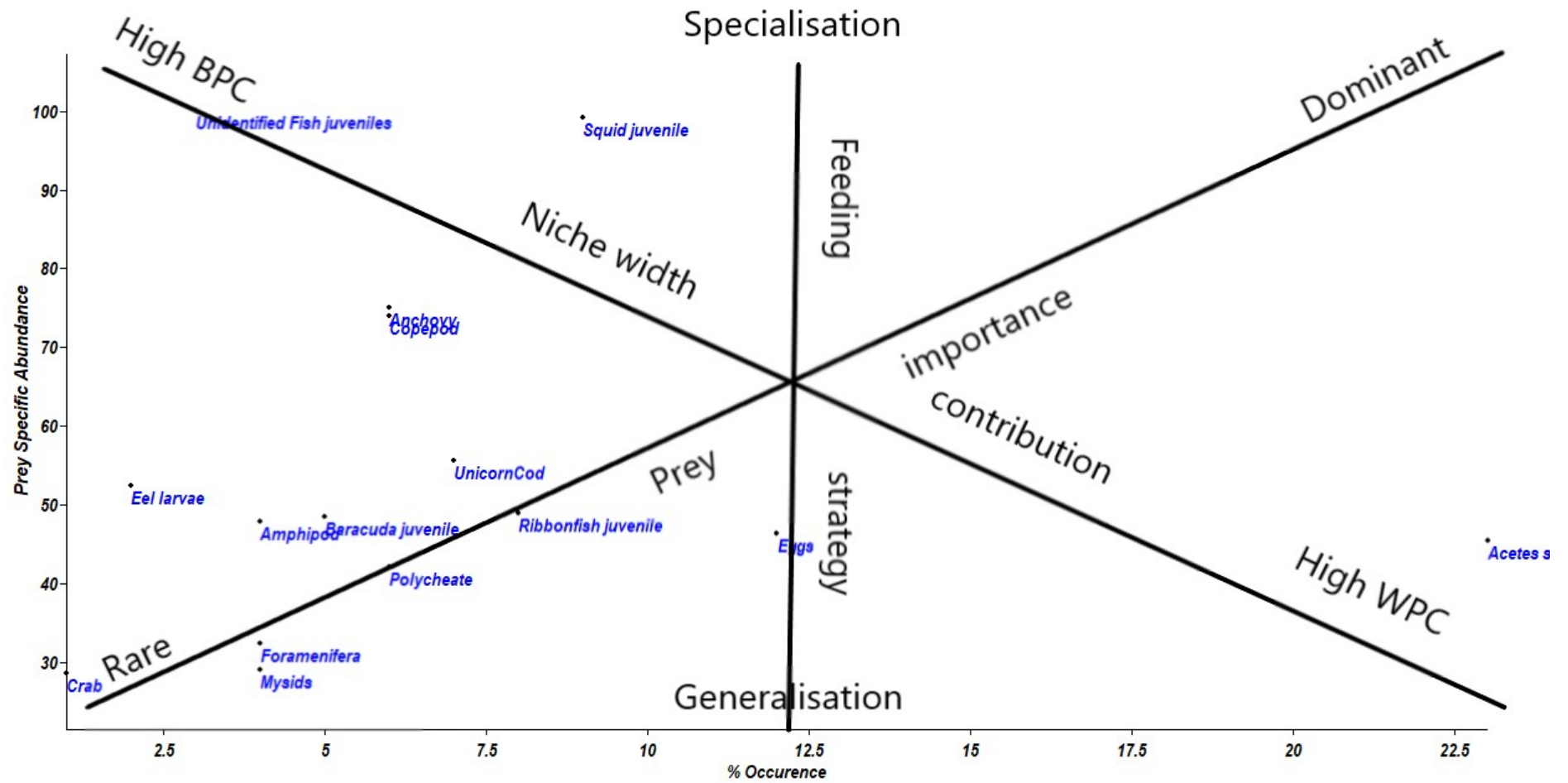


Fig. 4.4.2.4.1. Costello's modified graph (1990) for the illustrating the foraging strategy in adult moonfish

4.4.3. Estimation of trophic overlap between adult and juvenile moonfish

The degree of trophic overlap between the diet of juveniles and adults was estimated as 0.34. This indicates that percentage of diet overlap of adults and juveniles was 34%. The overlap is considered significant only if it is greater than 60% and hence dietary overlap is not significant between juveniles and adult moonfish.

4.4.4. TROPH and OI estimation of moonfish

The major gut content which is used for the estimation of TROPH value is given in the Table 4.4.4.1. The estimated TROPH value for moonfish was 3.56 (SE = 0.81), and the Omnivory Index (OI) was 0.665.

Table: 4.4.4.1. The diet content used in the estimation of TROPH value

Sl.No.	PREY	DC _{ij}	TROPH	DC _{ij} × TROPH
1	Squid juvenile	0.244679	3.5	0.856376
2	Amphipod	0.080992	2.3	0.186281
3	Copepod	0.181246	2	0.362492
4	Mysids	0.006727	2.2	0.014799
5	<i>Acetes</i> sp	0.288571	2.2	0.634855
6	Crab	0.000358	2.5	0.000894
7	Unicorn cod	0.059415	3.3	0.196070
8	Barracuda juvenile	0.021976	3.3	0.072521
9	Ribbonfish juvenile	0.013017	4.5	0.058576
10	Eel larvae	0.029618	3.7	0.109585
11	Anchovy	0.003463	3.6	0.012466
12	Foraminifera	0.010701	1	0.010701
13	Polycheate	0.02905	1	0.02905
14	Eggs	0.008714	2	0.017428

4.5. Fishery

4.5.1. All India status

Moonfish formed a minor fishery along the coast of India. The average annual landing of moonfish along the Indian Coast during the last one decade was 5,613 t. It formed 0.11% of the average annual marine fish landings of the country. The annual landings fluctuated between 1,430 t (2007) and 13,341 t (2013) (Fig. 4.5.1.1 and Table. 4.5.1.1). In 2016, the estimated landing of moonfish, along the Indian Coast, was 10,648 t.

The fishery along the Indian Coast is usually divided into 4 zones, *i.e.*, north west zone comprising of Gujarat, Daman & Diu and Maharashtra; the south west zone consisting of Goa, Karnataka and Kerala; the north east zone consisting of Odisha and West Bengal and south east zones consisting of Tamil Nadu and Andhra Pradesh. The analysis of the moonfish landing data of the last one decade indicated that the south west coast (70%) had the major share of the fishery followed by north east coast (17%), north-west coast (7%) and south east coast (6%) (Fig. 4.5.1.2).

Among the Indian States, Kerala (33%) had the major share in the capture of moonfish followed by Goa (28%), Orissa (17%), Karnataka (9%), Maharashtra (5%), Tamil Nadu (4%), Andhra Pradesh (2%) and Gujarat (2%). The average annual (2007-2016) landings of moonfish in the maritime states indicated the highest catch in Kerala (1,826 t) followed by Goa (1581 t), Orissa (956 t), Karnataka (497 t), Maharashtra (303 t), Tamil Nadu (237 t), Andhra Pradesh (104 t) and Gujarat (97 t). The percentage proportion of the moonfish production by different states of India is shown in Fig. 4.5.1.3. The average production of moonfish in different states is shown in Table. 4.5.1.2 and Fig. 4.5.1.4.

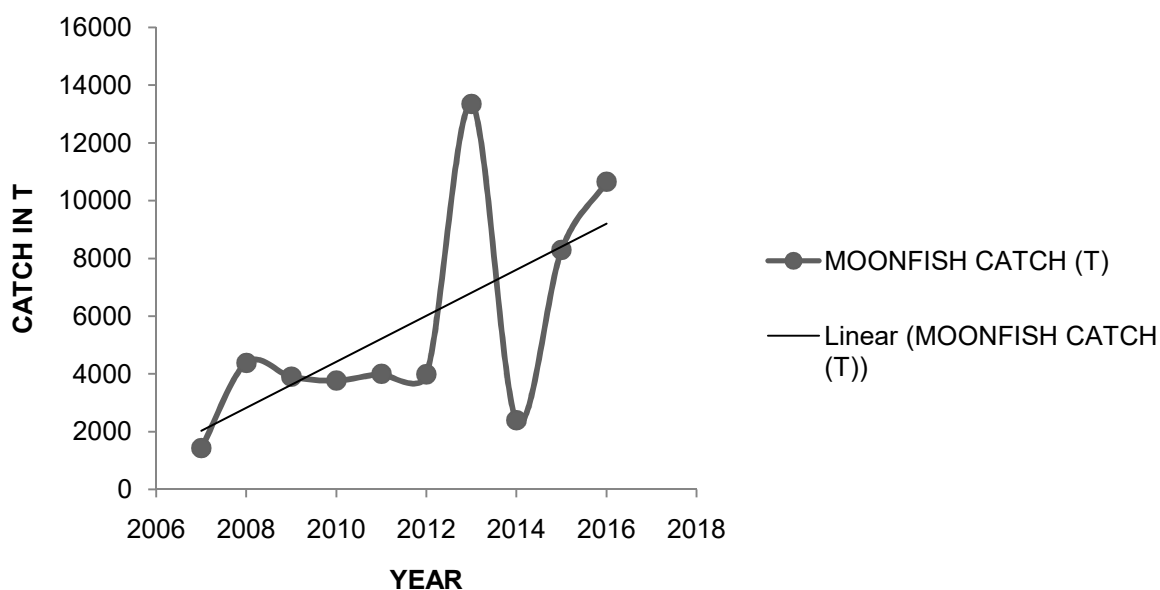


Fig. 4.5.1.1. Year wise catch data of moonfish along the Indian Coast (2007-2016)

Table: 4.5.1.1. The average all India catch of moonfish for 10 years from 2007 to 2016

Sl. No.	Year	Quantity landed (t)
1	2007	1430
2	2008	4380
3	2009	3902
4	2010	3766
5	2011	3996
6	2012	3982
7	2013	13341
8	2014	2395
9	2015	8287
10	2016	10648

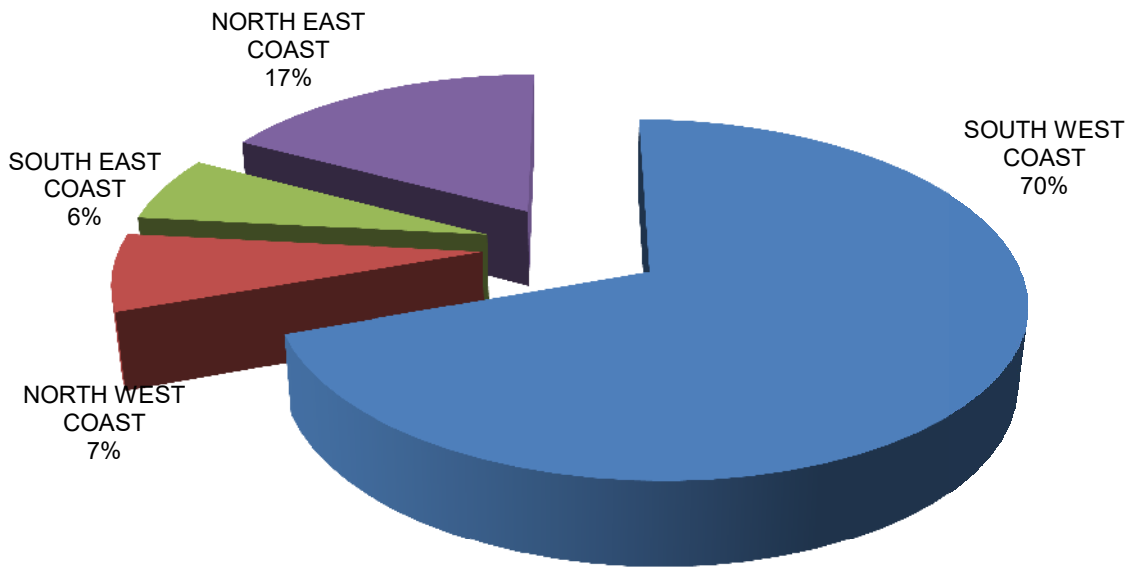


Fig. 4.5.1.2. The zone wise distribution of moonfish along the Indian Coast

Table: 4.5.1.2. The state wise average production for 10 years (2007 - 2016) of moonfish

Sl. No.	States	Production / Yr (T)	% Composition
1	Andhra Pradesh	103.9	1.9
2	Daman & Diu	2.1	0.0
3	Goa	1581.3	28.2
4	Gujarat	96.6	1.7
5	Karnataka	496.5	8.8
6	Kerala	1825.8	32.5
7	Maharashtra	302.5	5.4
8	Orissa	955.8	17.0
9	Pondicherry	3.4	0.1
10	Tamil Nadu	236.6	4.2
11	West Bengal	8.3	0.1

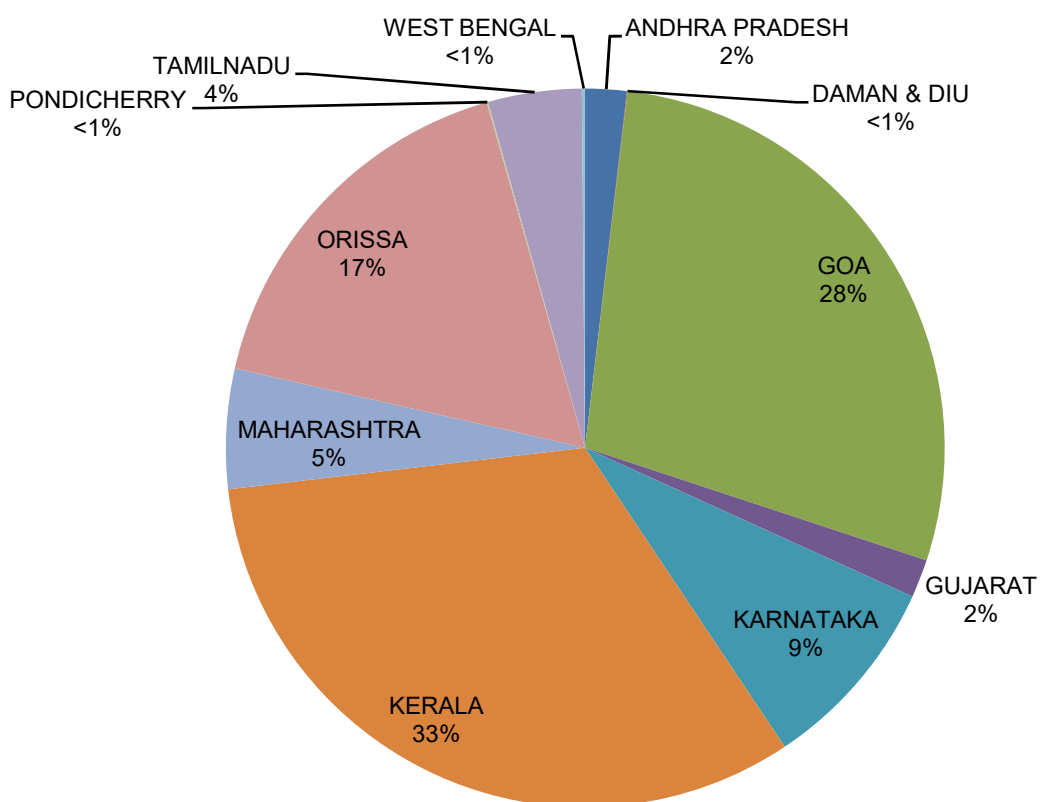


Fig. 4.5.1.3. Share of moonfish landings by different states of India

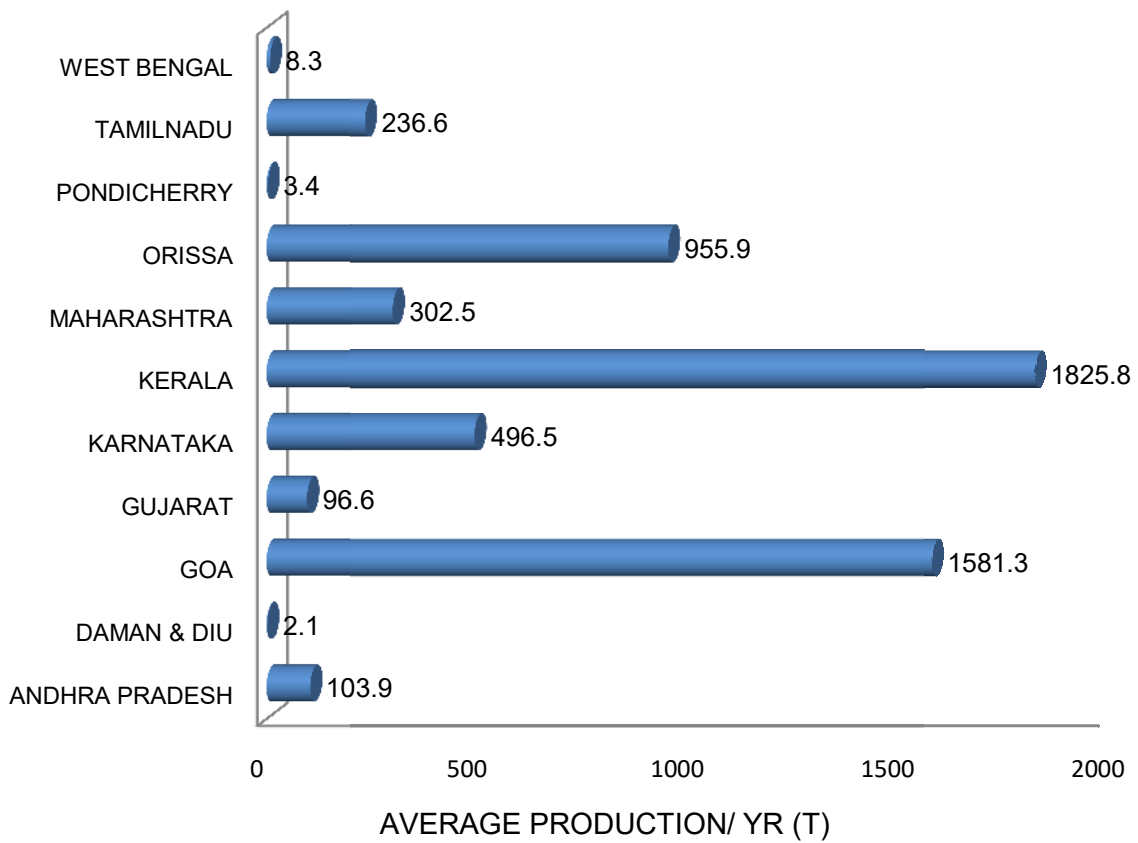


Fig. 4.5.1.4. The average annual production (2007-2016) of moonfish in different states

4.5.1.1. Craft and gear

The major gears exploiting moonfish include trawls (Mechanised Multiday Trawl Net - MDTN and Mechanised Single day Trawl Net - MTN) and purse seines (Mechanised Purse Seines - MPS). The ring seines (Mechanised Ring Seine - MRS and Out-Board Ring Seine - OBRS), boat seines (Out-Board Boat Seine - OBBS), gillnet (Out-Board Gillnet - OBGN), and hook and lines (Out-Board Hand Line - OBHL) were the minor gears employed to the catch the moonfish along the Indian Coast. The gear wise and craft wise catch of moonfish along the Indian Coast is shown in the Table. 4.5.1.1.1, Fig. 4.5.1.1.1 and Fig. 4.5.1.1.2. The moonfish was landed by both mechanised/motorised (99.7%) and non motorised (0.3%) crafts. The major share of capture came from the mechanised sector (84%) *i.e.*, trawlers and purse seiners and out board motorised vessel (15.7%). The adult fish were caught at a depth range of 40m to 120m while the juveniles at depths less than 50m. The deeper zones were least accessed by traditional vessels except in Vizhinjam. Of the total catch of moonfish landed along the Indian Coast, 38.7% were contributed by multiday trawlers, 4.8% were by single day trawlers and 35.3% by purse seiners. In trawlers, moonfish was non targeted resources while in purse seiners, it was targeted resource in the absence of high value fishes.

Table: 4.5.1.1.1. The gear wise catch of moonfish along the Indian Coast.

Sl. No.	Gear	Average Catch (t)
1	Multiday Trawl	21869.8
2	Purse Seine	19958.
3	Single day Trawl	2686.2
4	Mechanised Others	3836.6
5	Non-Mechanised	173.5
6	Motorised Boat Seine	4751.6
7	Motorised Ring Seine	947.6
8	Motorised Others	1904.7

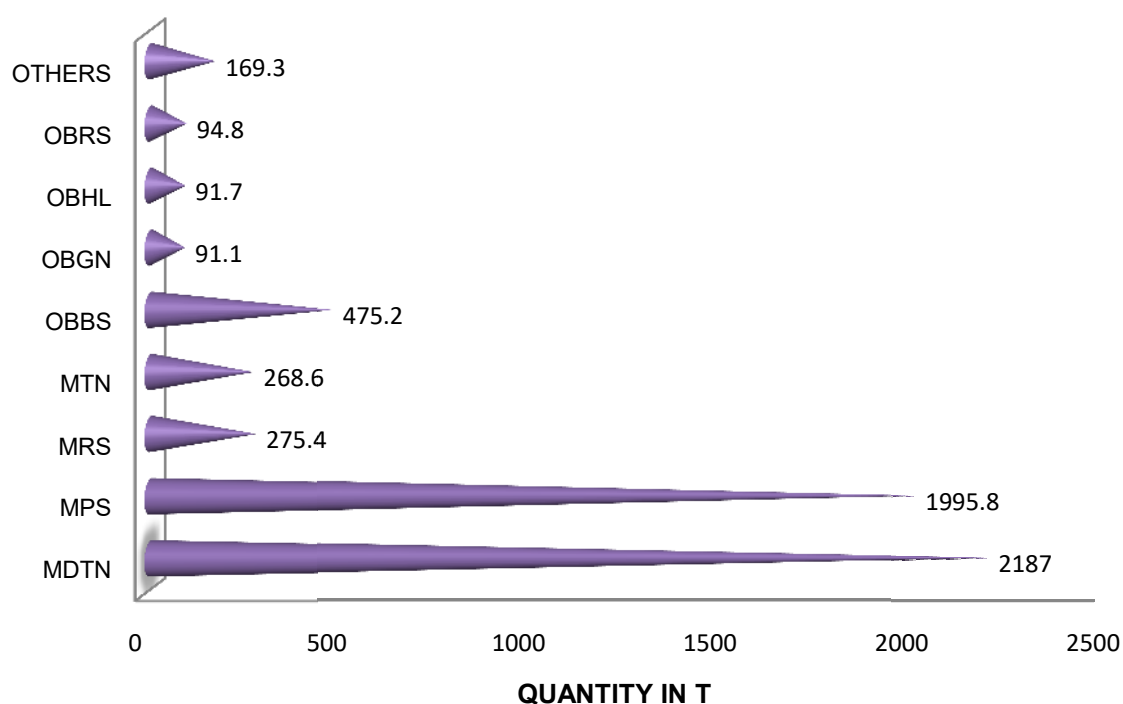


Fig. 4.5.1.1.1. The annual average quantity of moonfish landed by each gear along the Indian Coast (MDTN: Multiday trawl, MPS: Purse seine, MRS: Mechanised ringseine, MTN: Single day trawl, OBBS: Outboard boat seine, OBGN: Outboard gillnet, OBHL: Outboard Hook and line, OBRS: Outboard ringseine, OTHERS: includes dolnet and hand trawls)

■ TRAWL ■ PURSE SEINE ■ RING SEINE ■ BOAT SEINE ■ GILL NET ■ HOOK AND LINE ■ OTHERS

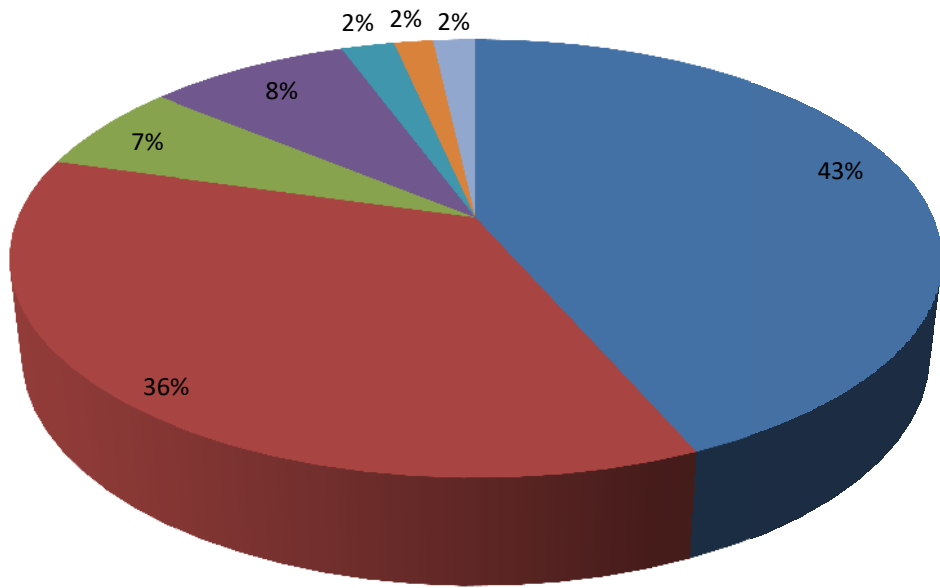


Fig. 4.5.1.1.2. The contribution by different gears in the catch of moonfish along the Indian Coast

4.5.2. Konkan Malabar status

The Konkan Malabar Coast contributed 4,206 t (75%) of the total moonfish production in the country. The mechanised sector (82.7%) contributed maximum to the production in the region followed by motorised (17%) and non motorised sectors (0.03%). The major crafts which contributed to the moonfish fishery were purse seiners (47.4%) followed by trawlers (26.4%), boat seiners (11.3%) and others (14.9%). The major gears contributing to the capture of moonfish were purse seines (47.4%), trawls (26.4%), boat seines (11.3%), ring seines (2%), gillnets (2%), hook & line (2.15%) and others (Fig. 4.5.2.1).

4.5.2.1. Distribution of moonfish in Konkan Malabar Coast

The study on the distributional pattern of moonfish along the Konkan Malabar Coast had shown that the adult fishes were caught at a depth of 40m-120m with an average of 110m and the juveniles were caught from shallower depths ranging from 30 - 50m depth with average of 40m. Though the occurrence of the fish had been reported from estuaries, samples were not observed from the estuaries of Konkan Malabar Coast.

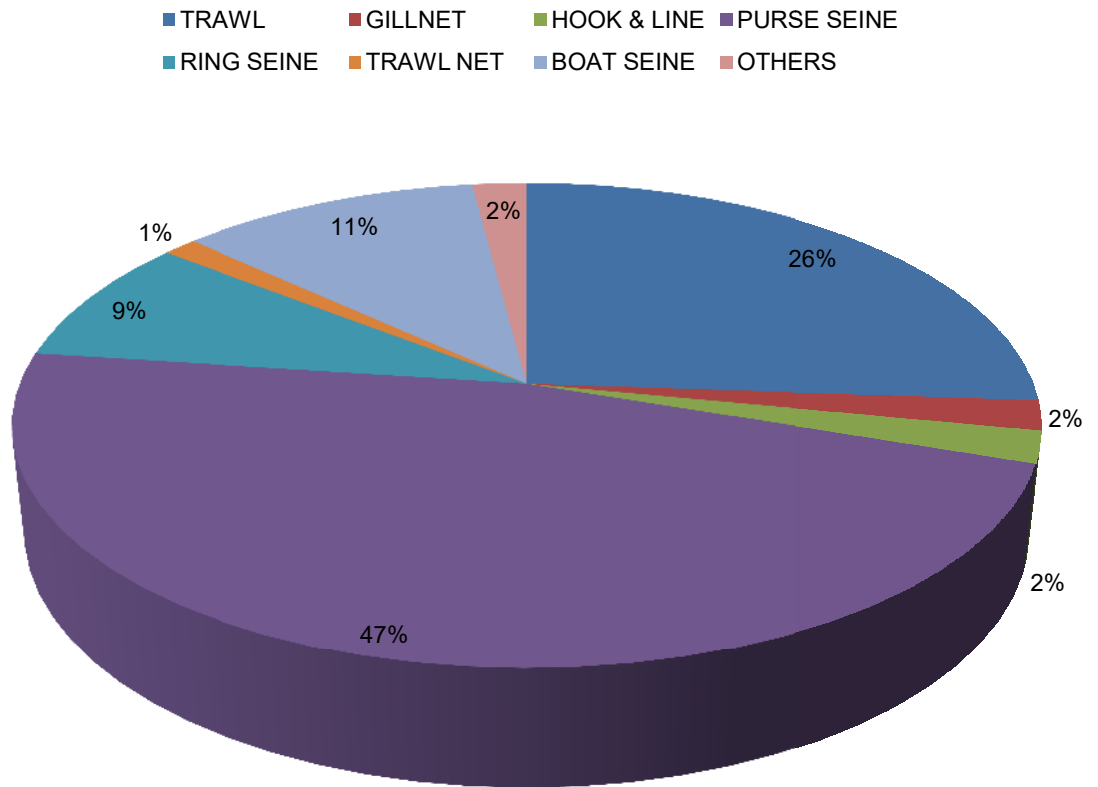


Fig. 4.5.2.1. The gear wise catch in the Konkan Malabar Coast

4.5.3. Karnataka status

In the 2016, Karnataka was the fourth major contributor of moonfish along the Indian Coast. The moonfish, locally known as “*DoddaKurchi*” or “*CD*” contributed 0.06% of the total marine fish landings of Karnataka. The fishery was mainly supported by mechanised (95%) and motorised (5%) crafts. The multiday trawlers contributed 69% followed by purse seiners (26%) and out board canoe (5%) (Fig. 4.5.3.1 and Table. 4.5.3.1). Among the major gears, trawl contributed 71%, followed by purse seines, ring seines and gillnets (Fig. 4.5.3.2 and Table. 4.5.3.2). The average catch of moonfish, considering last ten years data (2007-2016), was 496.5t/ yr. During 2016, the moonfish catch had increased more than 5 times the decadal average annual landings and reached 2,483.5t. This sharp hike in moonfish landings was due to the introduction and modifications in existing fishing practices by fishers. The practice of light fishing by purse seiners and pair/bull trawling by multiday trawlers were the major reasons for increase landings of moonfish in 2016.

Dakshina Kannada (52%) had contributed maximum to the moonfish catch followed by Udupi (41%) and Uttar Kannada (7%) (Fig.4.5.3.3). The total catch of moonfish in the coastal districts of Karnataka from 2007 to 2016 is shown in Table. 4.5.3.3. and Fig.4.5.3.4. gives the annual landings of moonfish.

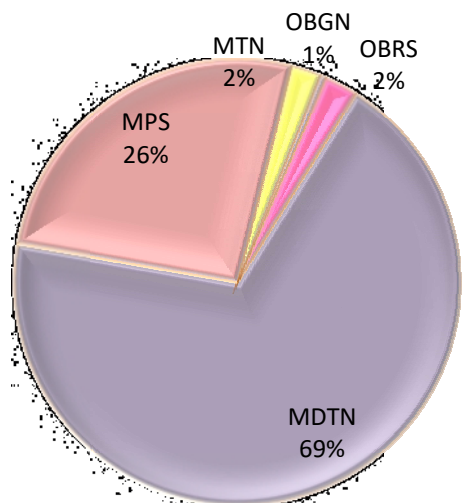


Fig. 4.5.3.1. Contribution of different crafts types to the total moonfish landings in Karnataka (MDTN: Multiday trawler, MPS: Mechanised Purse seiner, MTN: Single day trawler, OBGN: Out-board Gillnetter, OBRS: Out-board Ring Seiner)

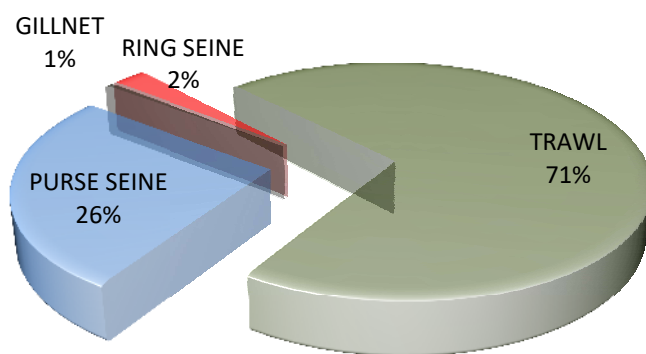


Fig. 4.5.3.2. Contribution of various gears to the moonfish landed in Karnataka

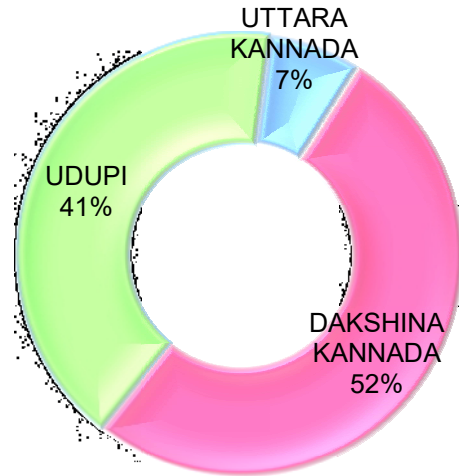


Fig. 4.5.3.3. The percentage of the average production of moonfish in coastal districts of Karnataka

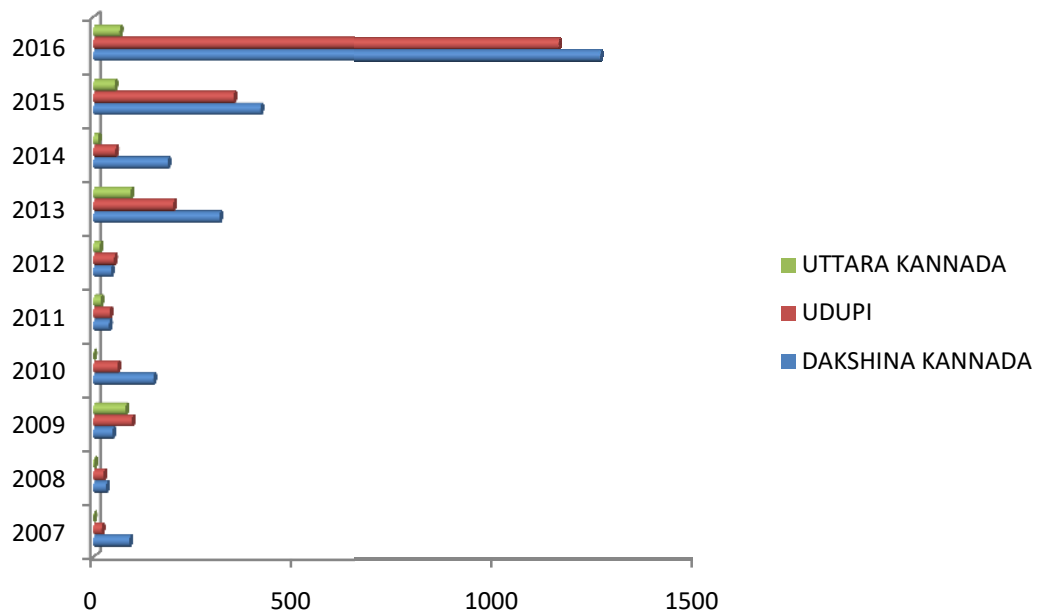


Fig. 4.5.3.4. The landing of *Mene maculata* in different districts of Karnataka from 2007 to 2016

Table: 4.5.3.1. Craft wise contribution of moonfish along Karnataka Coast

Sl. No.	Craft	Contribution (T/Yr)
1	Multiday Trawler	340.76
2	Purse Seiner	129.34
3	Single Day Trawler	10.66
4	Motorised Gillnet	2.11
5	Motorised Ring Seine	11.97

Table: 4.5.3.2. Gear wise contribution of moonfish along Karnataka Coast

Sl. No.	Gear	Contribution (T/Yr)
1	Trawl	351.42
2	Purse Seine	129.34
3	Gillnet	2.11
4	Ring Seine	11.97

Table: 4.5.3.3. Average annual catch of moonfish in the coastal districts of Karnataka from 2007 to 2016

Sl. No.	Year	Dakshina Kannada (t)	Udupi (t)	Uttara Kannada (t)
1	2007	89.354	20.492	0.744
2	2008	31.856	25.201	2.211
3	2009	47.347	95.225	79.689
4	2010	149.175	59.609	0.674
5	2011	38.977	40.47	17.781
6	2012	43.37	51.711	15.795
7	2013	313.458	198.756	92.345
8	2014	184.683	54.867	11.25
9	2015	415.088	348.793	52.509
10	2016	1260.964	1157.479	65.008

4.5.3.1. Purse seining and moonfish fishery

Purse seine is one of the major fishing gears which capture moonfish in huge quantity. The schooling nature of the fish is exploited in the capture of this species in good quantities by seines. The purse seine vessels are large with the OAL ranging from 17m to 24m and a fish hold capacity of 12 to 20 t. These vessels are powered by engines capacity of 140 to 350 hp. The vessels go for fishing for 36 to 48 hours in open sea. From 2015 onwards, the purse seines have been using lights for the capture of fishes. The lights have played a major role in the capture of many shoaling fishes including moonfish. The moonfish is not a targeted species for purse seiners. However, the species is caught in the absence of high value fishes. The purse seiners that operate with lights used only large meshed nets (>45 mm) and hence captured only large sized individuals. The large sized fish (TL > 160 mm) fetch INR 60-90/Kg. while small sized fishes (<100 mm) were considered trash and are not used for human consumption but sold to fish meal plants at a very low price of INR 12-13/Kg. In the present study, the proposed Minimum Legal Size (MLS) for moonfish was estimated at 85mm for Karnataka waters and 98.9% of the total moonfish landed in Karnataka by purse seiners are found to be above the proposed MLS (Fig. 4.5.3.1.1). It seems that light fishing had not affected the stock of this species in Karnataka in an adverse way.

4.5.3.2. Trawling and moonfish fishery

The trawl was another gear which contributed to the catch of moonfish. Single day trawl, multiday trawl and bull trawl had contributed to the trawl catch of moonfish along the Karnataka Coast. The single day trawls usually landed juveniles as they operate at depth lesser than 50m, where juveniles were seen more than adults. The multiday trawls and bull trawls usually landed adult moonfish except in the month of December – January, when juveniles were observed along with the adults in the trawl catch. It had been observed that the 95.5% of the moonfish caught by trawls were above proposed MLS (Fig. 4.5.3.2.1). Hence trawling had not affected the stock of this species in an adverse way in Karnataka.

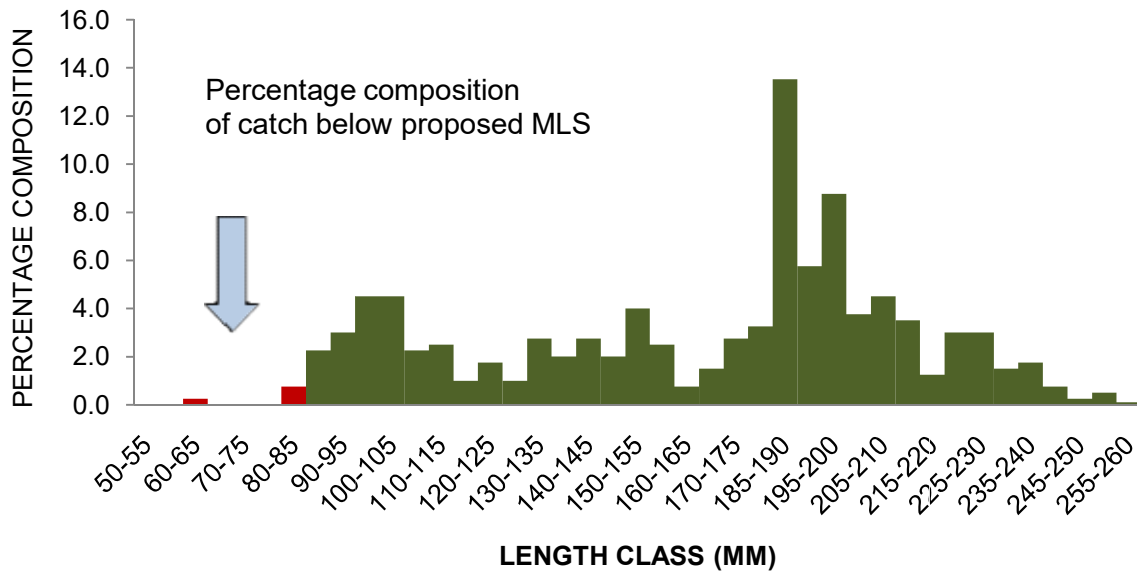


Fig. 4.5.3.1.1. Representation (percentage composition) of different length class in purse seine.

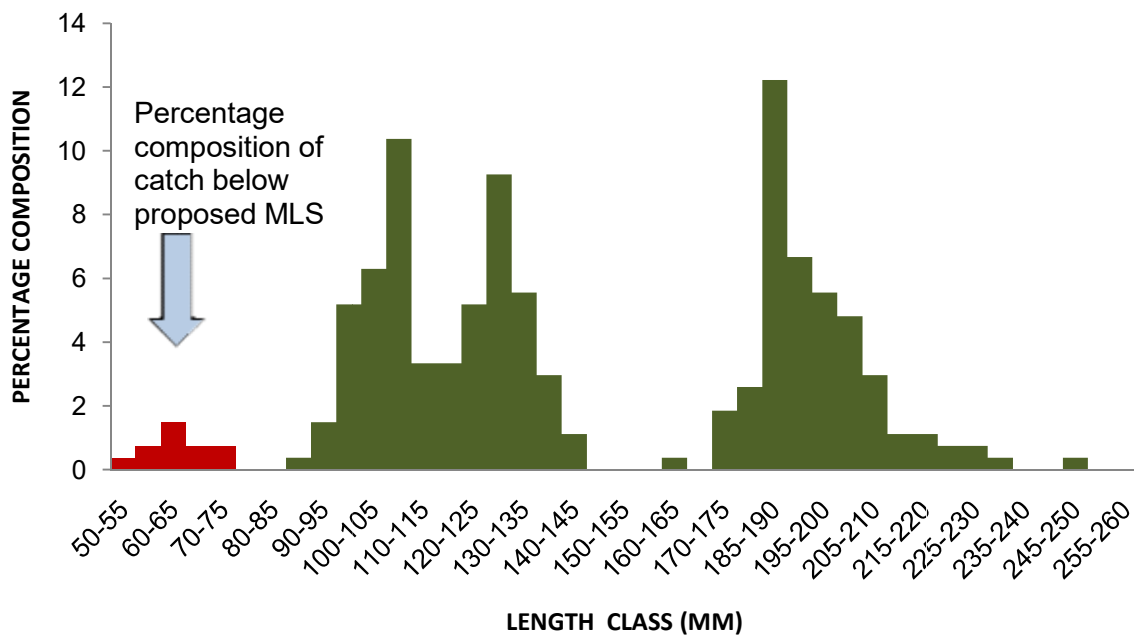


Fig. 4.5.3.2.1. Representation (percentage composition) of different length class in trawl nets.

4.6. Stock delineation

4.6.1. Differentiation based on meristics traits

A total of 5 meristic characters were recorded for the present study (Table 4.6.1.1). All the 5 meristic variables were subjected to PCA. The PC 1 and PC 2 show 64.8% and 30.5% variations, respectively (Table 4.6.1.2). The principal component loadings for 5 meristic traits are listed in Table 4.6.1.3. The scattered plot of PC1 and PC 2 shows no difference between the locations (Fig. 4.6.1.1).

4.6.2. Differentiation based on TRUSS morphometrics

4.6.2.1. Transformation of TRUSS measurements

All the transformed truss measurements, subjected to correlation test with the standard length did not show significant correlation among them. This indicates that the influence of body length has been removed by allometric transformation. The multivariate analysis of variance performed for the morphometric trait revealed significant difference between the three stock of the species (Wilk's Lambda= 0.07; F=15.9 and $p < 0.0001$). The univariate comparison showed high significance for the compared morphometric traits.

Table: 4.6.1.1. Overall and location wise descriptive statistics of meristic traits

Sl. No.	Meristic traits	Overall			Ratnagiri			Mangalore			Vizhinjam		
		Min	Max	Mode	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
1	Dorsal fin spine	3	4	4	3	4	4	3	4	4	4	4	4
2	Pelvic fin rays	4	6	5	4	5	5	4	5	5	4	6	5
3	Gillracker count	6	7	7	6	7	7	6	7	7	7	7	7
4	Dorsal soft fin rays	38	47	43	39	45	43	38	46	44	40	46	45
5	Anal fin rays	28	35	33	29	34	32	30	33	32	29	34	33

Table: 4.6.1.2. Eigenvalues and proportions of variance contribution to the total variance from selected meristic traits

Sl. No.	PC	Eigen Value	Total Variance (%)	Cumulative (%)
1	1	5.996	64.839	64.839
2	2	2.816	30.452	95.291
3	3	0.297	3.213	98.504

Table: 4.6.1.3. Variable loadings in the principal component analysis on meristic characters

Sl. No.	Variables	PC 1	PC 2	PC 3
1	DFS	0.004468	-0.02586	0.8578
2	PFR	0.000487	0.02455	-0.5072
3	GRC	0.006861	0.000213	0.07605
4	DSR	-0.1422	-0.9892	-0.0337
5	AFR	0.9898	-0.142	-0.00899

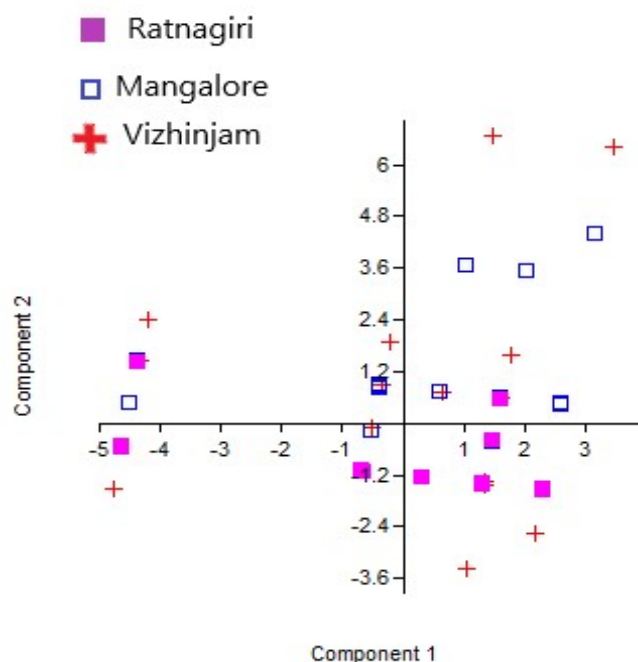


Fig. 4.6.1.1. Scatter plot of scores of PC 1 and PC 2, extracted from meristic traits of moonfish from Konkan Malabar Coast

4.6.2.2. PCA of transformed TRUSS measurements

The result of the PCA showed that the first 3 factors were responsible for 70.51% of the total morphometric variation with eigen values of 47.44%, 15.82%, and 7.25%, respectively (Table. 4.6.2.2.1). Hence only 3 factors were considered for further interpretation. The truss distance which had loadings more than 0.7 were selected (Table. 4.6.2.2.2). The variables CJ, BJ, BK, CK, CI, DJ, ID, DE & EI showed high loadings on PC 1; while variables AK & BC showed high loadings for PC 2 and LK showed high loadings for PC 3. These variables are related to the middle portion of the body related to the depth of fish and few on anterior and posterior region related to the length portion of the fish (Fig. 4.6.2.2.1). The PCA revealed significant morphological variation between the selected regions along the Konkan Malabar Coast. The morphological variables connected with the factors could differentiate the fishes from different locations. The bivariate plots showed intermixing of Ratnagiri and Mangalore samples while Vizhinjam samples were distinct from them (Fig. 4.6.2.2.2).

4.6.3. Discriminant analysis of selected TRUSS measurements

The discriminant analysis, conducted using the truss traits CJ, BJ, BK, CK, CI, DJ, ID, DE, AK, BC, LK and EI, revealed three stocks, of which two stocks *i.e.*, Mangalore and Ratnagiri indicated intermixing while the third stock, the Vizhinjam was purely distinct. The misclassification rate shown was 15.15% between these stocks. Even though the PCA shows separation of stock in selected regions of the Konkan Malabar Coast, discriminant analysis showed greater misclassifications which indicate intermixing of stocks of Ratnagiri and Mangalore (Table. 4.6.3.1).

Table: 4.6.2.2.1. Eigen values and proportions of variance contribution to the total variance from transformed morphometric measurements

Sl. No.	Eigenvalue	% Total - variance	Cumulative - Eigenvalue	Cumulative - %
1	9.013933	47.44175	9.01393	47.44175
2	3.005981	15.82095	12.01991	63.26271
3	1.377482	7.24991	13.39740	70.51261

Table: 4.6.2.2.2. Variable loadings in the principal component analysis on transformed truss morphometric measurement

Sl. No.	Truss distance	Factor - 1	Factor - 2	Factor - 3
1	AL	-0.041309	0.661453	-0.161657
2	LK	0.144398	-0.175812	0.829338
3	BK	0.838922	0.405943	-0.039484
4	AK	-0.005770	0.726169	-0.103907
5	BL	0.193844	0.572306	-0.323585
6	BC	-0.222161	-0.933495	-0.029167
7	KJ	0.120933	0.550926	-0.237329
8	CJ	0.974087	0.010236	0.075028
9	BJ	0.943314	0.092436	0.197161
10	CK	0.972746	-0.033609	0.021626
11	CD	-0.660560	0.457875	0.215524
12	CI	0.959160	0.093459	0.084842
13	DJ	0.957710	0.120616	0.098667
14	ID	0.959397	0.094698	0.035773
15	DE	0.795422	-0.116112	-0.244272
16	IH	0.531365	0.042465	0.416124
17	EH	0.149385	0.019759	0.545875
18	DH	0.605014	-0.024584	-0.128544
19	EI	0.898363	0.063030	0.004288

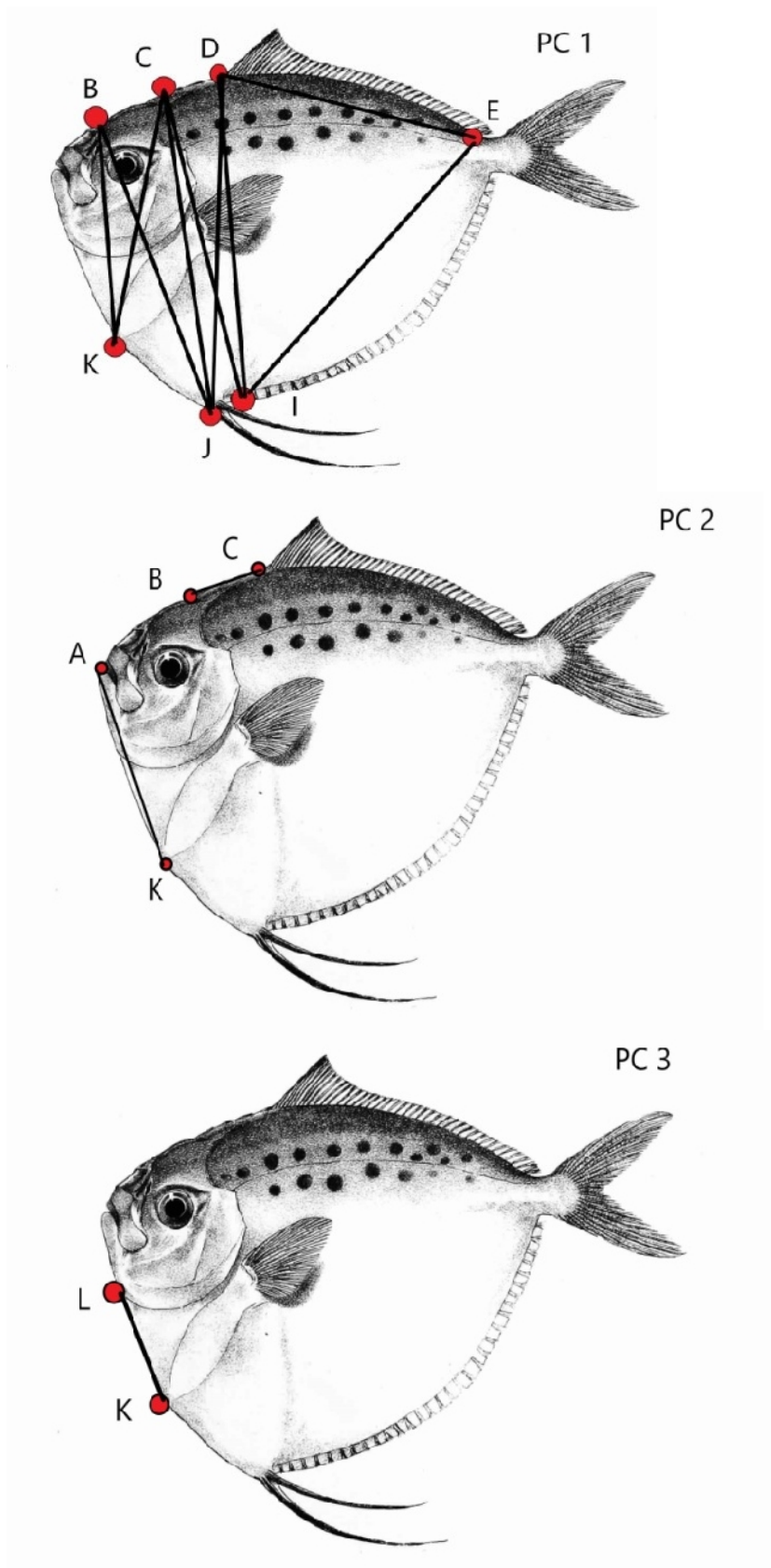


Fig. 4.6.2.2.1. Distance with meaningful loadings on the first three principal components in the truss network analysis of moonfish

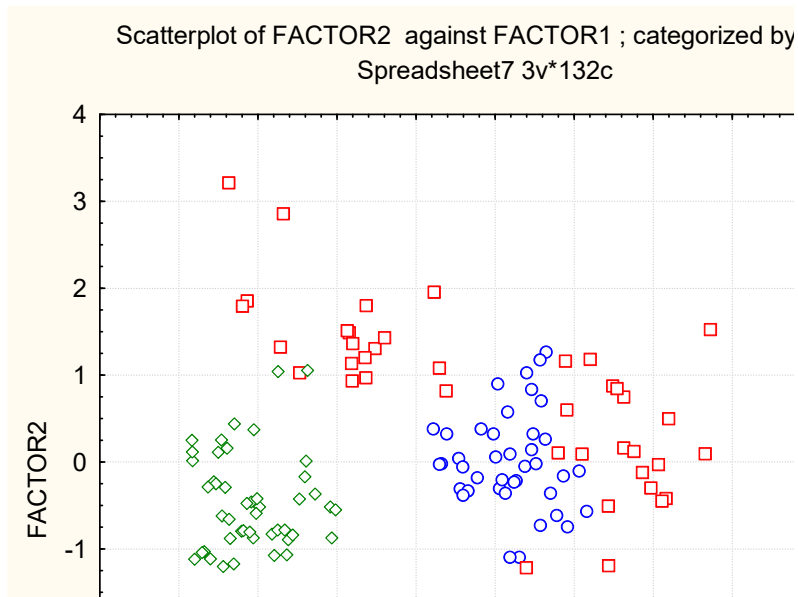


Fig. 4.6.2.2.2. Screen plot of the scores of the PC1 and PC2, extracted from TRUSS distance of moonfish from Konkan Malabar Coast

Table: 4.6.3.1. Cross validated location wise classification matrix for TRUSS network analysis

Sl. No.	Location	Ratnagiri (62)	Mangalore (63)	Vizhinjam (60)
1	Ratnagiri	85 %	15%	0%
2	Mangalore	32 %	68%	0%
3	Vizhinjam	0%	0%	100%
4	Total successful classification rate: 84.85%			

5. DISCUSSION

5.1. Length-weight relationship

In the present study, the length-weight relationships of moonfish indicated major deviation in the 'b' values reported in the previous studies (Table 5.1.1.). The present study has revealed a positive allometric growth in case of adult fishes and a negative allometry in the case of indeterminates. This does not approve the hypothesis that all the three categories (male, female and indeterminate) will have b value of 3 (isometric pattern of length weight relationship). The significant positive allometric growth for adult fishes was observed only in the present study. Pauly *et al.* (1998) reported isometric growth, while negative allometry growth was reported by Hwang *et al.* (2002) from Taiwan waters and Du *et al.* (2012) from South China. The variations in the b values in the same species from different water bodies is attributed to ecological variations due to geographical separation of the water bodies.

The variations in growth between the indeterminates and adults is indication of higher growth rate during the early phase of life and after a particular age the increment in weight is more rapid than length, resulting in a change over from negative allometry to a positive allometry (Munro and Pauly, 1983; Viswambharan *et al.*, 2018). Growth in VBGF is described by an asymptotic functional relationship, where fish grow faster in early life, as measured by percent increase in body mass per unit time. A faster growth before maturity may be an adaptation to escape predation (Nikolsky, 1963). After attaining maturity, the gain in length level reduces or ceases, but weight still increases leading to a positively allometric pattern. An increase in weight may also be influenced by the increase in gonad weight. A significant relation between fecundity to body weight in fish is a support to the statement. The differences seen in the 'b' value during present study from earlier findings could be due the differences in environment and ecological parameters prevailing in these ecosystems as reported by Saona *et al.* (2003). Nikolsky(1963) also opined that the growth rate in fishes can differ in the same species inhabiting different geographical locations due to the

influence of several biotic and abiotic factors, since growth is a specific adaptive property, ensured by the unity of the species and its environment. Similarly, Ahmed *et al.* (2011) reported the regional differences in the growth and maturation of the fish is result of difference in the growth pattern.

Table: 5.1.1. Comparison of length-weight studies conducted on moonfish across different seas around the world

Sl. No.	a	b	Sex	Sample size	Length (cm)	Length type	r ²	Locality	Reference
1	0.034	2.939	Unsexed	150	10.0 -21.0	SL	0.955	South-western waters, 1981-84 , Taiwan	Hwang <i>et al.</i> (2002)
2	0.015	3	Unsexed	5	10.2 -15.5	TL	-	-	Pauly <i>et al.</i> (1998a)
3	0.023	3	Unsexed	5	9.0 - 13.0	SL	-	-	Pauly <i>et al.</i> (1998a)
4	0.022	3.147	Unsexed	154	11.0 -20.0	SL	0.994	South-western waters, 1995-97, Taiwan	Hwang <i>et al.</i> (2002)
5	0.023	3.186	Unsexed	30	7.2 - 17.5	SL	0.995	Davao Gulf / 2009-12, Phillipines	Gumanao <i>et al.</i> (2016)
6	0.00006	2.842	Unsexed	1025	8.3-25.6	FL	0.94	Beibu Gulf, South China Sea- 2011-12	Du <i>et al.</i> (2012)
7	0.005	3.440	Female	153	7.5-25.5	TL	0.98	Eastern Arabian Sea- Off Karnataka Coast	Present study
8	0.006	3.316	Male	105	7-25.6	TL	0.96	Eastern Arabian Sea- Off Karnataka Coast	Present study
9	0.023	2.905	Indeterminates	81	6-15	TL	0.96	Eastern Arabian Sea- Off Karnataka Coast	Present study

5.2. Population parameter

The estimated value of L_{∞} (29.1 cm) falls well within the range of 21.8-33.4cm as observed in the past studies (Table 5.2.1). The estimated growth parameters in the present study were found to be different from that of Hwang *et al.* (2002) estimates in Taiwan waters, while the estimates were similar to those reported by Armada (2004) in Davao Bay in Philippines. The natural mortality estimate of moonfish along Davao Gulf was reported to be 1.98/yr (Armada, 2004) while estimates along the Karnataka Coast was 1.82/yr which is slightly lower. The natural mortality of fish includes mortality due to predation, spawning stress, disease out breaks and others. These reasons could differ in different region, which leads to the differences in natural mortality of the same species at different locations (Christian and Rebecca, 2013).

The fishing mortality for the species along the Karnataka Coast is 1.62/yr, which is less than the natural mortality (1.82/yr) of the species along the coast. This implies that the fishing stress on moonfish along the Karnataka Coast is below the optimum level of 0.5. This under utilization could be due to the absence of targeted fisheries for the fish in the region.

In the present study, the growth performance index (ϕ) was estimated at 2.934. This growth performance index (ϕ) value obtained were comparable with values (2.79 & 2.87) by Ingles and Pauly (1984), and Armada (2004), while differs abruptly from the reports of Hwang *et al.* (2002) and Du *et al.* (2012). The difference in the growth performance index (ϕ) value may be due to impact of variation in the environmental parameters and geographical variations. The present report is the first report on the population parameter for the species from Karnataka Coast of eastern Arabian Sea. Since these estimates are only preliminary, estimated based on samples collected only for 2 years, a detailed stock assessment study with larger sample size and larger period of data collection needs to be attempted before suggesting management measures for the resource to the concerned stakeholders.

Table: 5.2.1. Comparison of growth parameter studies conducted in moonfish across different seas around the world

Sl. No:	L_{∞}	Length type	K (yr^{-1})	ϕ	t_0	L_{max}	Country/ Locality	Reference
1.	21.8	SL	0.285	2.13	-	21	Taiwan- south western waters	Hwang <i>et al.</i> (2002)
2.	22.5	TL	1.22	2.79	-	21.4	Philippines- Manila Bay	Ingles and Pauly (1984)
3.	26	-	1.1	2.87	-	-	Philippines- Davao Bay	Armada (2004)
4.	28	SL	0.186	2.16	-	20	Taiwan- south western waters	Hwang <i>et al.</i> (2002)
5.	33.49	FL	0.17	2.28	-0.92	25.6	Beibu Gulf, South China Sea	Du <i>et al.</i> (2012)
6.	29.1	TL	1.014	2.93	-0.01	25.5	India- Eastern Arabian Sea	Present Study

5.3. Reproductive biology

The conservation and effective management of any exploited fish populations is possible only if, the information on biological characters of the species is available, particularly related to the reproduction and growth (Santos and Freire, 2015). These data are important as they provide information like length at first maturity and breeding season, which are of importance for fisheries managers in the region.

The sex ratio of moonfish was in favour of females, significantly deviating from the stated null hypothesis. However, this trend was observed in finfish species in the region (Zacharia and Jayabalan, 2007; Rajesh *et al.*, 2015). Previous studies round the world have proposed various reasons for the biased sex ratio. One reason would be the differential growth rate between sexes which can lead to a disturbed proportion, as the sex with faster growth rate will go through the most vulnerable phase (juvenile stage) quickly and, therefore, reduces the chance of the predation, while, the sex with slower growth rate will be more likely to undergo predation (Vicentini and Araujo, 2003). This reason can neither be accepted nor rejected as differential growth rate between sexes are not studied or reported related to the species. Nikolsky (1963) reported that when dietary items are abundant, females predominate, with the situation inverting in regions where food is limited. This could not be the reason as we found ESR (Empty Stomach Ratio) was high in moonfish (87% of adult and 85% of juveniles had empty stomach) which points to the unavailability of enough food to meet the nutritional requirement in moonfish. Finally, variation and changes in the pattern of migration of fishes of different sexes, to and from the fishing grounds, contributing to the dominance of females in the catches (Rajesh *et al.*, 2015). However, further investigations are needed to understand the actual pattern of the spawning/ feeding migration with regard to the spatial and temporal aspects, before giving final statement for the skewed sex ratio.

From the present study, it is clear that moonfish is a multiple spawner. This is confirmed by the occurrence of different batches of growing oocytes, including hydrated eggs in the oocyte size-frequency distribution of gravid females. The oocyte size frequency distribution also points out the

incidence of fractional spawning in moonfish. Further the species with fractional spawning show protracted spawning, which is also observed in moonfish.

The length at first maturity (L_m) was observed to be 13.8cm (TL) which falls in the 0+ year group (0.8 years). In this context, Qasim (1973) opined that most of the tropical marine fishes mature early and spawn in the first year (0+ years) of their life. In Taiwan water, the L_m of moonfish was reported to be 14cm (SL) (Hwang *et al.*, 2002) which is slightly higher than the present finding. These variations might be due to inherent physiological characteristics which arise as a result of several external factors like availability of food, intra-specific and inter-specific competitions, wide fluctuations in environmental characters, fishing stress etc., influencing the same species in different niches (Nikolsky, 1963). In the case of moonfish in Karnataka waters, it could be the availability of food and intra-specific/ inter-specific competitions which led to the slightly lower value of L_m .

The average fecundity of the fish was estimated to be $43,795 \pm 4,197$, that ranged from 8,354 to 1,08,829 eggs. The fecundity varied drastically in the current study. Earlier studies (Muchlisin, 2005) states that the gonad development in fish depends on a number of factors, of which, the major ones are nutrition, physiology of the organism and hydrographical parameters like ocean current, temperature and salinity. In the current study, the fecundity estimates are based on fish samples collected at different months (March 2017 and May 2017) within the peak spawning period of the same year, *ie*, between March to August, 2017. Hence the physiology or nutritional requirement of the organism might have played a major role for the disparity in fecundity than hydrographical parameters. Bagenal (1963) opined that the disparity in fecundity is more related to the variations in food availability than changes in hydrographical conditions. The ESR (Empty Stomach Ratio) was high in moonfish (87% of adult and 85% of juveniles had empty stomach) which points to the unavailability of enough quantity of preferred food to meet the nutritional requirement that could be the major reason for the high variability in the fecundity estimates. According to the modified classification of reproductive styles by Blaxter (1988) and Balon (1990), the fecundity is higher for fishes which are non-

guarders, open substratum and pelagic spawners. As moonfish has high fecundity (upto 500 oocyte/g body weight), the fish comes under this reproductive category.

The comparison of correlation coefficient values of fecundity with length, weight and ovary weight indicated linear relationship but better correlation of fecundity was observed with ovary weight ($r=0.71$; $p<0.01$) and body weight ($r=0.448$; $p<0.01$) than the body length ($r= 0.284$; $p>0.07$). The poor correlation of fecundity with body length could be due to the positive allometric growth pattern in adult moonfish which is a result of the extreme body shape of the fish (Viswambharan *et al.*, 2018).

Gonado somatic Index has been widely used to evaluate the spawning periodicity. The monthly GSI value in moonfish showed no variation in trend between males and females, except for a slightly lower GSI value in males. A protracted breeding was seen from February to June (pre-monsoon and starting of monsoon period) which coincides with high GSI values. In most of the marine aquatic species observed from the region, the process of gonadal maturation was positively correlated with the progress of the summer season, in such a manner that the fully mature fishes of stage VI are observed during the summer months and spawning occurs with the arrival of summer rains (Zacharia and Jayabalan, 2007; Rajesh *et al.*, 2015). The GSI values of moonfish fluctuate widely in all season, irrespective of sex. The fluctuating GSI values are due to asynchronous maturation of gonads, which was supported by the occurrence of mature gonads (stage V, VI, VII) in the commercial catches during most of the months of the year (Zacharia and Jayabalan, 2007). The presence of oocytes of different sizes in same ovary was a criterion for the existence of multiple spawning (Clark, 1934; De Silva, 1937) in fishes, which were observed in moonfish too. Asynchronous gonad maturation was also supported by the occurrence of ova in multiple stage of development in same ovary.

The specific observations based on studies related to GSI, oocyte size-frequency distribution and fecundity estimations, it can be concluded that, moonfish is a protracted batch spawner. Based on general observation, the fish can be concluded as iteroparous, gonochoristic, non-guarder, open pelagic

spawner which possess no sexual dimorphism and exhibit external fertilization without any parental care.

Minimum legal sizes of a particular fish is the smallest size which can be legally retained, if caught (Hill, 1990). It is ideal that MLS is fixed at the size at first maturity (SFM) as this would provide an opportunity for the fishes to spawn at least once in their life time (Sivadas *et al.*, 2017). In certain cases, the minimum size of mature (MSM) fish or even lesser values are taken as MLS. If the fish is a non-guarder and follows 'r' type growth/reproductive strategy with reproductive load greater than 0.5 and exploitation ratio less than 0.5, then MLS could be fixed at or between Minimum Size of Maturity (MSM) or Size at First Maturity (SFM). On the otherhand, for fishes which were guarders and follow the 'k' type of growth/reproductive strategy with reproductive load less than 0.5 and exploitation ratio greater than 0.5, one has to be careful in fixing the MLS at/ or much above the length at first maturity so as to ensure the good health of stock. Over and above these set criteria, the social acceptance of the fixed MLS is another concern. So, the opinion of all the stakeholders need to be considered before the finalisation of MLS of the species for wider acceptance.

The present study proposes the minimum legal size (MLS) of the species to be set at 85mm, which is minimum size of maturity (MSM).MLS has been fixed for 72 species landed in Karnataka, of these, MLS was fixed at minimum size of maturity (MSM) for 58 species (Rohit *et al.*, 2016).The moonfish fishery is an emerging fishery and the level of exploitation needs to be regularly assessed and the MLS has to be reviewed at regular intervals for the effective conservation and management of the species. Moreover, the present study was conducted within a limited time and low sample sizes were used for age, growth and maturity estimates. Since, MLS is a major regulatory measure with legal binding, it is recommended to re-confirm the findings by conducting research for larger duration with sufficient data. Till then the current proposal of MLS can be considered.

5.4. Food and feeding biology

Food and feeding habits are major aspects of fishery biology on which the behaviour, habitat and morphology of many of the fishes depend and hence needs to be understood fully, not only for commercial purposes, but also for formulation of policy for management of its fishery (Manojkumar and Acharya, 1990). The present study gave the basic understanding of the food and feeding habit of moonfish along the Karnataka waters. The TROPH value of 3.56 ± 0.81 as well as the diet of fish indicated that moonfish was a carnivorous fish. The TROPH value given by Froese and Pauly (2018) for moonfish is 3.5 ± 0.41 . The higher value of Omnivory Index (0.665) in the current study showed that the fish fed on multiple trophic levels. The value showed high uncertainty of the TROPH value estimated, giving rise to high standard error (0.81). The TROPH value for fishes varies with prey composition and is usually high with high standard error for medium to small carnivores. This is because the juveniles of medium to small carnivores have a low trophic level owing to the fact that the prey composition and diversity was much less for juveniles (Pauly *et al.*, 1998b, 2001). Similar is the case with moonfish, where juvenile moonfish was observed to feed on polychaetes, whose trophic value is 1.

In the study, 86.2% of the fishes examined were having empty gut. The occurrence of high percentage empty stomachs could be due to the reduction in the number of prey as a result of competition by different species inhabiting the water body (Arawomo, 1976). There are large number of small and large predators like *Epinephelus diacanthus* (Tessy, 1994), *Priacanthus hamrur* (Philip, 1998), *Otolithes cuvieri* (Manojkumar, 2003) *Lactarius lactarius* (Zacharia, 2003), *Saurida tumbil* (Manojkumar and Pavithran, 2016), inhabiting the same niche with similar feeding behaviour and diet composition. Hence inter-species competition could have played a major role in the occurrence of higher percentage of empty stomach.

The juvenile moonfish were observed to feed mainly on the zooplankton crustaceans like copepods, amphipods and *Acetes* sp and as the fish grows; it feeds mainly on juvenile cephalopods like squids, juvenile and larvae of large carnivorous fishes and small teleosts like anchovies and unicorn cod. In most carnivorous fishes of the eastern Arabian Sea, the juveniles prefer

planktonic crustaceans but latter shifts to teleost diet and other larger prey items as they grow old (Abdurahiman *et al.*, 2010). Similar ontogenic diet shift with size was observed in many fishes like *Epinephelus diacanthus* (Tessy, 1994), *Priacanthus hamrur* (Philip, 1998), *Otolithes cuvieri* (Manojkumar, 2003) *Lactarius lactarius* (Zacharia, 2003), *Saurida tumbil* (Manojkumar and Pavithran, 2016) of eastern Arabian Sea region.

Diet breadth is an important parameter for the assessment of the level of dietary specialization in a given group of organisms (Crovetto *et al.*, 2012). The groups with narrow diet breadth are relatively specialized, whereas more ample diets are typical of generalist or opportunistic feeder. In the present study, the juveniles were observed to be relatively more specialised feeders than adults. The juveniles fed on small planktonic crustaceans like amphipods and copepods as their major diet whereas adult moonfish fed on a number of items like squid juveniles, smaller teleost fishes, juveniles and larvae of large carnivorous fishes. Increase in the dimensions and variety of prey are often associated with increasing fish size. Growth in length and weight is generally accompanied by increased mouth dimensions, allowing larger prey items to be ingested and hence adults would always have wider diet breadth (Boubee and Ward, 1997).

According to the results of dietary specialisation and feeding strategies observed in juvenile and adult moonfish, the species showed both opportunistic predation and feeding specialization. The juvenile moonfish showed specific affinities for amphipods, copepods and *Acetes* sp. But in adult fish, no diet affinities were observed. Similar observations were made in Indo-Pacific Sailfish along the eastern Arabian Sea (Varghese *et al.*, 2013). Amundsen method (1996) indicated that the feeding strategy of adult moonfish was mostly mixed to generalised because, sometimes, individuals chose specific prey but, the population was mostly opportunistic nature with regard to prey selection (Costa *et al.*, 2015).

5.5. Fishery

The marine fishing scenario have undergone significant changes in terms of operational depth and area (Dineshbabu *et al.*, 2016) leading to diversification of catch. The analysis of moonfish catch along the Indian Coast for the past one decade (2007-2016) indicated sudden increase in catch after 2012. This hike in catch was mainly contributed by the change in fishing practice observed along the major landing states. After 2012, the trawl boats, operating along the coast of Kerala and Karnataka, started operating in pairs, which lead to the indiscriminate catch of many midwater/ column species like ribbonfish, carangids and other finfishes including moonfish (Viswambharan *et al.*, 2016). But pair trawling had also led to severe conflicts between different sectors in fisheries, which in turn resulted in reduced fishing days by pair trawling and consequently reduced catches in 2014. By 2015, light fishing by purse seiners became rampant in major landing states like Kerala, Karnataka and Goa, and moonfish were landed in good quantities. A good market developed for this fish leading to their increased value and similar trend continued in 2016.

In the present study, distribution of juveniles was recorded upto a depth of 50m while adults were seen upto 140m. In Karnataka Coast, juvenile fishes were reported at depth of 16m to 47m (Dineshbabu *et al.*, 2012). Dineshbabu *et al.* (2012) also reported juveniles of moonfish contributing to trash landings during the 2007-08. But by 2014, with the modified fishing operations, the larger sized moonfish were landed along Karnataka Coast. The increased trends in landings continued as there was an increased demand for the species from exporters in frozen conditions from south east Asian Countries.

5.6. Stock delineation

Fishes, in general, show higher degree of morphological variation within and between populations than other vertebrates. They are more vulnerable to environmentally induced morphological variation (Wimberger, 1992). These variations in morphology are usually due to the isolation of part of population within local habitat conditions. A prolonged isolation may result in prominent phenotypic and genetic separation among fish populations within a species and these results in the separation of fish population and lead to formulation of separate management of distinct populations (Turan, 2004). These

differentiations can happen through varied processes like reproductive separation between stocks of fishes which give rise to diverse spawning areas (Hourston, 1982) or by hydrographical features, which reduce or evade the migration of individuals between areas (Iles and Sinclair, 1982). Failure to distinguish or to report the various stock available in a locality might lead to mismanagement which could lead to an erosion of spawning components, finally leading to loss of genetic diversity, and other unknown ecological consequences (Begg *et al.*, 1999).

The results of the current study had shown that moonfish available in Mangalore, Ratnagiri and Vizhinjam might belong to different stocks, emphasising the chance of existence of multiple stocks of moonfish in the Konkan-Malabar Coast. The fishes of Vizhinjam Coast, were distinct one while fishes from Mangalore and Ratnagiri showed overlapping characters. The studies conducted by Rao *et al.*(1976, 1992) indicated that the region south of Quilon banks (*i.e.*, the region including Vizhinjam Coast) showed great deviations in many oceanographic parameters from the rest of eastern Arabian Sea regions. The separation of the Vizhinjam stocks might be due to different biotic and abiotic factors such as food availability, salinity, temperature and oceanographic parameters like water circulation, upwelling, currents, productivity etc., which are affecting the morphometry of the fish in the location. Similar observations were also made on the populations of *Decapterus russelli* from the eastern Arabian Sea (Sen *et al.*, 2011).

Assuming that the fish stocks are dispersed in space as gradients (Murta *et al.*, 2008), it is highly unlikely that fish from two different seas could probably be of one stock but the possibility are high for the fishes of the same seas and coast. The misclassification results of discriminant function clearly support this probability. The similarity between the stocks within a coast may be due to a common environment, similar genetic origin at earlier period and the similarity may also be due to the genetic introgression of the fishes, especially those in the transition zones (Sen *et al.*, 2011). However, this needs to be verified through the molecular genetic studies.

As in the present study, the fishes were collected only from 3 locations within a comparatively smaller area *i.e.*, Konkan-Malabar Coast. The fishing grounds for multiday vessels of Karnataka and Maharashtra are overlapping (Dineshababu *et al.*, 2016). The samples were collected from the catches of commercial vessels, and it is highly likely that the fishes caught at one location may land at other location leading to the mixture of the stocks. Thus, a useful follow up study would involve more genetic study to achieve greater understanding of these newly identified stocks.

The TRUSS system can be used effectively to separate stocks within a species, as reported for other species (Sajina *et al.*, 2011; Sen *et al.*, 2011; Pazhayamadom *et al.*, 2015 and Sreekanth *et al.*, 2016). In present study, the truss protocol revealed existence of multiple stocks of *M. maculata* in the Konkan Malabar Coast, suggesting a need for separate management strategy to sustain the stocks for future exploitation. The observations reported in the present study can further be confirmed based on molecular and biochemical methods. Application of molecular genetic markers such as microsatellite and mtDNA applications (Graves, 1998; Turan *et al.*, 1998; Shaw *et al.*, 1999) along with morphometric studies would be effective methods to further examine the genetic component of phenotypic discreteness between geographic regions and to facilitate the development of management recommendations.

SUMMARY

Mene maculata (Bloch and Schneider, 1801); commonly known as moonfish or razor moonfish is seen in the sub-littoral zone of coastal open waters of northwest Pacific, western central Pacific, south west Pacific and eastern Indian Ocean. The species is free-swimming in schools and performs diel vertical migration. The fishery of moonfish is emerging along the Konkan–Malabar Coast after the introduction of pair trawlers and light based fishing by purse seiners. Though the fish form a minor fishery along the eastern Arabian Sea, no literature on the morphology, biology, stock structure and status of fishery is available. Hence a study was taken up to understand the biology and the stock structure of moonfish along the Konkan–Malabar Coast.

A total of 1227 moonfish samples were collected fortnightly from the mechanised trawlers and purse seiners landing at Mangalore and Malpe Fishing Harbours from December 2015 to November 2017. The samples were dissected and sex, gonad weight, maturity stage of the fish, stomach condition and stomach content were recorded. For stock delineation studies, a total of 185 samples of moonfish from the fish landing centres of Ratnagiri, Mangalore and Vizhinjam were collected. A total of 21 TRUSS measurements and 5 meristic counts were used to delineate the stocks of moonfish along the Konkan Malabar Coast. The catch data of moonfish for the Indian sub-continent was obtained from the National Marine Living Resource Data Centre (NMLRDC) of the Central Marine Fisheries Research Institute.

The regression coefficient (b) obtained in the length weight relation was 3.390 and 2.90, for adults and juveniles, respectively. The result indicated positive allometric growth for adults while juveniles exhibited negative allometry. The annual population parameters estimated for moonfish off Karnataka Coast were: L_{∞} = 29.1cm, K = 1.014/yr, t_0 = -0.014yr, M = 1.82/yr, F = 1.62/yr and Z = 3.44/yr. The growth performance index (ϕ) of the fish in the present study was estimated at 2.934.

During the studies on the reproductive biology the length at first maturity (L_m) was found as 13.8cm (TL) and the average absolute fecundity was $43,795 \pm 4,197$ that ranged from 8,354 to 1,08,829 eggs. The comparison of correlation coefficient values of absolute fecundity with length, weight and ovary weight indicated linear relationship but better correlation of fecundity was found with ovary weight ($r=0.71$; $p<0.01$) and body weight ($r=0.448$; $p<0.01$) than the body length ($r= 0.284$; $p>0.07$). The species is found to be a protracted spawner from February to June and the Minimum Legal Size (MLS) of the species was set at 85mm.

The food and feeding studies indicated that the species is carnivore. The juvenile moonfish fed mainly on the small zooplankton crustaceans but adults' shifted to cephalopods, larger zooplankton crustaceans and teleosts. The degree of trophic overlap between juveniles and adult was found to be insignificant with C value of 0.34. The estimated TROPH value for moonfish was 3.56 (SE = 0.81), and the Omnivory Index (OI) was 0.665.

Moonfish formed a minor fishery along Indian Coast with an average annual catch of 5613 t/yr. Among the Indian maritime states, Kerala (33%) had the major share in the capture of moonfish followed by Goa (28%), Orissa (17%), Karnataka (9%) and others. Trawlers and purse seiners contributed maximum (84%) to the catch of moonfish of the country. The Konkan Malabar Coast contributed 4,206 t (75%) to the total moonfish production of the country. Among the maritime states of India, Karnataka is the 4th major contributor of moonfish with Dakshina Kannada District recording the maximum catch.

Stock delineation studies conducted using meristic counts failed to delineate stocks, while TRUSS morphometric studies indicated the presence of multiple stocks along the Konkan-Malabar Coast. The results of discriminant function analysis showed that there was high mixing of fishes from Mangalore and Ratnagiri Coast while the fishes of Vizhinjam Coast were purely distinct. The results of the TRUSS analysis suggest the possibility of occurrence of multiple stocks in the study region. Therefore this aspect needs further confirmation in future, based on molecular studies.

In order to plan and manage the fishery resources in a sustainable manner, the knowledge on the biology, fishery, stock structure and population status of fish species is essential. The current study is an attempt to address the knowledge gap existing in the trophodynamics, reproductive biology and stock structure of moonfish along the Konkan-Malabar Coast. This study would form a baseline for the future researches on the resource and aid in the optimum utilization and effective management of moonfish fishery along the eastern Arabian Sea.

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*Paper not referred in original