SYSTEMATICS, LIFE HISTORY TRAITS, ABUNDANCE AND STOCK ASSESSMENT OF COBIA *RACHYCENTRON CANADUM* (LINNAEUS, 1766) OCCURRING IN INDIAN WATERS WITH SPECIAL REFERENCE TO THE NORTHWEST COAST OF INDIA

THESIS

Submitted to

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in partial fulfillment of the requirement for the degree of

DOCTOR OF PHILOSOPHY

By

M.K. SAJEEVAN, M.F.Sc.

SCHOOL OF INDUSTRIAL FISHERIES
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COCHIN-682016

December, 2011

DECLARATION

I, M.K. Sajeevan, do hereby declare that the thesis entitled "**SYSTEMATICS, LIFE HISTORY TRAITS, ABUNDANCE AND STOCK ASSESSMENT OF COBIA *RACHYCENTRON CANADUM* (LINNAEUS, 1766) OCCURRING IN INDIAN WATERS WITH SPECIAL REFERENCE TO THE NORTHWEST COAST OF INDIA**" is a genuine record of research work done by me under the supervision of Prof.(Dr.) B. Madhusoodana Kurup, Vice Chancellor, Kerala University of Fisheries and Ocean Studies, Kochi and has not been previously formed the basis for the award of any degree, diploma, associate ship, fellowship or other similar title of any University or institution.

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December, 2011 **M.K.SAJEEVAN**

CERTIFICATE

This is to certify that the thesis entitled "**SYSTEMATICS, LIFE HISTORY TRAITS, ABUNDANCE AND STOCK ASSESSMENT OF COBIA *RACHYCENTRON CANADUM* (LINNAEUS, 1766) OCCURRING IN INDIAN WATERS WITH SPECIAL REFERENCE TO THE NORTHWEST COAST OF INDIA**" to be submitted by Mr. M.K. Sajeevan, M.F.Sc. is an authentic record of research work carried out by him under my guidance and supervision in partial fulfilment of the requirement of the degree of Doctor of Philosophy of Cochin University of Science and Technology, under the faculty of Marine Sciences.

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1. GENERAL INTRODUCTION

Cobia, *Rachycentron canadum* is a coastal pelagic, fast growing fish and belongs to the monotypic family Rachycentridae, under the order Perciformes. They are distributed worldwide in tropical and subtropical seas except for the eastern pacific (Briggs, 1960; Shaffer and Nakamura, 1989; Franks *et al*., 1999). Adult fish inhabits coastal waters and occasionally enters estuaries (Collette, 1978; Benson, 1982; Robins and Ray, 1986). In India, they occur along the coastal waters of both west and east coast. They are mainly caught in bottom trawls, hand lines, troll lines and drift gill nets. Cobia can reach a total length of 2 m and maximum weight of 68 kg (Shaffer and Nakamura, 1989).

Rachycentron canadum commonly known as Cobia, Black king fish, Black salmon, Ling, Lemonfish, Crabeater etc. is an esteemed table fish with high demand in the market. Fast growth (reach 6-7 Kg in one year), high conversion ratio and high unit price make Cobia as a very good candidate species for aquaculture. Commercial production of Cobia is successful in some parts of Asia mainly in Taiwan, where Cobia is stocked in around 80% of ocean cages. High salinity tolerance of the fish in the range of 05- 44.5 ppt. qualifies it as a potential species for brackish water aquaculture (Denson *et al*., 2003).

In India, there is no target fishery for Cobia; they are mostly caught as bycatch from trawlers, hook and line and gill nets. Compared to major pelagic resources, Cobia landings are very low, however due to its high price and emerging popularity as a candidate species for culture, the species is considered as an important resource. Unlike other pelagic resources, Cobia is solitary or move in small schools and found near some kind of floating objects (Kaiser and Holt, 2005).

Cobia exhibits tenacious fight when hooked, thus sharing the quality of an excellent sport fish. Recreational fishery of Cobia exists in areas like Gulf of Mexico, United States of America, Australia and the Caribbean (La Monte, 1952; Hatchell, 1954; Smith, 1965; Grant, 1972) No organized sports fishing has been reported from India. However, there exist tremendous scopes to develop an organised sport fishery targeting Cobia inhabiting the coastal waters of the country.

Briggs (1960), Richards (1967), Shaffer and Nakamura (1989), Smith (1995), Meyer and Franks (1996), Franks *et al*. (1999), Arendt *et al*. (2001), Brown-Peterson *et al*. (2001), Williams (2001) and McLean *et al.* (2008) provides valuable information on the fishery and culture practices of Cobia. In India, Somvanshi *et al*. (2000) reported the biological and population parameters of Cobia based on exploratory survey data gathered by the Fishery Survey of India (FSI). In the present study an attempt is made to bridge the knowledge gaps existing in respect of *Rachycentron canadum*, with a view to provide vital information such as systematics, life history traits, population dynamics, exploitation status and culture prospects of this species inhabiting the Indian Exclusive Economic Zone (EEZ).

Morphological characters are invariably used as major tools in traditional taxonomy of finfishes. Certain unique characters of Cobia such as possession of seven to eight detached dorsal spines help the researchers for its easy identification. However, similarity in body shape with remora and close resemblance of it juvenile stages with the latter species makes for a little confusion. In this study an attempt is made to establish its taxonomic identity with the help of morphometric, meristic and osteological characters.

Osteological study of the species not only helps the researchers in confirming the taxonomic position of a species but also provide key information on interrelationships. Compared to the tool used in modern taxonomy, the significance of osteological studies are unquestionable in establishing the interrelationship, evolutionary pattern and behavior of finfishes. Information on osteological features of Cobia is scanty and no such information is available on Cobia occurring in Indian waters. Hence osteological characters of Cobia have been studied in detail and re-described.

Research on food and feeding habits of fishes is considered as an essential part of fishery biology, as food regulates or influences the growth, reproduction, migration and abundance of fish stock. Availability of prey items in the habitat is often considered as an indicator for the occurrence and abundance of any fish species. Further, knowledge of the relationship between the fishes and their food items provide general information on their relative position in the food chains of the ecosystem. Information on the food and feeding habits of Cobia occurring in

Indian water is meagre; hence a detailed study on food and feeding habit has been carried out to fill the knowledge gaps in this important field of research.

Information on the life history traits of a fish is very essential for understanding and predicting the likely changes in the fish population. Knowledge on age and size at which fish attains maturity, time and duration of spawning and rate of regeneration of stock are vital for the judicious management of any fish stock. Information on reproductive biology of Cobia inhabiting the Indian EEZ is very limited. Present study made an attempt to provide a detailed account on the reproductive biology of Cobia occurring in Indian waters.

Sound knowledge on distribution, abundance and population dynamics of the fish is essential for ensuring sustainable exploitation of the fish stock. Information on distribution and abundance of Cobia in Indian waters is very scanty and hence present study made an attempt to understand the distribution, abundance and population dynamics of the Cobia by utilizing the exploratory survey data collected by the Fishery Survey of India.

The Fishery Survey of India of the Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Govt. of India carries out exploratory surveys in and around Indian EEZ, since its inception in 1946. Exploratory survey data thus collected by FSI trawlers form the basis of the present study. Exploratory survey data have certain limitations on evaluation of present fishery scenario and such limitations have been overcome by collection and utilization of samples from landing centers. The data base of the present study includes exploratory data collected by FSI trawlers since 1985 together with the commercial landing data collected from Mumbai waters.

Cobia is considered as a potential candidate species for aquaculture and attempts to set up Cobia farms is getting momentum around the world. In India, a major constraints faced by the farmers in setting up of Cobia farms is non-availability of seeds. Continuous supply of seeds for stocking is an important criterion for successful aquaculture of any species. As the developments of hatchery-produced seeds are still in experimental stage, live collection of seeds from trawlers is one of the sources for supply of seeds to the farms. In the study Cobia collected from bottom trawling were used for standardization of the methodology of live gene banking.

2. REVIEW OF LITERATURE

Rachycentron canadum is a well-known table fish cultured due to fast growth rate and high demand in the market; however, information on life history traits of Cobia is very limited. Solitary nature of the species, high price, non availability of required numbers of specimens etc. are the major bottlenecks in conducting research in this species especially in India. The available data are either based on very limited number of specimens or encompass a very short span of study. However, a few research attempts on Cobia carried out by researchers from different parts of the world could unravel some vital information on this species.

Somvanshi *et al.* (2000) reported the biological aspects of Cobia available along the north west coast of India on the basis of samples collected during a single voyage. Pillai *et al.* (2009) studied on some aspects of fishery and biology of Cobia, *Rachycentron canadum* (Linnaeus 1766) in the Indian Waters. Both studies provided preliminary information on the biological aspects of Cobia available in Indian waters and therefore much acclaimed.

2.1. SYSTEMATICS

Linnaeus (1766) in *Systema Natura* described a new species collected from Carolina. He originally described the species as *Gasterosteus canadus* and mentioned the type locality as Carolina. Bloch (1793) reviewed the status and renamed it as *Scomber niger* under the family Scombridae and genus *Scomber* (Linnaeus, 1758). Though the change of name was not accepted, it got the status as synonym of the species. Later, Lacepede (1802) described Cobia based on type specimen collected from Carolina water and proposed the name *Centronotus gardenii* under the family Pholidae, which is also considered as synonym of this species.

Mitchill (1815) collected type specimen from New York, explained morphological characters and named the specimen as *Centronotus spinosus* under the family Pholidae. Kaup(1826) described genus *Rachycentron* and proposed the scientific name *Rachycentron typus*. The proposed new genus got acceptance but scientific name was not acceptable and thus considered as a synonym of the species. Cuvier and Valenciennes (1831) described Cobia specimens collected from Brazil, Molucca, Malabar, Orissa and Pondicherry. The authors proposed different scientific name for each type locality under the genus *Elacate*. Afterwards, Swainson (1839) proposed scientific names *Meladerma nigerrima* and *Naucrates niger,* both were not acceptable, on the other hand agreed as synonyms.

DeKay (1842) collected Cobia specimen from New York waters and named as *Elacate canada*, which was subsequently treated as synonym. Fisher (1891) reported occurrence of Cobia from the lower Hudson Valley, New York. Jordan and Gill (1895), Evermann (1896) and Jordan (1905) investigated on the taxonomic status and nomenclature of finfishes also list out the synonyms of Cobia.

Fowler (1936) described the morphological characters and coloration of this species, while Baughman (1950) studied the interrelationships of fishes and observed that Cobia was found associated with the schools of large fishes, sea turtle and are commonly found under and around floating objects. Ueno (1965) provided morphometric data of Cobia caught at Yoichi, Hokkaido, Japan. Detailed morphological description of the species is also available in Briggs (1958, 1974), Kuronuma and Abe (1972), Briggs *et al.* (1979) and Smith (1907).

Hardy (1978) studied on egg, larval and juvenile stages of fishes, which also include detailed description of pre-adult form of Cobia. Wang and Kornhen (1979) explained morphological characters of juvenile Cobia and also attempted to compare it with adult phase of this species. Markle *et al.* (1980) studied on Scotian shelf ichthyofauna and reported the occurrence of Cobia along Scotian shelf and provided morphological characters of specimen collected from the shelf. Robins *et al.* (1980) studied the common names and scientific names of fishes from the United States of America and reported that *Rachycentron canadum* is commonly called as Cobia in English all over the U.S.A.

Johnson (1984) discussed interrelationships of the families like Nematistiidae, Carangidae, Coryphaenidae, Rachycentridae and Echeneididae. He was of the view that Rachycentron and Echeneidids are closely related (sistergroups) on the basis of morphological similarities of early life stages and adults of *Rachycentron canadum* and *Echeneis naucrates*. Osteological examination points towards a greater likelihood of sister groups between *Rachycentron* and *Coryphaena* spp. A detailed study of the Cobia lateral line canal system was carried out by Siming and Hongxi (1986).

Robins and Ray (1986) provided important field identification characters of Cobia and reported that Cobia is marine and occasionally enters estuary. Carr (1987) explained its generalised sheltering behavior as a reason for its close association with other organisms and floating objects. Shaffer and Nakamura (1989) reported that this association is so common and fishermen consider schools of large rays as a sign of Cobia abundance. Kaiser and Holt (2004, 2005) summarized the species profile of Cobia and provided information on capture and culture fishery of this fast growing fish. Cervigon (1966) reported the occurrence of Cobia from Venezuela and also provided information on fishery in Venezuela.

Phylogenetic analysis by O'Toole (2002) based on 138 putatively informative characters of the 11 species of the super family Echeneoidea (Echeneidae, Rachycentridae, and Coryphaenidae) resulted in a single most parsimonious tree. This tree strongly supports the monophyly of the super family Echeneoidea (Coryphaenidae, Rachycentridae and Echeneidae).

2.2. FOOD AND FEEDING

Ever since the classical work of Linnaes(1766), research on Cobia provided some preliminary information about their feeding behavior. However, Miles (1949) in his account on the food and feeding habits of fishes occurring in Aransas Bay provided some baseline information on the feeding habits of Cobia, which is considered as a stepping stone in the research on life history traits of the species.

Knapp (1949, 1951) studied on the conservation of game fishes of Texas, Gulf coast and food habits of the game fishes, which includes the feeding habits of Cobia also. Joseph *et al*. (1964) and Richards (1967) correlated the migration of Cobia with food availability. The authors described the migratory pattern of Cobia in the western Atlantic Ocean. According to the above authors, Cobia migrate to Chesapeake Bay in spring and summer to spawn, and the productive waters of the Bay are believed to constitute important foraging grounds.

Takamatsu (1967) studied on the association of Cobia with sting ray and results recorded that the increased food availability near the region of inhabitation of rays might be the reason for its association. Rays stir up the benthic organisms in their vicinity and this will help Cobia to locate its prey and feed effectively. Sonnier *et al.* (*1976*) studied the offshore reef and platform fishes and found Cobia associated with flotsam objects, which is indicative of its feeding habits. Darracott (1977) studied the availability and bionomics of demersal fish stocks of western Indian Ocean and observed that Cobia is known to move to the areas of high food abundance, particularly crustacean abundance. His findings indicated that Cobia prefers crustaceans than other food items.

Smith and Merriner (1982) carried out research on association of Cobia with other organisms and reported that sheltering behavior of Cobia is related to food abundance. They tend to associate with rays, sharks and other large fishes. The results of the study showed that Cobia exhibits some degree of commensalism, as they have been observed in captivity in taking in a larger fish's rejected food scraps. They endorse the views of Takamatsu (1967).

Randall (1983) while studying on Caribbean food fishes reported that Cobia is called as crab eater due to dominance of crab in their gut contents. Smith and Heemstra (1986), based on observations on Cobia habitats of South Africa, reported that Cobia is often found along with groups of remoras. Dity and Shaw (1992) explained the ecology of Cobia inhabiting the Gulf of Mexico.

Food and feeding studies carried out by different authors reported that there exist geographic differences in the diet habits of Cobia. The studies indicated that the relative importance of fishes versus crustaceans is variable geographically while cephalopods constituted the least significant prey items. Smith (1995) studied life history of Cobia in North Carolina waters and reported that there exist the dominance of Elasmobranchs and Portunid crabs in the diet of Cobia weighing more than 9 kg.

In the northern Gulf of Mexico, Franks *et al.* (1996) studied the food and feeding habits of juvenile Cobia and reported that fish (primarily anchovies, *Anchoa* sp.) dominated the diet of juvenile Cobia (236–440 mm FL). Fishes, mainly hardhead catfish, *Arius felis*, and American eel, *Anguilla rostrata* dominated in the stomach content of adult Cobia. Fishes were found in 58.5% of all Cobia stomachs but occurred in 84.4%of stomachs of Cobia in the length group of 1150–1530 mm FL.

Meyer and Franks (1996) reported that crustaceans occurred in 79.1% of stomachs and represented 77.6% of total prey items consumed by Cobia (373–1,530 mm FL) in the northern Gulf of Mexico. Portunid crabs dominated among crustaceans found in the stomach content of the Cobia. Arendt *et al.* (2001) studied the feeding habits of Cobia inhabiting along lower Chesapeake Bay and compared their results with similar studies from North Carolina and the northern Gulf of Mexico. They reported that Cobia predominantly consumes benthic and epibenthic prey items, most notably Portunid crabs.

Chou *et al*. (2004) studied the food and feeding habits of juvenile Cobia in captivity and reported that substitution of fishmeal in the diet of juvenile Cobia is found very effective in the formulation of diet for aquaculture.

According to Somvanshi *et al*. (2000) cobia mainly feed on fishes and cephalopods along the north west coast of India.

2.3. REPRODUCTIVE BIOLOGY

Several in-depth studies have been carried out during the past to understand the reproductive biology of Cobia. Cobia occupies a wide range of distribution in the oceans and seas of world around. Reports on changes in their size at maturity, spawning season, spawning frequency, sex ratio and fecundity according to the habitat they dwell are very common. Day (1878) reported a mature female from Indian waters, which is the first record of its kind which provided some insight on the reproductive biology of Cobia.

Goode (1884) reported that R.E. Earll, succeeded in artificially fertilizing Cobia eggs in 1880. This successful fertilization is considered as a mile stone in the reproductive biology of Cobia. Ryder (1887) described the developmental stages of Cobia eggs under laboratory condition. The author reported a rapid growth of the blastoderm within 8 hours from fertilization. The entire vitellus was included and covered by the blastoderm's epibolic growth. Eggs hatched within approximately 36 hours from fertilization.

Hildebrand and Schroeder (1928) studied on fishes of Chesapeake Bay illustrated morphological characters of juveniles of Cobia and opined that juveniles differ from adults in some morphological characters. Joseph *et al*. (1964) studied the spawning behavior of Cobia and reported the occurrence of juveniles along Chesapeake Bay. Richards (1967) provided information on age, growth, and fecundity of Cobia from Chesapeake Bay and adjacent mid-Atlantic waters. These investigations have invariably reported the migration of Cobia to Chesapeake Bay in spring and summer to spawn. Age at first maturity, fecundity, spawning season and sex ratio of Cobia were discussed in this paper.

Rajan *et al.* (1968) collected a mature specimen of 42.6 cm total length from Chilka Lake which manifests the early maturation of Cobia. This is considered as the pioneer work on Cobia in Indian waters. Study on spawning season of Cobia in Puerto Rica waters reported August as the peak month of spawning (Erdman, 1968). Swingle (1971) studied on the effect of salinity on early stages of Cobia and opined that early juveniles of Cobia move towards coastal waters, river mouth and Bays of relatively high salinity.

Dawson (1971) described on juvenile and pre-juvenile Cobia and occurrence of juveniles in the waters of Gulf of Mexico. Schwartz (1972, 1981) reviewed the status of hybrid development in fishes and stated that no hybrids of Cobia are hitherto known. Hoese and Moore (1977) discussed about the habitat of juveniles of Cobia along Gulf of Mexico and the findings are correlating with Swingle (1971), who reported that juveniles prefer high saline water. Finucane *et al.* (1978) reported the occurrence of Cobia larvae off Texas and also provided information on the morphological characters of larvae. Wang and Kornhen(1979) studied on early life history of fishes, which provided information on morphological characters of juvenile Cobia. Franks *et al.* (1991) studied seasonal movements of Cobia based on tagging and recapture studies. Dity and Shaw (1992) presented the larval development of Cobia occurring in Gulf of Mexico.

Biesiot *et al* (1994) established that Cobia in northern Gulf of Mexico spawns during spring and summer by resolving biochemical and histological studies. In the eastern Gulf, Cobia typically migrates from their wintering grounds off south Florida into northeastern Gulf waters during early spring. It is available off northwest Florida, Alabama, Mississippi and southeast Louisiana from late-March through October, and return to their wintering grounds in the fall. Smith (1995) studied the life history of Cobia in North Carolina waters. Lotz *et al.* (1996) studied reproductive biology of Cobia occurring in waters of Gulf of Mexico. They suggested that Cobia have a protracted reproductive season from April to October with peak spawning activity during May to June and are typical multiple spawners.

Lotz *et al.* (1996) illustrated gonadal maturation of Cobia occurring in north central Gulf of Mexico and concluded that this species is endowed with a prolonged spawning season and is a multiple spawner. Franks *et al.* (1999) studied the age and growth of Cobia from recreational catches of the northeastern Gulf of Mexico during the period of 1987 to 1995 and reported the male: female ratio as 1:2.7.

Brown-Peterson *et al.* (2001) studied the reproductive biology of Cobia from coastal waters of United States. Arnold *et al.* (2002) carried out research on spawning of Cobia in captivity and reported that Cobia is having high fecundity and the spawning could be induced by ambient seasonal cycles. Kaiser and Holt (2004, 2005) reviewed research works on reproductive behavior and life history of Cobia in wild and contributed vital information on the life history traits of this species.

Somvanshi *et al*. (2000) and Pillai *et al.* (2009) reported the fecundity, spawning frequency and sex ratio of the species and these are the only available information of this kind about Cobia occurring in Indian waters.

2.4. LENGTH-WEIGHT RELATIONSHIP AND CONDITION FACTOR

Richards (1967) studied age, growth and fecundity of the Cobia, *Rachycentron canadum*, from Chesapeake Bay and adjacent Mid-Atlantic waters and also estimated its length-weight relationship. The length-weight relationship for Cobia was calculated by Richards (1967) as: Log W = (3.088 log L) - 3.506, where W = weight in pounds and L = fork length in inches. The curvilinear relationship was the same for males and females. Later Darracott (1977) reported the length-weight relationship of Cobia from the Tanzanian area of the Indian Ocean as Female $W = -4.57\ L^{2.79}$ (n=9, r=0.97) Male $W = -5.19\ L^{3.15}$ (n=9, r=0.99) Total $W = -4.58\ L^{2.83}$ (n=48, r=0.96). This shows that the curvilinear relationship was different for males from its counterpart, the females.

Hassler and Rainville (1975) described development and growth rates of larvae hatched from eggs collected along the Gulf Stream in the Atlantic off north Carolina. The authors also made an assessment on exponential weight and length increases in Cobia larvae and juveniles older than 10 days. The equations so arrived at are: Log W = 4.360 Log X - 4.318, where W = weight in mg, and X = age in days. Log L = 1.425 Log X - 0.587, where L length in mm, and X = age in days. The authors also established the length-weight relationship of larval and juvenile of Cobia with the exponential equation: Log W = 2.4035 Log L - 1.3007.

Edwards *et al.* (1985) studied fishery yields of fish from the Gulf of Aden and also assessed length weight relationship of Cobia occurring along Gulf of Aden. Bohnsack and Harper (1988) assessed length-weight relationships of selected marine reef fishes from the southeastern United States and the Caribbean waters. Similar studies on length weight relationships in Cobia are those of Torres (1991) occurring along southern Africa; Claro and García-Arteaga (1994) along Chesapeake Bay and adjacent mid-Atlantic waters and Franks *et al*. (1999) from northeastern Gulf of Mexico.

Burns *et al.* (1998) studied on stock assessment of Cobia occurring along Gulf of Mexico and south Atlantic and calculated length-weight regressions for both male and female Cobia by each geographic area, the Carolinas, Florida east coast, Florida west coast and northern Gulf of Mexico. Later Williams (2001) established the relationship by utilising data collected from commercial fishery.

Somvanshi *et al.* (2000) established length-weight relationship of Cobia occurring along north-west coast of India. Abdurahiman *et al.* (2004) carried out an exhaustive study on length-weight relationship of commercially important marine fishes and shellfishes of the southern coast of Karnataka, India.

2.5. AGE AND GROWTH

Studies on age and growth are essential to understand the population, fishery and well being of the stock. Information gathered thereby helps managers to formulate suitable managerial measures. Regarding age and growth of Cobia, Cadenat (1950) made the classical study. Based on his observation, he suggested that Cobia can grow up to a length of 2 m. Joseph *et al*. (1964) studied the spawning behavior of Cobia along Chesapeake Bay and also made some preliminary observations on the age and growth of the species occurring along the U.S. Atlantic coast.

Richards (1967) provided information on age and growth of the Cobia *Rachycentron canadum* occurring in Chesapeake Bay and adjacent mid-Atlantic waters. Age analysis by scale methods, growth estimates by von Bertalannfy equation and observations of juvenile Cobia indicated that the species is capable of undergoing rapid growth. He reported the occurrence of ten age groups on the basis of scale collections from 284 specimens ranging from 4.2-56.4 inches in fork length. Growth equations so arrived at are: males, $L_t = 49(1-e^{-0.21(t+0.67)})$, $W_t = 59 \text{ X } (1-e^{-0.13(t-0.62)})$; females, $L_t = 59(1-e^{-0.20(t+0.65)})$, $W_t = 120(1-e^{-0.10(t-0.80)})$. The study also reported that mean observed length of females was larger than male in all age group except at zero age fish. Richards (1977) later updated the age and growth values of Cobia through tagging and recapture studies.

Thompson *et al*. (1991) studied age, growth and reproductive biology of greater amberjack and Cobia from Louisiana waters. Franks *et al*. (1991) carried out some preliminary studies on age and growth of Cobia occurring in northeastern Gulf of Mexico through tagging and recapture studies. Smith (1995) estimated age and growth parameters of Cobia occurring in north

Carolina waters and reported that maximum age of male is 14 years while that of female it is 13 years.

Franks *et al*. (1999) studied the age and growth of Cobia from the northeastern Gulf of Mexico. Age of 565 numbers of Cobia was estimated from thin-sectioned otoliths (sagittae). Age ranging from 0-11 was recorded during the study. The relationship of observed fork length and age was described by the von Bertalanffy growth equation for males: $FL_t = 1171(1-\exp[-0.432(t+1.150)])$ and for females: $FL_t = 1555(1-\exp[-0.272(t+1.254)])$. Estimates of the von Bertalanffy growth equation parameters L_∞ and K were significantly different for males and females, whereas estimates for t_0 were not significantly different.

Williams (2001) studied population dynamics of the Cobia occurring in territorial waters of United States, Gulf of Mexico, and also assessed age and growth of Cobia by using recreational and commercial fishery data. Fry and Griffiths (2010) assessed age and growth parameters of Cobia caught in Australian recreational and commercial fishery.

Somvanshi *et al*. (2000) estimated L_∞, K value and natural mortality of Cobia inhabiting the north west coast of India.

2.6. BIOMASS, STOCK ASSESSMENT AND DISTRIBUTION

Henshall (1895) in his studies on fishes collected during the year 1892 from Florida reported the occurrence of Cobia in recreational fishery of the area and he highlighted the importance of Cobia as a game fish. Jordan and Seale (1906) provided distribution of Cobia along Samoa and described the fishes found in the archipelago. Nichols and Breder (1926) described the distribution and abundance of Cobia along western Atlantic.

Chacko (1949) reported the occurrence of Cobia from Gulf of Mannar, India. La Monte (1952) in his study on world game fishes, provided information on the recreational fishery of Cobia along Australia and Carribean waters. Hatchell (1954) provided information on distribution and fishery of Cobia along south-eastern African coast.

Springer and Bullis (1956) examined the bathymetrical distribution of Cobia and stated that Cobia is mostly available at a depth above 50 m. The authors also reported the occurrence of Cobia even up to a depth of 1200 m, which is quite interesting. The study assumes significant since there is no such report till date. Briggs (1958) studied on Florida fishes and their distribution. According to him, the distribution of Cobia is extends from Massachusetts and Bermuda to Argentina in the western Atlantic Ocean.

Briggs (1960) studied on fishes having worldwide distribution and reported that Cobia is distributed widely in sub tropical and tropical oceans and seasonally in temperate waters. This study emphasized that Cobia is a migratory pelagic species which is found all along tropical and subtropical seas of the world, except in the central and eastern Pacific Ocean. Richards (1967) provided information on distribution of Cobia from lower Chesapeake Bay and adjacent mid-Atlantic waters.

According to Moe (1970) Cobia is found to move in a group of 2-8 fishes, which is generally associated with rays. Wickham *et al.* (1973) studied on efficacy of artificial structure for attracting game fishes also endorsed the sheltering behavior of Cobia**.** Kuronuma and Abe (1972) reported the occurrence of Cobia from Persian Gulf and also endorses the view that Cobia is common as a bycatch from the shrimp fishery.

Lindberg and Krasyukova (1971) provided information on occurrence and distribution of Cobia along the Sea of Japan and the adjacent areas of the Sea of Okhotsk and the Yellow Sea. Dawson (1971) reported about the distribution of Cobia in the Gulf of Mexico (Gulf), which shows that they are distributed from Key west, Florida, along the entire coast to Campeche, Mexico. Monod (1973) described distribution pattern of Cobia along Atlantic coast.

Hoese and Moore (1977) discussed about the habitat of adult and juveniles of Cobia along Gulf of Mexico. Champagnat and Domain (1978) observed migratory movements of Cobia along African coast from the Senegal-Guinea area. Relyea (1981) provided information on distribution pattern of Cobia along Arabian Gulf. Benson (1982) studied the life history pattern of fishes in Mississippi Sound and adjacent areas and was of the view that Cobia may be solitary and move in small groups of 2-8 fishes or more.

Burgess (1983) reported that in the Gulf of Mexico Cobia is fished in the spring and summer with a strong spring run in the northern Gulf during March to May. Menni *et al.* (1984) provided information on distribution of Cobia along western Atlantic. Sasser (1984) reported that Cobia is attracted by sound. The distribution of Cobia along eastern U.S. waters and its association with rays was reported by McNally (1985, 1987)

Golani and Ben-Tuvia (1986) reported that Cobia do not occur in the Mediterranean, except for possible strays from the Red Sea through the Suez Canal. Shaffer and Nakamura (1989) reported that Cobia is most common along the U.S. south Atlantic coast and in the northern Gulf of Mexico. Dity and Shaw (1992) studied on distribution of Cobia occurring in Gulf of Mexico. Thompson (1993, 1996) assessed Cobia stock of Gulf of Mexico, Atlantic and Southeast U.S. waters. Burns *et al.* (1998) also assessed the stock of Cobia occurring in Gulf of Mexico and South Atlantic.

Williams (2001) assessed the distribution, biomass and migratory movements of Cobia occurring in territorial waters of United States, Gulf of Mexico on the basis of data available on recreational and commercial fishery.

Studies on environmental parameters that affect the distribution of Cobia begin with the work of Reid (1954). He provided some information on the ecological preferences of Cobia based on environmental parameters collected from the site of Florida. Springer and Bullis (1956) presented information on environmental data of Cobia habitat at Gulf of Mexico. Later, Springer and Woodburn (1960) carried out ecological study of the fishes of the Tampa Bay area and provided similar information.

Christensen (1965) furnished information on environmental data of Cobia collected from Western Atlantic. Roessler (1967) provided information on environmental data of Cobia habitat of Florida, Gulf of Mexico, while Milstein and Thomas (1976) also provided similar data of Cobia habitat off New Jersey. Wilk and Silverman (1976) correlated hydrographic parameters and occurrence of Cobia. Lhomme (1983) studied the habitat of Cobia in Ivory

Coast, where data on temperature and salinity were collected from the fishing ground.

2.7. MORTALITY AND EXPLOITATION

Cobia fishery exists in different parts of the world. Due to the high demand in market and qualities of game fish Cobia is equally important in both recreational and commercial fishery. Most of the studies mentioned in the former part of this chapter embarking upon taxonomy, reproduction and food & feeding also encompass information on fishery of Cobia. Works of Bearden (1961), who studied on fishes of South Carolina, provided information on Cobia fishery prevalent along South Carolina. He reported that Cobia fishing season in South Carolina extends from May to September.

Richards (1965) observed that Cobia season in the Chesapeake Bay region extends from May to October, with a peak in July. Smith (1965) studied on sea fishes of southeastern Africa and described salient features of recreational fishery existing along southeastern Africa. He also emphasized the importance of Cobia as a game fish. Cobia makes determined runs and leaps, characteristic of game fish, when hooked (Smith, 1965; Grant 1972).

Deuel and Clark (1968) and Deuel (1973) furnished landing details of US recreational fishery. Manooch and Laws (1979) and Manooch (1984) also explained Cobia fishery of U.S waters. Grant (1972) reported that Cobia is fished recreationally in Australia. Aprieto and Villoso (1979) and Aprieto (1985) reported about the incidental catches of Cobia in purseine and trawl fishery off Philippines.

Pillai (1982) furnished some information on fishery of Cobia along Indian water and its landing during 1969-1980. Franks *et al.* (1999) reported that during a 12-yr period (1984- 1995) Cobia landings from the Atlantic and Gulf of Mexico averaged 1 million kg/yr, of which 87% was recreational catch. The instantaneous rate of total mortality (Z) estimated in the above study using catch curve analysis for fully recruited age 4 to 8 was 0.75.

McClane (1974) and Daigle (1984) reported about the fishing gears and bait fishes used in recreational fishery. Bianchi (1985) brought out a field guide of commercial fishes of Pakistan and reported that Pakistan (world's largest producer of Cobia) fishermen catch them by using handlines, bottom trawl, driftnet and floating gillnet. The United States ranks third in total commercial production of Cobia, however, recreational landings generally exceed commercial landings by an order of magnitude (Shaffer and Nakamura, 1989).

Williams (2001) compared the landings of recreational fishery against commercial fishery of Cobia occurring in territorial waters of United States, Gulf of Mexico. This study reported that standing stock of Cobia increased since 1980 and population is either depleted/ near MSY, or well above MSY depending on the choice of mortality value. Cobia is considered as low in abundance throughout their range with most of the U.S. landings coming from recreational fishermen.

Sidwell (1981) reported the proximate composition of raw tissue of Cobia. According to the author, in raw fish, moisture is 74.9%, protein 18.9%, fat 5.4 %, ash 1.3% and carbohydrates 0%. The caloric content was 124 calories per 100 g. Cobia is a highly prized food fish and generally sold fresh. It holds up well as a frozen product, and also makes a fine smoked product (Seafood Leader, 1987).

2.8. LIVE GENE BANKING AND CULTURE PROSPECTS

Hassler and Rainville (1975) were the first to propose the scope of Cobia culture. Rapid growth rates, high-quality flesh and wide distribution are the major features of Cobia as a candidate fish for culture. The authors collected Cobia eggs from the Gulf Stream off North Carolina, successfully hatched them and reared the larvae through juvenile stages. They described development and growth rates of larvae hatched from eggs collected along the Gulf Stream in the Atlantic off North Carolina.

Cobia is a promising candidate for aquaculture because of its rapid growth rate, hardiness and excellent flesh quality. They can grow in the range of 4-6 kg in one year and are considered to have the greatest potential among candidate species for production in cage aquaculture systems. According to Caylor *et al.* (1994) synchronization of the capture of mature male and female for spawning research is a major challenge for marine culturist; hence cryopreservation of eggs and induced spawning is the best alternate option for ensuring continues supply of juveniles for culture.

Su *et al.* (2000) reviewed the status of cage culture in Taiwan with special emphasis on Cobia culture in marine cages. He reported that in Taiwan the technology of larval rearing, nursery and grow out farm of Cobia have been standardised. Dodd (2001) narrated the initial success story of Cobia culture in United States. The author reported that Cobia adult fish captured off the coast of South Carolina during the summer of 2001 spawned naturally two to three days after their capture. This success was instrumental in initiating researchers to try various larval grow out techniques.

Chou *et al.* (2001) provided information on protein and lipid requirements of juvenile Cobia. He opined that Cobia have greatest potential for cage culture and will grow fast in cages. Chen *et al.* (2001) reported mass mortality of juvenile Cobia cultured in marine cages of Taiwan due to myxosporidean infestation. Franks *et al.* (2001) reported the success of induced breeding of female Cobia by using human chorionic gonadotropin (HCG). The authors illustrated the fertilization, mating and larval development of Cobia in captivity.

Liao *et al.* (2001) reported that Cobia have been successfully spawned from captive brood stock in Taiwan since 1994 and Cobia become one of the most economically important species currently cultured in that country. Arnold *et al.* (2002) studied on reproductive behavior of Cobia in captivity and provided information on reproductive biology of Cobia.

Kilduff *et al.* (2002) studied early larval development and induced breeding of Cobia. Faulk and Holt (2003) studied the food and feeding and lipid nutritional requirements of juvenile Cobia in captivity and reported that Cobia eggs and ovary contain high levels of polyunsaturated fatty acids (PUFAs).

Denson *et al.* (2003) studied the effect of salinity on growth and survival of juvenile Cobia and reported that Cobia survive in wide range of salinity. Juvenile Cobia fed with commercial diets has reported signs of osteopenia, inter-muscular lesions and discoloration when reared in salinities below15 g/l. Various haematological parameters of Cobia were also discussed in this paper.

Chou *et al*. (2004) studied the food and feeding habits of juvenile Cobia in captivity and is of the view that mixture of soyabean with fish meal is an effective diet for juveniles. Liao *et al.* (2004) discussed present status and prospects of Cobia culture in Taiwan and illustrated latest technologies used for Cobia culture in Taiwan. The authors also reported that Cobia initially reared in outdoor and subsequently transferred to open ocean cages grows to 6-8 kg in one year.

Resely (2004) studied the salinity tolerance of juvenile Cobia in different salinity gradients and reported that Cobia can tolerate vide range of salinity. The study indicated that culture of Cobia is possible in salinity as low as 5 ppt. Wang *et al.* (2005) studied the effect of lipid level on growth performance in juvenile Cobia and the results shared that lipid level above 15% in the diet would negatively affect growth of Cobia juveniles. Resely *et al.* (2006) described the type of culture practices to be followed when Cobia are reared in low saline water. The authors observed that juvenile Cobia when reared in low salinities appeared normal, if they are fed with a prepared diet supplemented with chelated minerals and a complete vitamin mixture. The results of the study indicated that Cobia may have additional nutritional requirements in low salinities. The results of these studies suggest that Cobia can be reared in salinities as low as 15 g/l but culture of this species in salinity below15 g/l may only be possible with the use of supplemented feeds.

Weirich *et al.* (2004) studied the suitability of larval and juvenile culture of Cobia in ponds of southeastern United States. The authors illustrated the culture techniques and narrated the advantages of Cobia as a candidate species for culture. In the meantime, Schwarz (2004) reported the status of fingerling production of Cobia. He opined that low production rate of Cobia fingerlings is a major bottleneck for the establishment of Cobia culture industry. Schwarz *et al.*(2004) reviewed the status of Cobia research and production and were of the view that Cobia are adaptable to commercially available feeds and easily acclimatise to tank and pen and are resistant to diseases.

Kaiser and Holt (2004, 2005) presented species profile of Cobia and provided information on capture and culture fishery of this fast growing fish. Culture techniques and important measure needed to be taken during transportation of juveniles were also explained. This study categorically proved that photo-thermal conditioning induce spawning is possible in respect of this species.

Craig *et al.* (2005) studied the nutritional requirements of Cobia and reported that availability of species specific diet for Cobia is a major pre requisite for assessing Cobia as an established marine finfish culture species. Faulk and Holt (2005) studied the effect of live feed and green water culture on larval rearing of Cobia. Above study revealed that Rotifers and Artemia enriched with *Isochrysis galbana* or commercial products (Algamac 2000 and Aquagrow) in conjunction with green water culture provided the best growth and survival of Cobia larvae in re-circulating aquaculture systems.

Faulk and Holt (2006) evaluated stage specific salinity tolerances. Yolksac, first feeding and older larvae were subjected to either acute or gradual salinity changes The tolerance of Cobia larvae to low salinities was age dependent with older larvae surviving better at lower salinities than younger larvae. No significant differences in the survival of Cobia were observed at salinities ranging from 15 to 33 g/l. However, survival in salinities below 15 g/l was significantly lower and several of the fish were discolored and suffered from apparent external fungal infections.

Hitzfelder *et al.* (2006) studied the effect of stocking intensity on growth and survival of Cobia. In intensive systems, growth and in some cases survival of larvae can be affected by density dependent processes. Growth and survival of Cobia were negatively correlated with increasing density (1 to 20 larvae l^{-1}). At the highest density, all larvae did not initiate feeding and mortality was high over the first 10 days.

Schwarz *et al.* (2007) reviewed the present status of Cobia culture and observed that constant supply of juveniles to meet the requirement of culture industry is the major bottleneck affecting Cobia culture. The authors suggested that future of Cobia culture depends on the success of its hatchery production. Holt *et al.* (2007) reviewed the present status of larviculture of Cobia. This paper provided an overview of production, limitation, focus on recent spawning and larviculture research results and ongoing research initiatives. Benetti *et al.* (2008) provided information on hatchery and grow out technology of Cobia practiced in US. The authors indicated that Cobia grown in tanks in Miami, USA at densities of 2 -3 kg/m3 reached about 2 kg in 12 months and this low growth performance was attributed to the high stocking densities maintained.

Galtsoff (1954) investigated causes of mortality among fishes and reported that Cobia is affected by red tide organisms. Howse *et al. (*1975) examined several hearts of Cobia and reported that pericardial adhesions probably resulted from pericarditis. Parasites of Cobia include trematodes, monogeneans, cestode, nematodes, Acanthocephalans and copepods.

Linton(1905), Sogandares-Bernal and Hutton (1959), Jahan (1973), Madhavi (1976), Hafeezullah (1978), Parukhin(1978) and Ahmad (1981) furnished details of trematodes infestation on Cobia. Koratha (1955), Hargis (1957), Young (1970) and Rohde (1978) provided information on monogeneans attack on Cobia. Linton (1905) reported parasite cestodes attached to Cobia. Linton (1905), Rasheed (1965), Khan and Begum (1971), Overstreet (1978), Deardorff and Overstreet (1980) and Deardorff and Overstreet (1981) reported nematode infestation in Cobia and its features. Linton (1905), Golvan (1956), Overstreet (1978), George and Nadakal (1981) and Soota and Bhaltacharya (1981) illustrated Acanthocephalans parasite on Cobia and its effect on Cobia. Wilson (1908), Pearse (1952), Causey (1953), Causey (1955), Pillai (1962), Kabata (1967) and Dawson (1969) reported infestation of copepods on Cobia.

An appraisal of the cobia culture prospects revealed that there exist tremendous scopes to culture *Rachycentron canadum* as a suitable candidate species for the brackish and coastal aquaculture of the country. However, attaining self sufficiency in the supply of seeds is one of the pre-requisites to be achieved before the utilization of brackish water and coastal regions of the country for Cobia farming. However, the possibilities of exploring alternate seed sources of this species are significant.

3. SYSTEMATICS

3.1. INTRODUCTION

Cobia, *Rachycentron canadum* (Linnaeus, 1766) is coastal pelagic, large, fast growing fish belonging to the monotypic family Rachycentridae (Plate 1.A). By looking at its shape and first dorsal fin, one can easily diagnose Cobia. First dorsal fin is modified to six to nine independent, short, stout and sharp spines, an important diagnostic feature of this species. The Etymology of family name *Rachycentridae* (from the Greek words *rhachis* meaning vertebral column and Greek word *kentron* meaning sharp point) is an allusion to these dorsal spines.

Linnaeus (1766) described a new species collected from Carolinas in his book *Systema Natura*. He originally described the species as *Gasterosteus canadus* and mentioned the type locality as Carolina. Linnaeus (1766), Bloch (1793), Lacepede (1802), Mitchil (1815), Kaup (1826), Cuvier and Valenciennes (1831), Swainson (1839), Dekay (1842), Gill (1895), Jordan and Evermann (1896), Jordan (1905), Berg (1940), Smith and Smith (1963) and Weitzman (1974) provided information on systematics of Cobia.

Information on systematics of Cobia inhabiting the Indian EEZ is meagre and no attempt has been made to study the osteological characters of the species. Hence, morphometric, meristic and osteological studies has been carried out to understand the systematics and interrelationships of the species. Results of osteological studies were compared with the findings of the O'Toole (2002), with a view to confirm the systematics position and interrelationship of the species inhabiting the Indian waters.

A review of historical account of systematic study of Cobia was carried out. Synonymy, common name and vernacular names of the species are also presented with an aim to provide information on the local name by which the species is known in different parts of the world.

3.2. MATERIALS AND METHODS

The present study was conducted based on the samples collected from the catches of *M. V. Matsya Nireekshani*, a trawler belonging to Mumbai base of Fishery Survey of India, Mumbai. This vessel was operated along the north west coast of India. Samples collected from landing centers at Mumbai, (New Ferry Warf and Sassoon Dock) were also used for the study. The colour of the specimens was noted in fresh condition itself. Specimens collected from the haul were photographed immediately by using a digital camera. Specimens were identified up to species level by using standard references (Day, 1878; Goode and Bean, 1895; Munro, 1955; Fisher and Bianchi, 1984; Smith and Heemstra, 1986). Taxonomic status, history of nomenclature, common names and vernacular names of Cobia were collected by scanning available literatures and electronic sources.

Morphometric and meristic data were obtained from fresh specimens. All measurements were taken from point to point on the left side of the fish with one mm accuracy (Philip, 1994). Fin rays, branchiostegal rays and gillrakers counts were done manually. The morphometric data are presented in percentage of total length, except measurements from the head region. Measurements from the head region were expressed as percentage of head length. Aspect ratio of the caudal fin calculated following Ngatunga and Allison (1996) and by using the formulae:

Aspect ratio = h^2/ S………………………………………………… (1)

Where,

h = caudal fin height

S= Caudal fin surface area.

Caudal fin surface area was calculated by using image processing with image J (Abramoff *et al*., 2004). Three images were used for estimation and average has been taken as aspect ratio.

Adult specimens collected onboard vessel (preserved in frozen condition) and landing centers (fresh specimens) were brought to shore laboratory for osteological study. Dry skeleton of adult specimens were prepared by the method of Bemis *et al.* (2004). The osteological terminologies employed follow the current usage as exemplified by Patterson and Johnson (1995), Taylor *et al.* (1999), O'Toole (2002) and Hilton and Johnson (2007). Results of osteological study were compared with O'Toole (2002). An attempt has been made to re-describe the species by using the findings recorded from morphological, meristic and osteological studies.

3.3. RESULTS AND DISCUSSIONS

3.3.1. Distinguishing characters

According to Collette (1978) Cobia has an elongated body, sub cylindrical; head broad and depressed. Mouth large, terminal, with projecting lower jaw; villiform teeth on jaws and on roof of mouth and tongue. First dorsal fin with 7-9 (usually 8) short but strong isolated spines, not connected by a membrane; second dorsal fin long, anterior rays somewhat elevated in adults; pectoral fins pointed, becoming more falcate with age; anal fin similar to dorsal, but shorter; caudal fin lunate in adults, upper lobe longer than lower (caudal fin rounded in young, the central rays much prolonged). Scales small, embedded in thick skin; lateral line slightly wavy anteriorly.

3.3.2. Common names and vernacular names of the species

As per the Food and Agricultural Organisation (FAO) the common names of *Rachycentron canadum* are Cobia (English), Mafou (French) and Cobie (Spanish) (Collette, 1978). The accepted common name in the United States is Cobia (Robins *et al.* 1980; Humann, 1994). Other names appearing in the literature are shown in Table 1.

Table 1.Common names and vernacular names of *Rachycentron canadum*

Name of the country	Common name / vernacular name	Reference
Argentina	Bonito negro	Menni *et al*. (1984)
Australia	Black kingfish	La Monte (1952)
Brazil	Bijupini	Figueiredo and Meneses (1980)
	Ceixupira	Duarte-Bello and Buesa (1973)
Colombia	Bacalao	Menni *et al*. (1984)
Cuba	Bacalao	Menni *et al*. (1984)
	medregal	Duarte-Bello and Buesa (1973)
Guyanas	Cabilo	Org. Econ. Coop. Develop. (1978)
Japan	Sugi	Ueno (1965)
Madagascar	Sao ambina and Poisson-sergent	Fourmanoir (1957)
Mexico	Bacalao	La Monte (1952)
	Bonito and Esmedegral	Duarte-Bello and Buesa (1973)
Pakistan	Black kingfish, Sanghra and Sanglor	Bianchi (1985), Bianchi *et al*. (1993)
Persian Gulf	Sikin	Kuronuma and Abe (1972)
Puerto Rico	Bacalao	La Monte, (1952), Erdman (1956)
Senegal and Gambia	Warangall	Menni *et al*. (1984)
South Africa	Runner and Prodigal son	Smith (1965)
Sri Lanka	Mudhu luhala and Mudhilla	Munro (1955)
Tanzania	Runner and Songoro	Hatchell (1954)
United States	Ling, Sergeant fish, Bonito and Coalfish	Goode (1884)
	Cabio and Crabeater	La Monte (1952)
	Lemonfish	Manooch (1984)
	Black bonito	Hildebrand and Schroeder (1928)
	Lingcod and Black salmon	Moe (1970)
	Cubby-yew and Flathead	Burgess (1983)
U.S.S.R.	Kobievye and Sserzhant-ryby	Lindberg and Krasyukova (1971)
Uruguay	Bonito and Bonito negro	Menni *et al*. (1984)
Venezuela	Bacallao	Menni *et al*. (1984),Cervigon (1966)
India- English	Black kingfish	Pillai (1982)
India Maharashtra	Sakala	Day (1878)
India Tamil	Caddal veral	Day (1878)
India- Kerala	Modha and Kadal braal	Present study

3.3.3 Taxonomy

Systematic position of Cobia *Rachycentron canadum* (Linnaeus, 1766) as follows:

Kingdom: Animalia

Phylum: Chordata

Subphylum: Vertebrata

Superclass : Gnathostomata

Class :Osteichthyes

Division: Euteleostei

Superorder : Acanthopterygii

Order : Perciformes

Suborder :Percoidei

Family:Rachycentridae

Genus : *Rachycentron* Kaup, 1826.

Species: *Rachycentron canadum* (Linnaeus, 1766)

3.3.4. Synonymy

Synonyms of Cobia (Gill, 1895; Jordan and Evermann, 1896; Jordan, 1905; Bailly, 2010) with type locality in bracket are as follows:

Gasterosteus canadus Linnaeus, 1766 (original, type locality- Carolinas)

Apolectus niger (Bloch, 1793)

Scomber niger Bloch, 1793

Naucrates niger (Bloch, 1793)

Elacate nigra (Bloch, 1793)

Centronotus gardenii Lacepede, 1802 (Carolinas)

Centronotus spinosus Mitchill, 1815 (New York)

Rachycentron typus Kaup, 1826

Elacate motta Cuvier and Valenciennes, 1829

Elacate atlantica Cuvier and Valenciennes, 1831 (Brazil)

Elacate bivittata Cuvier and Valenciennes, 1831 (Molucca)

Elacate malabarica Cuvier and Valenciennes, 1831 (Malabar)

Elacate motta Cuvier and Valenciennes, 1831 (Orixa)

Elacate pondiceriana Cuvier and Valenciennes, 1831 (Pondicherry)

Meladerma nigerrima Swainson, 1839

Naucrates niger Swainson, 1839

Elacatc Canada DeKay, 1842 (New York)

Elacate jalcipinnis Gosse, 1851 (Jamaica)

Thynnus Canadensis Gronow, 1854

Elacate nigra Gunther, 1860

Rachycentron canadus Jordan and Evermann, 1896

Rachycentron pondicerrianum Jordan, 1905

Rachycentron canadum Jordan, 1905

3.3.5. Taxonomy status and history of nomenclature

Cobia *Rachycentron canadum* (Linnaeus, 1766), is the only species belonging to the family Rachycentridae. No sub species is recognized (Shaffer and Nakamura, 1989) Linnaeus (1766) originally described this species as *Gasterosteus canadus* based on specimens collected from Carolina (type locality). Linnaes (1766) classified the species under Order Gasterosteiformes, Family Gasterosteidae and Genus *Gasterosteus* Linnaeus, 1758.

Bloch (1793) described this species as *Scomber niger* and placed it under Order Perciformes, Family- Scombridae and Genus *Scombe*r Linnaeus, 1758. Similarity in body shape with some members of scombrids may be the reason for adopting this scheme of classification. Lacepede (1802), based on specimen collected from Carolina (Type locality) re-described this species and named as *Centronotus gardenii* Lacepede, 1802; who also classified the species under Order Perciformes, Family Pholidae and Genus *Centronotus* Bloch& Schneider, 1801. Mitchill (1815) described it as *Centronotus spinosus*. Type locality of specimen was New York. He agreed to the classification followed by Lacepede (1802).

Kaup (1826) described Cobia as *Rachycentron typus* and classified it under Order Perciformes, Family Rachycentridae and Genus *Rachycentron* Kaup, 1826. The generic name and classification followed by him got acceptance, however, species name was not considered as valid, but it was considered as synonym. Later, Cuvier and Valenciennes (1829) classified Cobia under Order Perciformes, Family Rachycentridae and Genus *Elecate* Cuvier and Valenciennes, 1829 and species name *Elacate motta* Cuvier and Valenciennes, 1829**.**

Cuvier and Valenciennes(1831) described so many species under genus *Elacate* based on the collection from different part of the world such as *Elacate atlantica* Cuvier and Valenciennes, 1831(type specimens from Brazil), *Elacate bivittata* Cuvier and Valenciennes, 1831 (type specimen from Molucca), *Elacate malabarica* Cuvier and Valenciennes, 1831(type specimen from Malabar, India), *Elacate motta* Cuvier and Valenciennes, 1831 (type specimen from Orixa) and *Elacate pondiceriana* Cuvier and Valenciennes, 1831(type specimen from Pondicherry, India). They followed classification adopted by Cuvier and Valenciennes (1829)**.** All these nomenclatures were subsequently considered as synonyms of *Rachycentron canadum* (Linnaeus, 1766).

Swainson (1839) redescribed the species and named as *Meladerma nigerrima* Swainson, 1839. He classified the species under Order Perciformes, Family Rachycentridae and Genus *Meladerma* Swainson, 1839. Later, the authors modified this nomenclature as *Naucrates niger* Swainson, 1839 and placed under order Perciformes, Family Carangidae, and Genus *Naucrates* Rafinsque, 1810. DeKay (1842) based on type specimen from New York, renamed the species and described as *Elacatc canada* DeKay, 1842 under Order Perciformes, Family Rachycentridae and Genus *Elecate* Cuvier and Valenciennes, 1829**.**

Gosse (1851), based on type specimen from Jamaica, described this species as *Elacate jalcipinnis* Gosse, 1851 and placed under Family Rachycentridae. Gronow (1854), doesn’t agrees with the above classification and renamed it as *Thynnus canadensis* Gronow, 1854. He classified the species under Order Perciformes, Family Scombridae and Genus *Thynnus* Cuvier, 1816.

Gunther (1860) described this species as *Elacate nigra* Gunther, 1860 and placed the species under the family Rachycentridae. Jordan and Evermann(1896) described it as *Rachycentron canadus* Jordan and Evermann, 1896 and *Rachycentron pondicerrianum* Jordan, 1905 and kept it in the Order Perciformes, Family Rachycentridae and Genus *Rachycentron* Kaup, 1826.

Species name *Rachycentron canadum* (Linnaeus, 1766) is the only valid name and is a monotypic Family and Genus under Rachycentridae and *Rachycentron* respectively. Hitherto no sub species is reported from anywhere and specimens collected from Indian waters fully confirms with the diagnostic character described by the earlier workers.

3.3.6. Morphometry

93 specimens were subjected to morphometric measurements and measurements in centimeters (cm.) were expressed as percentage of total length (Measurements from the head region were expressed in percentage of head length). Ranges of percentage and its mean value and meristic counts in numbers are presented in Table 2. As furnished in the Table 2, body depth is equal to 12.5% of total length. Cobia is having very long dorsal fin and its anal fin originate behind dorsal origin.

Pectorals are long and always found in horizontal position. Head is flattened and broad, which occupies almost one fifth of the body. Eye is positioned almost in the center of the head. Inter-orbital space occupies almost 50% of the head. Body elongated and sub cylindrical with broad and depressed head. Detached dorsal spines in grooves and pointed mouth helps the fish to move faster in water and to gain cruise speed.

Broad head and large mouth provide more buccal cavity. Fine villiform teeth in jaws, tongue and palatine assist the fish to hold prey. Cobia has seven branchiostegal rays and is with pseudo branchi. First gill arch contains eleven gillrakers, three on upper arm and eight on lover arm (Plate.1.B.) Gillrakers are steep; distance between gillrakers was more at center and reduces to both sides. These features help the fish to sieve effectively and retain nektonic prey by allowing the engulfed water escape easily. Due to the absence of cutting and grinding teeth, prey engulfed by the fish is usually found intact in the stomach for quite some time.

First dorsal fin with 7-9 spines, second dorsal fin with 31-34 rays, anal with 2 spines (embedded in the body) and 24-26 rays; pelvic with 1 spine and 5 rays; pectorals with 20 –21 rays and caudal rays 17-22 are the fin counts of this species.

Aspect ratio of caudal fin of Cobia was 1.33.The same available in www. fishbase. org in respect of this species is 0.99, which is less than the result of present study. Normally, demersal fishes have low aspect ratio while in the case of large pelagics like tuna it is high (Christensen and Pauly, 1992). Cobia, which is a pelagic fish, occupies thought out the water column and the high aspect ratio of caudal fin obtained during the present study justifies its pelagic mode of life.

Table 2. Body proportions of *Rachycentron canadum* as percentage of total length and head length

S.No	Character	Range (in percentage)	Mean (in percentage)
1	Fork length	90.0-95.4	93.52
2	Standard length	80.3-84.4	81.92
3	Pre dorsal fin length	18.8-22.1	20.66
4	Pre pectoral fin length	20.7-21.7	21.17
5	Pre pelvic fin length	20.1-23.3	21.84
6	Pre anal fin length	37.7-47.6	45.44
7	Length of Dorsal fin base	35.5-38	36.7
8	Length of Anal fin base	26.6-29.1	27.88
9	Height of soft dorsal fin	9.1-13	11.68
10	Pectoral fin length	14.3-16.3	15.26
11	Pelvic fin length	7.0-9.1	7.59
12	Anal fin height	9-10.3	9.61
13	Head length	18.8-21.4	19.92
14	Body depth	7.4-14.9	12.48
15	Caudal peduncle length	4.9-6.4	5.51
In Head length			
1	Eye diameter	11.7-17.7	13.34
2	Pre orbital length	31-40	36.06
3	Post orbital length	45-53.3	49.15
4	Inter orbital length	43.8-53.3	48.74

3.3.7. Osteological features

In order to understand the evolutionary position, interrelationship and systematics of the species, an attempt has been made to study ostelogical characters of Cobia. Skull, appendicular and axial skeletons of the specimen were disarticulated, examined and presented in the form of figures. Results were compared with the osteological characters of members of Family Coryphaenidae and Family Echeneidae (O'Toole, 2002).

3.3.7. A. Neurocranium

Major features of neurocranium of Cobia **(**Ventral and dorsal view **(**Fig.1), Posterior view (Fig.2) and Lateral view (Fig.3) are as follows:

1. Cranium somewhat depressed
2. Medium sized supraoccipital extending from mid orbit to the exoccipitals of the cranium
3. Supraoccipital crest absent
4. Parietal pointed medially with three sides
5. Frontal width is almost equal to length and without any crest
6. Small and rhomboid ethmoid, extended anteriorly
7. Vomer is on ventral side of ethmoid
8. Sphenotic is square shaped and is with a lateral projection
9. Parasphenoid process of the vomer pointed.

Cranium of *Rachycentron* and Echeneids is somewhat depressed and without any supra occipital crest, but in the case of *Coryphaena* cranium is deep and have a supra occipital crest. Cranium of Echeneids is more depressed than *Rachycentron*. Parietal bone of *Rachycentron* has three sides, but *Coryphaena* and some members of Echeneids have four-sided parietal bone.

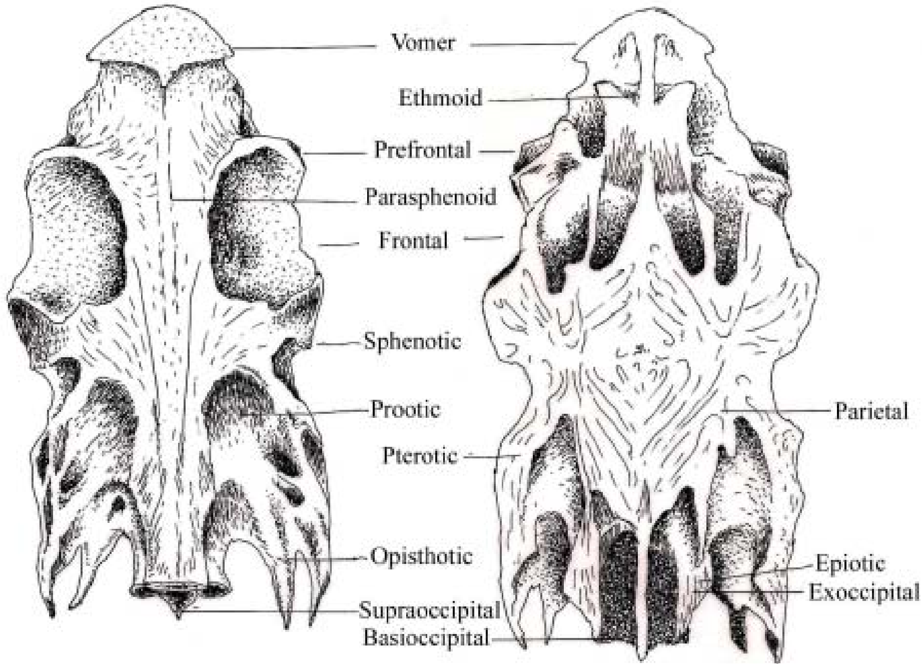

Fig.1. Neurocranium of Cobia – Ventral and dorsal view

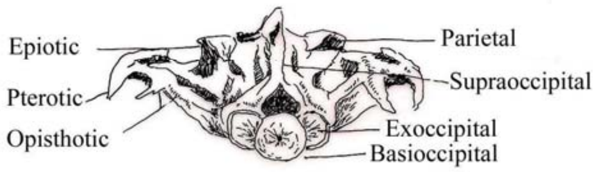

Fig.2. Neurocranium of Cobia – Posterior view

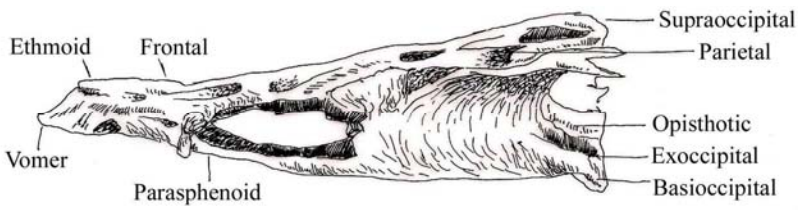

Fig.3. Neurocranium of Cobia – Lateral view

Ethmoid of *Rachycentron* and *Coryphaena* are small and rhomboid in shape, but the same is oval in shape in Echeneids. Ethmoid extended anteriorly in *Rachycentron* but these anterior extension is absent in Echeneids. Vomer of *Rachycentron* and *Coryphaena* are ventral to ethmoid, but vomer is parallel to the ethmoid in the case of Echeneids. Sphenotic of *Rachycentron* is square shaped and with a lateral projection, but *Coryphaena* have square shaped sphenotic without any leteral projection. Echeneids have varying size of square to rectangular shaped sphenotics in their members. Parasphenoid process of the vomer in *Rachycentron* and *Coryphaena* are pointed, but is forked in the case of Echeneids.

3.3.7 .B. Opercle bones

Major features of opercle bones **(**Fig.4) are as follows:

1. Posterior margin of the opercle with a notch on upper side
2. Opercle length almost equal to width
3. Dorsal margin of the opercle straight
4. Dorsally oriented anterior spur on the subopercle is small and reaches only up to midway point of opercle and hyomandibular articulation
5. Interopercle small.

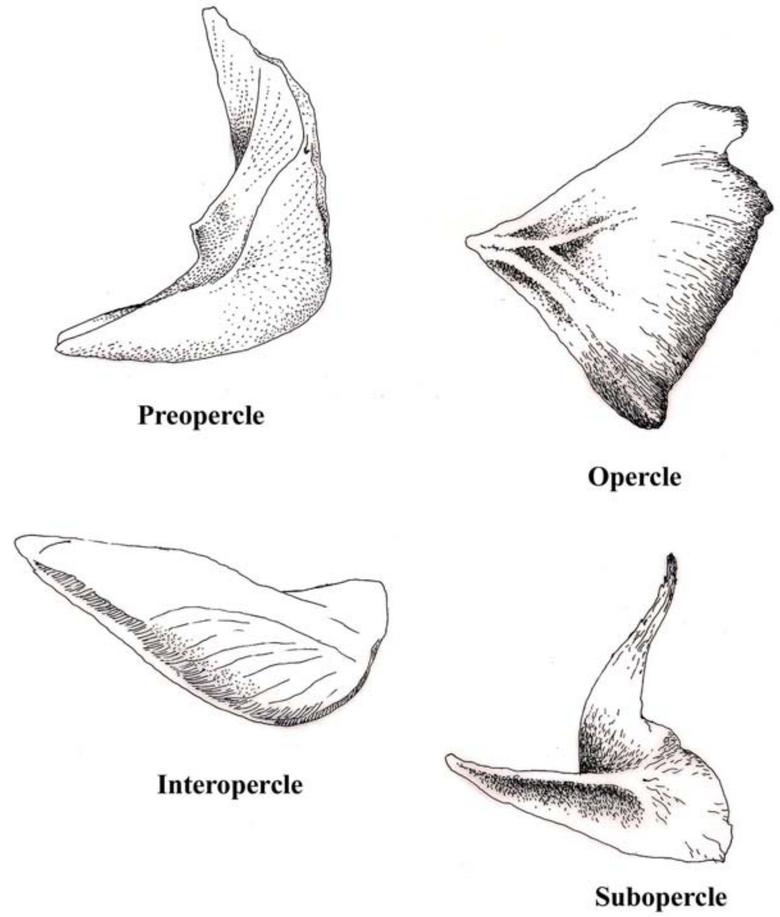

Fig.4. Opercle bones of Cobia

Opercle length of *Rachycentron* and Echeneids is equal to width while *Coryphaena* have a deep opercle. Notch present on the posterior margin of opercles of *Rachycentron* and *Coryphaena* is absent in the case of Echeneids. Opercle ridges are present in the case of Echeneids. The same is absent both in the cases of *Rachycentron* and *Coryphaena*. Size of the dorsally oriented anterior spur on the subopercle of *Rachycentron* and some members of Echeneids are small and extending midway to the point of articulation between opercle and hyomandibular. *Coryphaena* have large dorsally oriented anterior spur on the subopercle. Interopercle of *Rachycentron* and Echeneids is small, but *Coryphaena* have comparatively large inter opercle.

3.3.7. C. Anterior facial bones

Major features of anterior facial bones **(**Fig.5) are as follows:

1. Palatine teeth present
2. Short and wide hyomandibular
3. Metapterygoid deeper than symplectic
4. Endopterygoid present and Ectopterygoid with posterior projecting process
5. Metapterygoid overlap with the posterior process of ectopterygoid
6. Supramaxilla absent
7. Anterior groove on maxilla
8. Small canine teeth present on the premaxilla
9. Ventral process of the dentary slightly shorter than the dorsal process
10. Several rows of slightly recurved canines of equal size present on the dentary
11. Notch on the dorsal margin of lachrymal bone.

Palatine teeth are present in the case of *Rachycentron* and *Coryphaena* but are absent in some members of Echenids. Hyomandibular of *Rachycentron* and Echenids is short and wide, but they are deep and slender in the case of *Coryphaena*. Metapterygoid is deeper than symplectic in the case of *Rachycentron* and *Coryphaena* but are of medium size in some of Echenids.

Endopterygoid is absent in some of Echeneids, while the same is present in both *Rachycentron* and *Coryphaena*.

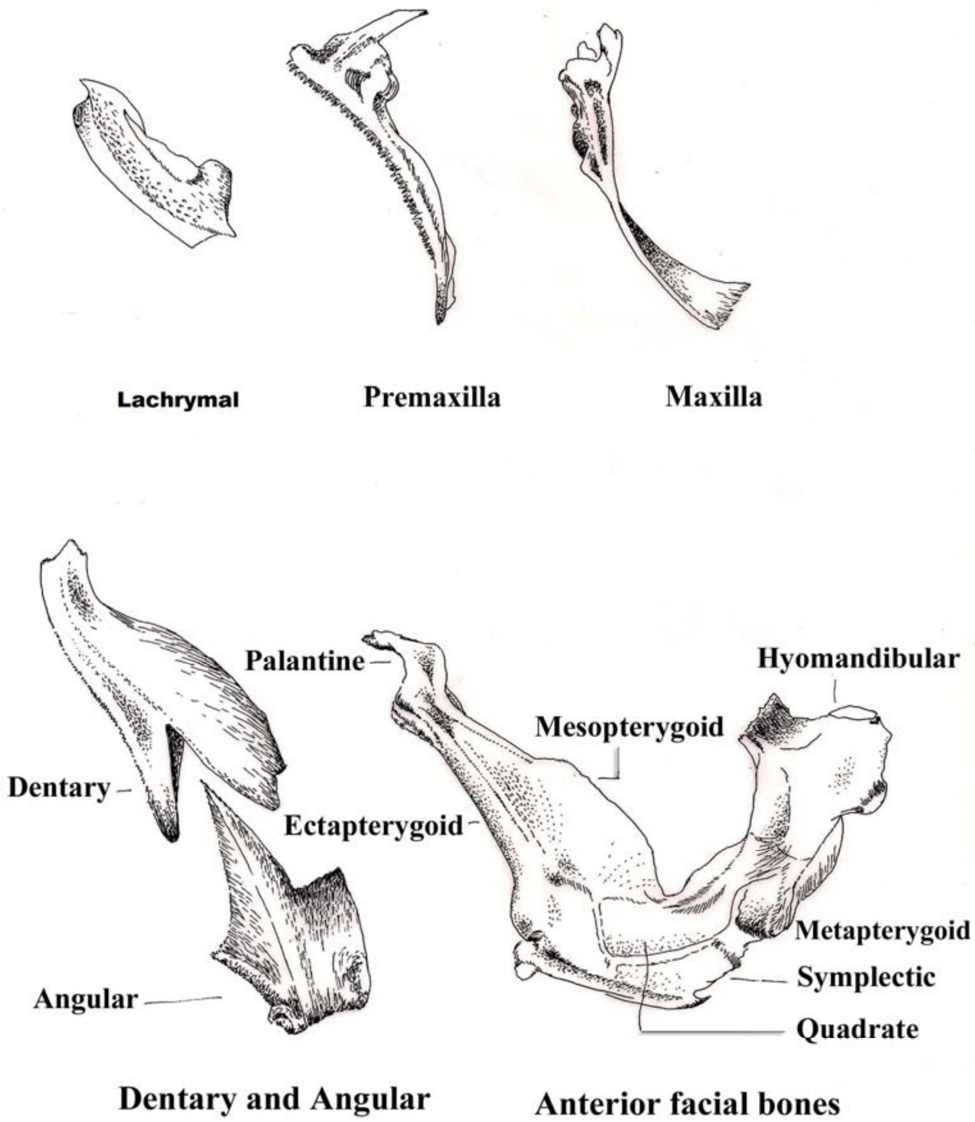

Fig. 5. Anterior facial bones of Cobia

Metapterygoid of *Rachycentron* and *Coryphaena* overlap with the posterior process of ectopterygoid, but Echenids have long anterior process which insert in to a shelf produced by the ectopterygoid. Supramaxilla is absent in *Rachycentron* and Echenids, but present in the case of Coryphaena. Maxilla of *Rachycentron* and *Coryphaena* are with an anterior groove but same is absent in the case of Echeneids.

Small canine teeth present on the premaxilla of *Rachycentron* and *Coryphaena*, while Echeneids have both canine and comb like teeth on the pre maxilla. Ventral process of the dentary of *Rachycentron* and *Coryphaena* are slightly shorter than the dorsal process, but in the case of Echeneids, ventral process of dentary is very short. Several rows of slightly recurved canines of equal size are present on the dentary of *Rachycentron* and *Coryphaena*, but canines present on the dentary of the members of Echeneids are of varying sizes. Deep notch present on the dorsal margin of lachrymal bone of *Rachycentron* and Echeneids is absent on lachrymal bone of *Coryphaena*.

3.3.7. D. Hyoid bones

Major features of hyoid bones **(**Fig.6) are follows:

1. Seven branchiostegal present,

2. Four branchiostegal inserted on ceratohyal and three are on epihyal.

3. Interhyal is long and in rectangular shape

4. Urohyal with longer peg for articulation, projecting anteriorly

5. Urohyal expanded laterally forming wings with posterior branch.

6. Teeth present on basihyal

7. Lower pharyngeal tooth plate well developed

8. Epibranchial 1 is thin and rodlike

9. Epibranchial 2 is wide anteriorly.

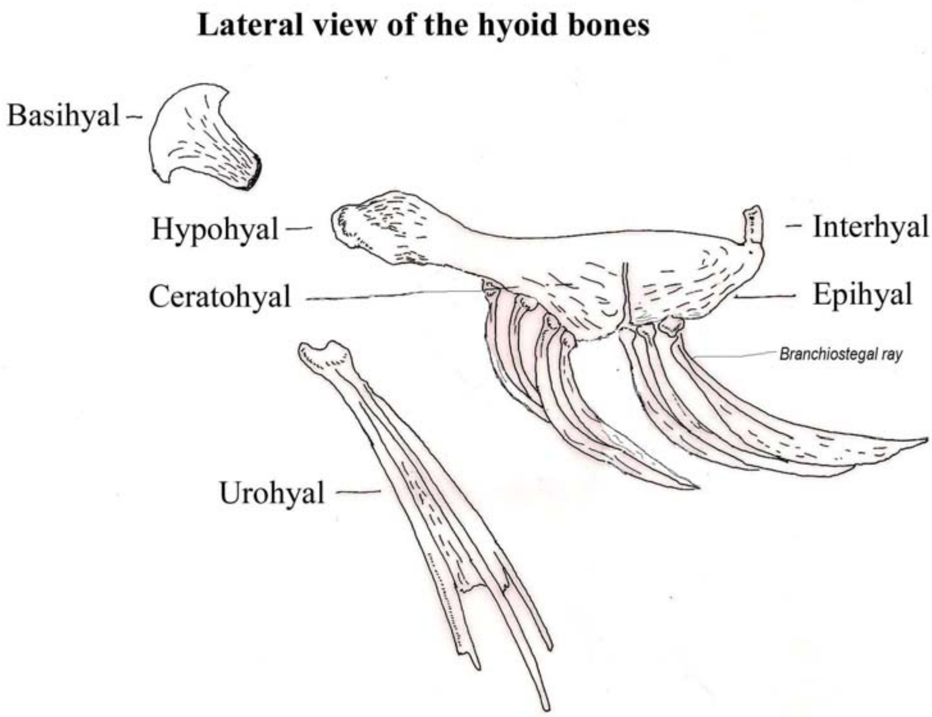

Fig.6. Lateral view of hyoid bones of Cobia

Urohyal of *Rachycentron* and *Coryphaena* is with longer peg for articulation, but Echeneids have smaller peg for articulation. Urohyal of *Rachycentron* and Echeneids is expanded laterally forming wings with posterior branch, but in the case of *Coryphaena* only ventral portion is expanded to form thin process.

Basihyal posterior end is narrow and rounded in *Coryphaena*, but same is rounded in shape with slight notches in *Rachycentron* and Echeneids. Teeth present on basihyal of *Coryphaena, Rachycentron* and in some members of Echeneids. Lower pharyngeal tooth plate is poorly developed in *Coryphaena*, but is well developed in *Rachycentron* and Echeneids. Epibranchial 1 is thin and rode like in *Coryphaena* and *Rachycentron,* but is short in Echeneids.

3.3.7. E. Pectoral and Pelvic girdle.

Major features of pectoral and pelvic girdle **(**Fig.7) are as follows:

1. Postcleithrum present
2. Supracleithrum rectangular in shape
3. Post temporal median process longer and broader than lateral process
4. Articulation of caracoid to the scapula is through cartilage
5. Posterior process of the pelvic girdle short, shorter than its width
6. Pelvic girdle long, almost equal to four times of its width
7. Dorsal wing of the pelvic girdle flat with slight dorsal expansion.

Postcleithrum is absent in the members of Echeneids**,** but is present in *Coryphaena* and *Rachycentron*. Shape of Supra cleithrum is rectangular in *Coryphaena* and *Rachycentron* but has gradually reduced in Echeneids. Median process of post temporal longer and broader than lateral process in *Coryphaena* and *Rachycentron,* but is thinner in the case of Echeneids.

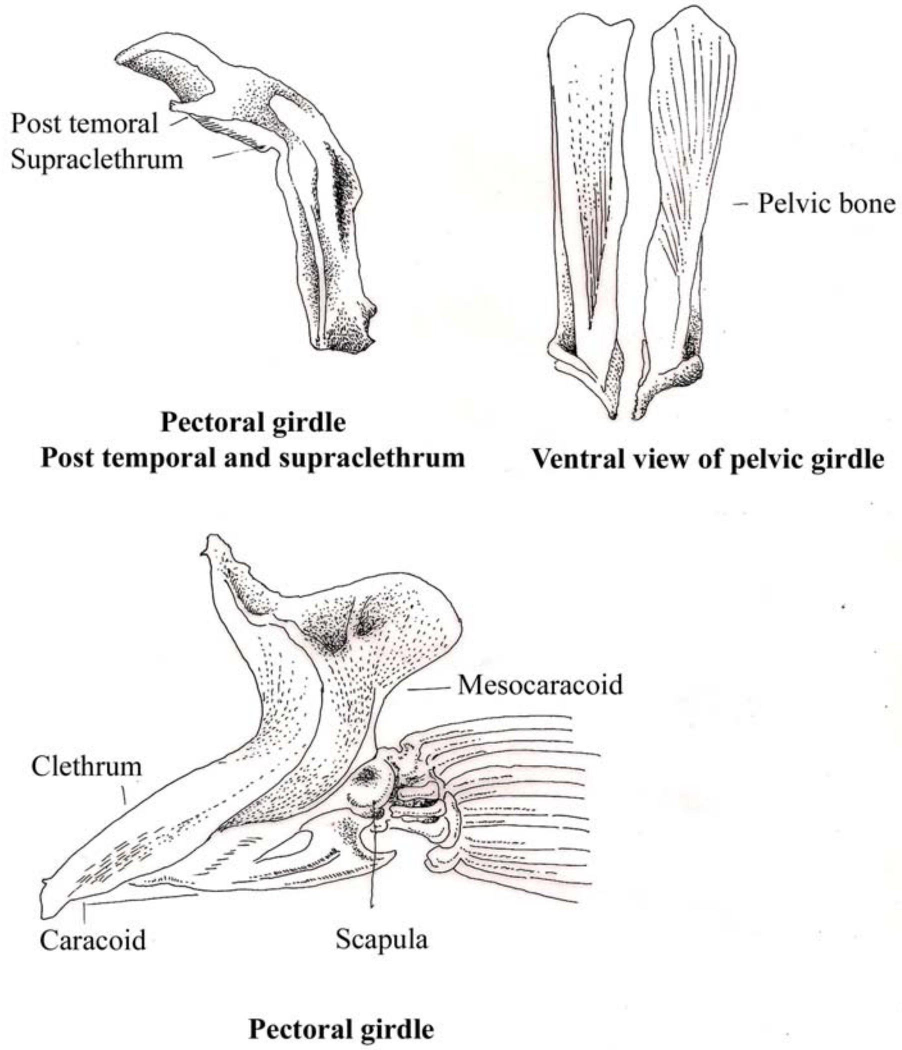

Fig.7. Pectoral and pelvic girdle of Cobia

Articulation of caracoid to the scapula is through cartilage in *Coryphaena* and *Rachycentron* and in some members of Echeneids, but some members of Echeneids have sutured articulation. Posterior process of the pelvic girdle short in *Rachycentron* and Echeneids, but longer in *Coryphaena*. *Coryphaena* and *Rachycentron* have long pelvic girdle, but this is shorter in Echeneids. Dorsal wing of the pelvic girdle is elevated in Echeneids, but is flat with slight dorsal expansion in *Coryphaena* and *Rachycentron.*

3.3.7. F. Dorsal Pterygophores, anal spine and vertebrae

Major features of dorsal pterygophore, anal spine and vertebrae are as follows:

1. Seven to eight thick and stout dorsal spines and two anal spines
2. Slight expansion on the proximal pterygophore of first dorsal
3. Posterior portion of the basal is laterally expanded in all pterygophores in the spiny portion of the dorsal fin
4. Distal pterygophore laterally expanded throughout the spiny portion of dorsal fin
5. Neural spine present in first three vertebrae
6. Parapophysis extended laterally and ventrally.

First proximal pterygophore of first dorsal greatly expanded in the case of Echeneids as a part of modification of its first dorsal to sucker, but is slightly expanded in *Coryphaena* and *Rachycentron*. Posterior portion of the basal and distal pterygophores laterally expanded in the spiny dorsal portion of *Rachycentron* , but the center section of the medial pterygophore is rounded and forming broad wings in Echeneids to suit to the modification of its first dorsal to sucker. These modification are completely absent in *Coryphaena* as there is no spiny portion of dorsal fin in them.

First vertebrae neural arch is not fused to the centrum of *Coryphaena* and *Rachycentron*, but is fused to centrum in the case of Echeneids. Neural spine is present in first three vertebrae of *Coryphaena* and *Rachycentron,* but is absent in the case of Echeneids. Parapophysis is extended laterally and ventrally in the case of *Coryphaena* and *Rachycentron,* but this expansion is more significant in the case of members of Echeneids.

3.3.7. G. Caudal skeleton

Major features of caudal skeleton are as follows:

1. Three thin rod-like epurals over the ural centrum is present
2. Haemal spine is present on preural centrum 3
3. Small neural spine is present on preural centrum 2
4. Neural spine on preural centrum 3 is long.

Three thin rod-like epurals over the ural centrum are present in *Rachycentron,* but *Coryphaena* and Echeneids have one and two epurals respectively. Haemal spine present on the preural centrum 3 of *Rachycentron* and *Coryphaena* and is absent in members of Echeneids. Small neural spine is present on the preural centrum 2 and a long neural spine is present on the preural centrum 3 of *Rachycentron,* but neural spine on the preural centrum 3 of Echeneids is small.

3.3.8. Interrelationship of the Species

Johnson (1984, 1993) and Smith- Vaniz(1984) recognized Nematistiidae, Carangidae, Coryphaenidae, Rachycentridae and Echeneidae as a distinct suborder: Carangoidei. Anterior extension of the anterior nasal canal surrounded by two tubular ossifications (Freichofer, 1978) and presence of small cycloid scales are the synapomorphy of the group. Within the Carangoidei, Coryphaenidae, Rachycentridae and Echeneidae have been grouped as SuperFamily Echeneoidea (Johnson, 1993). Absence of pre dorsal bones, anterior shifting of the first dorsal fin pterygophore, presence of several anal fin pterygophores anterior to the first hemal spine, absence of beryciform foremen in the ceratohyal, tubular ossifications surrounding both pre-nasal canal units and elongated shaped larvae with late dorsal fin completion are the common characters supported the above groupings (Johnson, 1984; Smith- Vaniz, 1984). Within this group, Regan (1912) suggested the possibility of a Rachycentridae-Echeneidae relationship based on superficial external appearances and similar osteology. Gudger (1926) also pointed out the remarkable resemblance between the young of certain Echeneids and the young of *Rachycentron*. Johnson (1984) contradicts with this and suggested a Coryphaenidae-Rachycentridae clad based on larval characters.

Morphological, meristic and osteological analysis of *Rachycentron* and comparative study with the osteological characters mentioned by O'Toole (2002) supports the view of Regan (1912). Comparative study of the osteological characters of *Rachycentron, Coryphaenae* and Echeneids points out towards the evolutionary changes taken place in the members of this group. Shape and size of neurocranium bones strongly support the view that *Rachycentron* is evoled from *Coryphaenae* and members of Echaeneid followed *Rachycentron*.

In the case of *Coryphaena,* cranium is deep and have a supra occipital crest, but both *Rachycentron* and Echeneids have depressed cranium without any supra occipital crust. Supra occipital crust of *Coryphaena* may be lost in the case of *Rachycentron* and subsequently in Echeineids. Modification of first dorsal in to detached spines in *Rachycentron* and then to sucker in Echeineids may be the evolutionary changes taken place in this group. Changes in shape of cranium bones and pterygophores support this view.

There are many osteological characters common to *Rachycentron and* Coryphaena, but closeness is more evident in the case of members of Echeineids and *Rachycentron*. Some members of Echeinids show more closeness to *Rachycentron* characters, but some of these characters are further modified in latest derived species in the Family Echeneidae. These findings also support the view of close relation of Echeneids and *Rachycentron.* Evaluation of the behavioral characters further supports the above findings. Closeness to the floating objects and other organisms found in *Coryphaena* may be changed to following behavior in *Rachycentron* and later to hitchhiking behavior in Echeneids (O'Toole, 2002). Morphological and osteological features were also found suitably modified to suit these behavioral changes.

Morphological, meristic and osteological analysis of the specimens collected from different coastal line of India confirms the occurrence of Cobia throughout Indian waters. This fish does not have any relative or similar species and is monotypic species belonging to the family Rachycentridae.

3.3.9. Re description of the Species

In depth analysis of morphological, meristic and osteological characters of *Rachycentron canadum* occurring in Indian waters calls for the need of redescription of the species in view of the fact that available description at present are mainly based on morphological characters. Very less attention has been paid to study the osteological features of the species. Inclusion of osteological features in the description will completely wipe out chances of misidentification. New description thus made by including osteological features of the species along with the morphological characters explained by traditional taxonomist is as follows:

The body is elongate and torpedo shaped. Head is long, broad and depressed with a pointed mouth. Cranium somewhat depressed, supraoccipital is of medium size and with out any crest. Parietal is a three-sided bone pointed medially and ethmoid is small and rhomboid in shape. Vomer is ventral to ethmoid and sphenotic is square shaped with a lateral projection.

Snout is broad and lower jaw projects slightly beyond the upper jaw. Pre opercle and opercle are finely serrated marginally. A notch is present on the posterior margin of the opercle and its length is equal to width. Dorsal margin of opercle is straight and without any ridge. Inter opercle small and is visible below the pre opercle.

Maxillary reaching anterior margin of eye, pre maxillaries are not protractile and supramaxilla is absent. Small canine teeth present on the premaxilla. Ventral process of the dentary is slightly shorter than the dorsal process. Dentary is with several rows of slightly recurved canines of equal size. Lachrymal bone has a deep notch on its dorsal margin. Eyes are small and are without adipose eyelid. Villiform teeth in bands present in jaws, palatine and on tongue. Short and wide hyomandibular; Metapterygoid is deeper than symplectic and overlap with the posterior process of ectopterygoid. Ectopterygoid is with posteriorly projecting process, and endopterygoid is present.

Seven branchiostegal rays with pseudo branchi and the first gill arch is with eleven gillrakers, eight on lover lobe (eighth one rudimentary) and three on upper lobe. Steep gillrakers are spaced between varying distances, with maximum at center. First and second branchiostegal rays are inserted into a notch on the ventral margin of the ceratohyal. Long and rectangular shaped interhyal is almost half the depth of ceratohyal. Urohyal is with longer peg for articulation projecting anteriorly and expanded laterally forming wings which branch posteriorly. Basihyal anterior edge is round shaped and posterior end is with slight notches. Teeth present on basihyal and lower pharyngeal tooth plate is well developed and almost in contact with enlarged ceratobranchial. Epibranchial 1 is thin and rodlike, but epibranchial 2 is wide anteriorly.

Pectoral fins are pointed, becoming more falcate with age and have 21-22 rays**.** Postcleithrum is present and supracleithrum is in rectangular shape. Post temporal median process is longer and broader than lateral process. Articulation of caracoid to the scapula is through cartilage. Pelvic fins are large and have one spine and five rays. Pelvic girdle is long and almost equal to four times of its width. Posterior process of the pelvic girdle is shorter than its width and the dorsal wing is flat with slight dorsal expansion.

First dorsal fin is with 7-9 (generally 8) independent, thick, stout and strong isolated spines. These sharp and stout spines are depressed in to a groove and are not connected by any membrane. Second dorsal fin long and anterior rays are somewhat elevated in adults and are with 28-33 rays. First proximal pterygophore of the first dorsal slightly expanded than other pterygophores. Posterior portion of the basal is laterally expanded in all pterygophores in the spiny portion of the dorsal fin. Distal pterygophore laterally expanded throughout the spiny portion of dorsal fin. Anal fin similar to dorsal fin in shape but originate behind the second dorsal origin; anal fin is with 2 spines and 23-27 rays.

24-28 numbers of vertebrae are present. First three vertebrae are with neural spine and parapophysis is extended laterally and ventrally. Body is smooth with small scales are embedded on thick skin. Lateral line slightly wavy anteriorly. They lack air bladders and pyloric appendages are branched. Caudal fin is rounded in young with much prolonged central rays; lunate in adults and upper lobe is longer than lower. Three thin rod-like epurals over the ural centrum of caudal skeleton is present. Preural centrum 3 is with haemal and have long neural spine. Small neural spine present on preural centrum 2.

Colour - Dark-brown above, a paler brown on sides and below; a black lateral band, as wide as the eye, extending from snout to base of caudal, bordered above and below by paler bands; below this is a narrower dark band. Black lateral band very pronounced in the juvenile, but tends to become obscured in the adult. Fins mostly all deep or dusky brown; anal and pelvics pale with gray or dusky markings. Ventral surface is grayish white to silvery.

4. **FOOD AND FEEDING**

4.1. INTRODUCTION

Food is the basis to all function of an individual fish as well as the population. Like any other organism fish also depends on energy received from its food to perform biological processes such as growth, development, reproduction and other metabolic activities. Fish devotes large portion of its energy for searching its food. Knowledge on the food, feeding habits and trophic inter-relationships of fishes is essential to understand the life history of fish including growth, breeding and migration (Bal and Rao, 1984). This will also help to understand the predicted changes on ecosystem due to natural or anthropogenic interventions.

Food and feeding ecology of fish species was an interesting subject for the researchers across the world. Some of the outstanding works in this field are those of Hynes (1950), Maclean (1971), Hyslop (1980), Gunn and Milward (1985), Motta (1988, 1995), Hyndes *et al.* (1997), Shaheen *et al.* (2001) and Hajisamae *et al.* (2003, 2004, 2006). Substantial works on the food and feeding habits of commercially important fishes from Indian waters were those of Chacko (1949), George (1953), Qasim (1972), Gowda *et al*.(1988), Chandru *et al*.(1988), Reddy (1991), Serajuddin and Mustafa(1994), Serajuddin *et al.* (1998), Rao and Rao(2002) and Serajuddin and Ali(2005).

Food and feeding habits of Cobia occurring in Aransas Bay provided by Miles (1949) shared preliminary information on food and feeding behavior of

Cobia. Other studies on food and feeding habits of Cobia are that of Knapp (1949, 1951), Joseph *et al*. (1964), Richards (1967), Takamatsu (1967), Sonnier *et al*. (1976), Darracott (1977), Smith and Merriner (1982),Randall (1985), Dity and Shaw (1992), Smith (1995), Franks *et al.* (1996), Meyer and Franks (1996), Somvanshi *et al*. (2000), Arendt *et al*. (2001) and Chou *et al*. (2004).

Except for some preliminary studies by Somvanshi *et al*. (2000), knowledge on food and feeding behavior of Cobia occurring in Indian water is scanty. To understand the life history, growth, and fishery and to propose exploitation strategy, detailed information on its food preferences, feeding behavior, trophic relationship, etc, are highly essential. Hence, an attempt was made here to study the food and feeding behavior of Cobia inhabiting along the north west coast of Indian EEZ.

4.2. MATERIALS AND METHODS

Samples of Cobia, *Rachycentron canadum* collected from the vessel *M.V. Matsya Nireekshani*, belonging to the Fishery Survey of India, Mumbai and samples from landing centers viz. Sassoon dock and New ferry wharf at Mumbai for a period of two years from January 2008 to December 2009 were used for this study. The length, weight, sex, stomach fullness of fish, and length of alimentary canal were recorded before dissecting the stomach (Philip, 1994). The stomachs were visually classified as gorged, full, ¾ full, ½ full, ¼ full, traces and empty based on the degree of fullness and the amount of food contained in them(Philip,1994). The stomachs were dissected out following standard procedures and the food (Plate.1.C) was preserved in 5% formaldehyde for further study. Most of the stomachs were analysed in fresh condition. Three hundred and eighteen guts were examined for the study, which includes 158 male, 121female and 39 juveniles (sex not identified).

Feeding behavior of fishes depends on the ecosystem, food availability and prey-predator relationship. Researchers followed different methods to study food and feeding habits of fishes. Each method has its own advantages and disadvantages, and suitability of these methods differs depends on fish, prey, and habitat. Hyslop(1980) opined that, in order to collect maximum information one should follow both amount and bulkiness of the gut content. As this being a primary study on food and feeding habits of Cobia, number, volume and weight of all gut contents were recorded. Gut contents were identified up to group/genus/species level and grouped in to eleven categories namely, squid, cuttlefish, octopus, other molluscs, crab, penaeid shrimp, non penaeid shrimp, squilla, fish, digested matter and others.

The methods employed for the quantitative and qualitative analysis of stomach contents do not give a complete picture of dietary importance when they are used singly. However, when used in combination, such as numerical or frequency of occurrence and volumetric or gravimetric, better results were achieved (Srivastava, 1999).Index of preponderance suggested by Natarajan and Jhingran (1961) is a combination of numeric/occurrence and volumetric/

gravimetric methods. Hence, index of preponderance (Natarajan and Jhingran, 1961) calculated by using the formula:

Index of preponderance = (Vi Oi/ Σ Vi Oi) x 100………………(2)

Where,

Vi = Percentage of volume of i^{th} food

Oi = percentage of occurrence of i^{th} food

Month wise Index of preponderance values were calculated separately for male, female, pooled and on length group basis. Lengthwise, fishes were grouped in to 10 cm length classes and calculated the value for each class and then they were further grouped in to juveniles (fishes below size at maturity) and adults to understand the food preference in these life stages.

The average intensity of feeding was evaluated by points method (Pillai, 1952). Points were assigned as 10, 9, 7.5, 5.0, 2.5, 1.0 and 0 for gorged, full, ¾ full, ½ full, ¼ full, trace and empty stomachs, respectively. Feeding intensity was assessed following two methods ie. Mean Index of Feeding intensity (MIF) and Index of Fullness (IF).Month wise Mean Index of Feeding Intensity (MIF) was calculated by taking the average value of points allocated to the fullness of stomachs of each month's sample(Robotham,1977). Index of fullness (IF) or Degree of satiation (Shorygin, 1952) values was calculated by applying the following formulae:

IF = (w x 10^4)/ W ……………………………………………..(3)

Where,

IF = Index of Fullness

w = weight of the gut content in gram

W = weight of fish in gram

Month wise average values of MIF and IF were assessed separately for male, female, and pooled to understand seasonal variation in feeding intensity and also to assess sex wise variation. Feeding intensity in different length groups were also assessed for understanding the changes in feeding behavior of the fishes in different life stages.

Month wise and lengthwise occurrences of empty stomachs were assessed separately for male, female and pooled data to understand the feeding absenteeism in the fish. The Gastrosomatic Index (GSI) is another method used to estimate the feeding intensity of fish. GSI values (Desai, 1970) were calculated following the changes in the gut weight in relation to body weight by using the following formula:

GSI = (w/W) X 100……………………………….…………….. (4)

Where,

GSI = Gastrosomatic Index

w = Weight of the gut

W = total weight of the fish100

Gastrosomatic index values of male, female and pooled were calculated on month wise and length group basis. Values thus obtained were compared with the relative condition factor values recorded during the month for the particular size group/ sex of fish. The trophic level (TL) of Cobia estimated based on their diet composition and by using the equation:

$$\text{Trophic level (TL)} = 1 + \sum (DCi \times TLi) \qquad (5)$$

Where,

TL = Trophic level of the species

DC= Proportion of prey species i in the gut content of Cobia

TLi is the trophic level of species i.

Trophic levels used are fractional trophic levels (Odum, 1975; Christensen and Pauly, 1992) obtained mainly from *Fish Base* (www.fishbase.org) for fishes (Froese and Pauly, 2011). For invertebrates, the estimates were based largely on Sea around us project (2011) (www.seaaroundus.org) database and the ISSCAAP table of Fish base 2000 (Froes and Pauly, 2000). Trophic level values estimated by Bathal (2005) were also used for calculation. Source of each trophic level values used for estimation are shown against the organism.

4.3. RESULTS

4.3.1. Food composition

Composition of gut contents of male, female and pooled data calculated by following index of preponderance method (Natarajan and Jhingran, 1961) are presented in Fig. 8, Fig.9 & Fig. 10. Fishes dominated among the gut content of males with 53%, followed by crab (28%) and digested matter (9%). Dominance of crab with 33% followed by fishes 31% and squilla 12% were noticed in the gut content of females. Fishes 72%, crabs, 17% squilla 3%, shrimp-non penaeid 1% , shrimp-penaeid 1%, and squid 1%, and digested matter 1% are the major components recorded from the gut of Cobia (pooled data). Octopus, cuttle fish, others and mollusc shells also occurred in the guts of Cobia, but in sparse quantity.

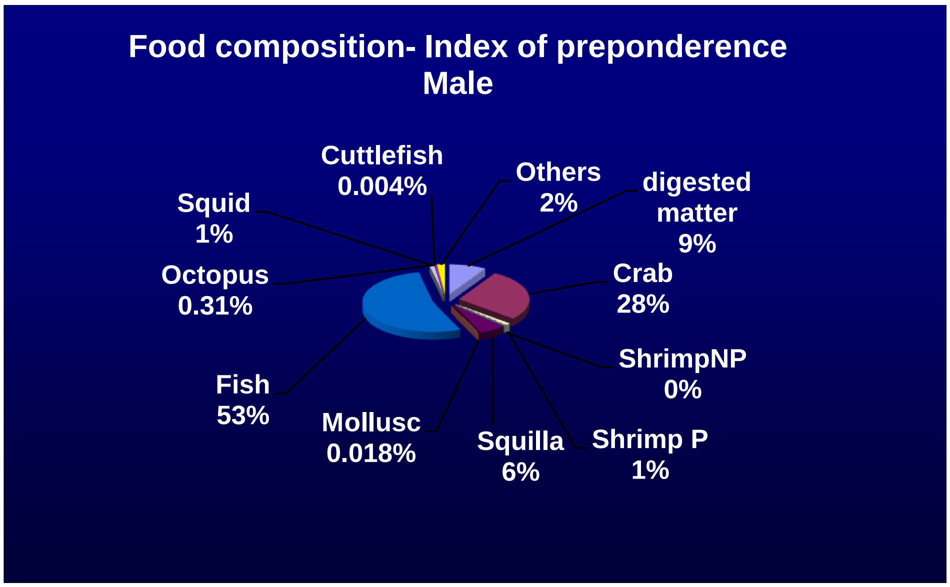

Fig. 8. Composition of gut contents of male *Rachycentron canadum*

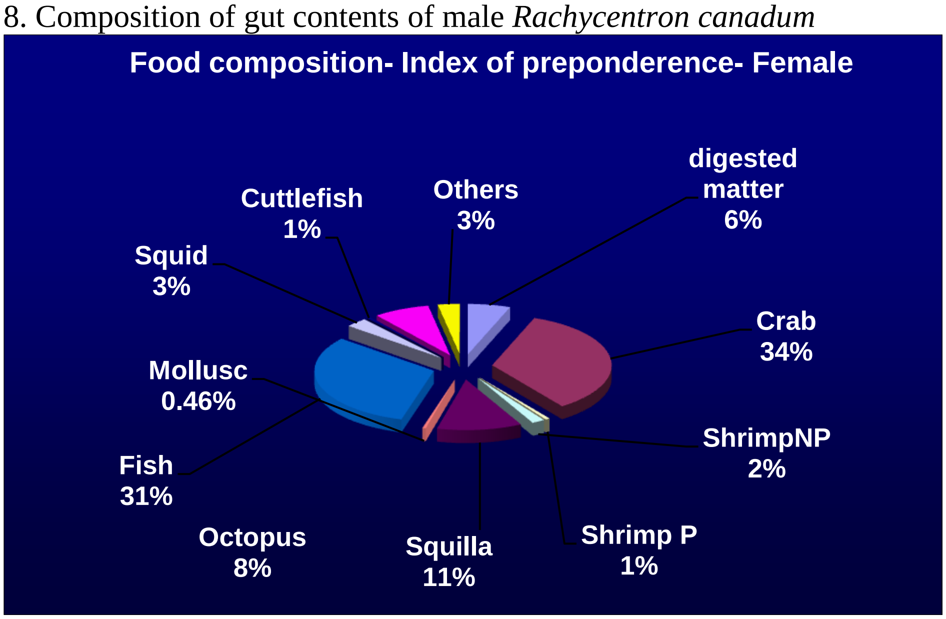

Fig. 9. Composition of gut contentsof female *Rachycentron canadum*

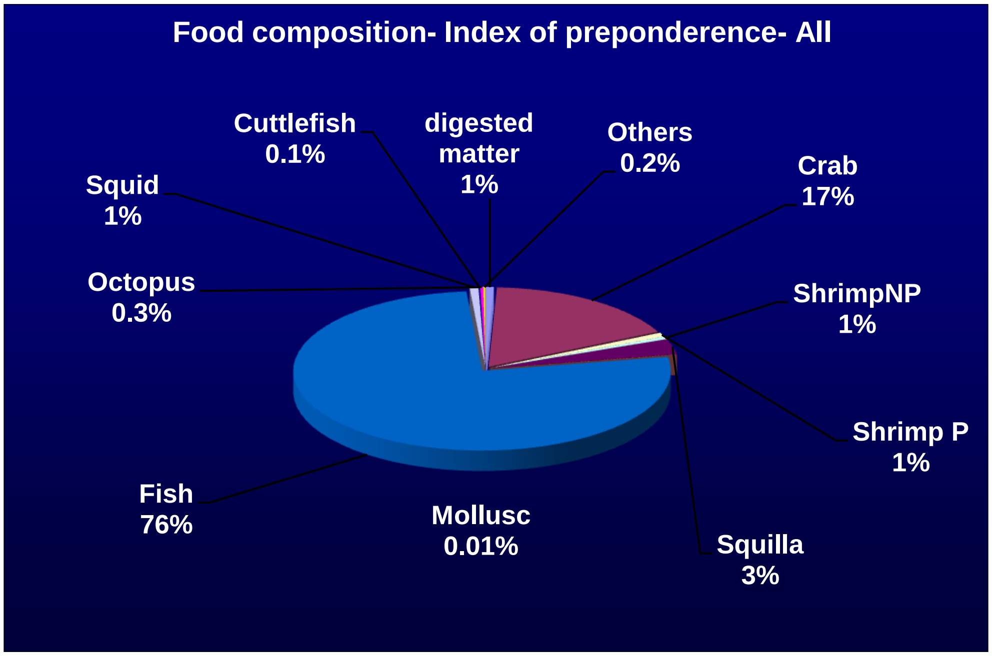

Fig. 10. Composition of gut contents of *Rachycentron canadum*- pooled

4.3.2. Seasonal variation in the food composition

Month wise compositions of food of male are given in Table 3. It could be seen from the Table 3 that fish dominated in the gut contents during February, March, April, May, August and November. During January, June, July October and December crab dominated among the gut contents. During March, crab was completely absent and squilla replaced crab. Similar trend was noticed during August also. Among shrimps, penaeid shrimps dominated in quantity throughout the period. Among molluscs, cuttlefish and octopus were recorded during February and May. In general, Cobia prefers fishes, but dominance of crab in some months especially during monsoon indicates that crabs also can be identified as preferred food.

Table 3. Month wise percentage composition of food of male *Rachycentron canadum* -Index of preponderance value

Month	Fish	Crab	Squilla	Shrimp penaeid	Shrimp non penaeid	Squid	Cuttle fish	Octopus	Other Mollusca	Digested matter	Others
Jan	23.0	69.3	0.00	1.2	0.0	5.6	0.00	0.0	0.0	0.9	0.0
Feb	98.8	1.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.0
Mar	64.4	0.0	33.8	1.3	0.0	0.00	0.0	0.0	0.2	0.31	0.0
Apr	98.6	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.0
May	85.3	6.9	0.0	0.0	0.0	3.0	0.0	3.8	0.1	0.1	0.8
June	23.5	67.8	8.1	0.1	0.0	0.5	0.0	0.0	0.0	0.0	0.0
July	29.2	31.6	19.6	0.4	0.5	0.0	0.0	0.0	0.0	0.0	18.7
Aug	82.5	3.3	10.70	2.3	0.9	0.0	0.0	0.0	0.0	0.0	0.42
Sept	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	100.0	0.00
Oct	48.3	50.1	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Nov	59.4	40.64	0.0	0.0	0.00	0.00	0.0	0.0	0.00	0.0	0.00
Dec	25.1	60.1	2.9	5.8	0.00	3.46	0.0	0.0	0.0	0.8	2.0
Average	53.1	27.6	6.0	1.04	0.12	1.07	0.00	0.32	0.02	8.50	1.83

Results of month wise analysis of composition of food in the guts of female Cobia are shown in Table 4. As shown in the Table 4 fishes dominated among the gut contents during February, May and June. During January, April, September, October and December crab was the dominant food item. Squilla was the dominant food item recorded during August. Octopus was found more during July (53.9%) and squid with 31.05% was the dominant food item during April. Compared to male, dominance of crab among the gut content of female Cobia was noticed during the period under study. However, no specific trend on the seasonal preference towards any food was noticed. In general, one can say that Cobia feeds on variety of food available in their vicinity.

Due to variation in percentage composition in gut content of the male and female Cobia, data of gut contents of male and female Cobia were pooled and the results are furnished in Table. 5. It appears that fishes dominated among the gut content during February, March, April, May, August and October. Crabs were dominated during January, June, September, November and December. Squilla was second item during March and August. Among shrimps, penaeid shrimps were dominated throughout the year except during July. Among cephalopods, squids and octopus dominated during April and July respectively. Occurrence of variety of food items in different proportions during different months indicated that more than preference towards any food, seasonal availability of food item in the habitat is the deciding factor in the feed intake by Cobia. In general index of preponderance values recorded during the period indicated that the species is opportunistic type in the feeding habit.

Table 4. Month wise percentage composition of food of female *Rachycentron canadum* -Index of preponderance value

Month	Fish	Crab	Squilla	Shrimp penaeid	Shrimp non penaeid	Squid	Cuttle fish	Octopus	Other Mollusca	Digested matter	Others
Jan	11.6	82.1	1.6	0.0	0.8	0.0	0.00	0.0	0.1	3.9	0.0
Feb	97.4	1.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	1.2	0.0
Mar	24.7	6.4	55.7	0.1	0.1	0.1	0.1	12.0	1.2	0.0	0.0
Apr	26.4	34.6	4.3	1.0	0.5	31.1	0.0	0.0	0.0	0.0	2.3
May	74.8	0.0	0.0	0.4	0.0	0.0	0.0	25.2	0.0	0.0	0.0
June	72.6	2.8	9.9	2..2	5.7	0.3	6.6	0.0	0.0	0.1	0.0
July	0.0	4.2	0.0	0.0	12.4	4. 5	0.0	53.9	0.0	0.0	24.9
Aug	13.7	12.3	66.6	1.4	1.3	0.0	0.0	0.0	4.3	0.2	0.2
Sept	11.3	80.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.1
Oct	42.4	52.4	0.0	2.3	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Nov	0.00	39.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.8	0.0
Dec	3.8	96.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	31.5	34.3	11.5	0.6	1.7	3.0	0.5	7.5	0.5	5.8	3.0

Table 5. Month wise percentage composition of food of *Rachycentron canadum* (pooled) -Index of preponderance value

Month	Fish	Crab	Squilla	Shrimp penaeid	Shrimp non penaeid	Squid	Cuttle fish	Octopus	Other Mollusca	Digested matter	Others
Jan	16.0	79.8	0.3	0.3	0.2	1.3	0.0	0.0	0.0	2.0	0.0
Feb	98.0	1.2	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.5	0.0
Mar	44.6	11.7	41.6	0.5	0.0	0.0	0.0	1.0	0.4	0.1	0.0
Apr	57.9	20.7	1.9	0.4	0.22	17.9	0.0	0.0	0.0	0.0	1.0
May	86.4	2.4	0.0	0.1	0.0	1.1	0.0	9.7	0.0	0.0	0.3
June	42.3	45.6	9.8	0.5	0.6	0.5	0.7	0.0	0. 0	0.0	0.0
July	16.1	26.6	10.8	0.2	4.7	0.9	0.0	10.9	0.0	0.0	29.8
Aug	60.7	6.5	28.0	2.6	1.3	0.0	0.0	0.0	0.6	0.0	0. 5
Sept	10.3	73.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	7.3
Oct	50.2	476	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Nov	34.2	55.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.1	0.0
Dec	14.8	79.9	1.0	2.0	0.0	1.2	0.0	0.0	0.0	0.3	0.7
Average	44.3	37.6	7.8	0.7	0.6	1.9	0.1	1.8	0.1	1.9	3.3

4.3.3. Variation of food in relation to size groups.

Results of index of preponderance method carried out to understand the variation on food preference of Cobia during their life history stages are presented in Table 6, Fig. 11 & Fig.12. Compositions of gut content of Cobia assessed on length group basis were pooled together as two groups i.e. juveniles and adults. All fishes below the size at maturity were pooled together and categorized under the group juvenile. As furnished in the Table 6 fishes dominated in the gut contents of juvenile and adult. 84% of gut content of adult Cobia was fish, followed by crab (13%), squilla (2%), and Octopus (1%). Almost similar trend was recorded in the case of juveniles. Major components are Fishes (69 %), Crab (21%), Squilla (5%), shrimp penaeid (2%), shrimp non-penaeid (1%), squid (1%) and digested matter (1%). Compared to adults, percentage of crustaceans in the gut of juveniles was more. Similar trend was visible in other varieties of food items. Crustaceans were of smaller size than fishes and this may be the reason for their dominance in the guts of juveniles.

4.3.4. Major food items

Gut contents of Cobia were identified up to species/genus/ group level and grouped in to eleven groups, namely fish, crab, squilla, shrimp penaeid, shrimp non penaeid, squid, cuttlefish, octopus, other mollsca, digested matter and others.

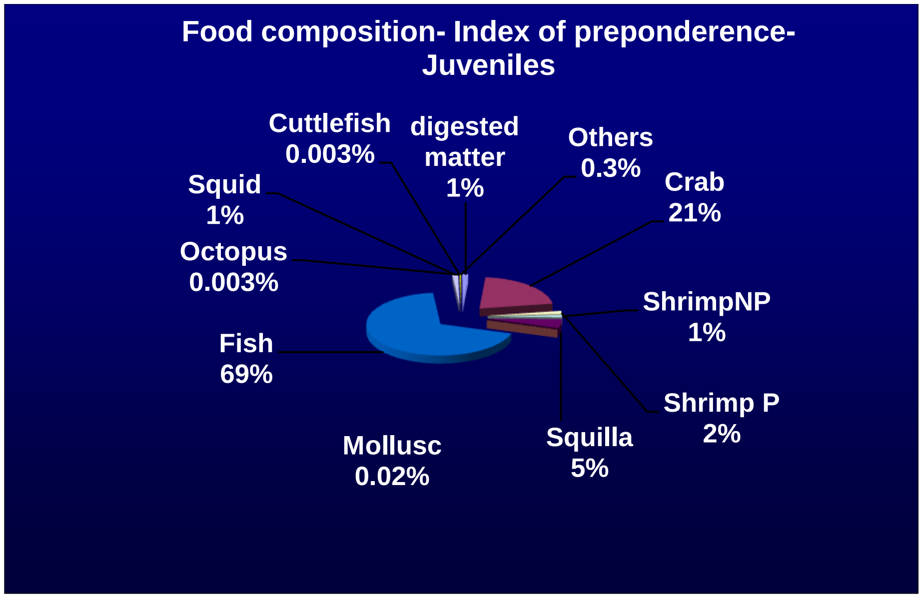

Fig. 11. Composition of gut contents of juvenile *Rachycentron canadum*

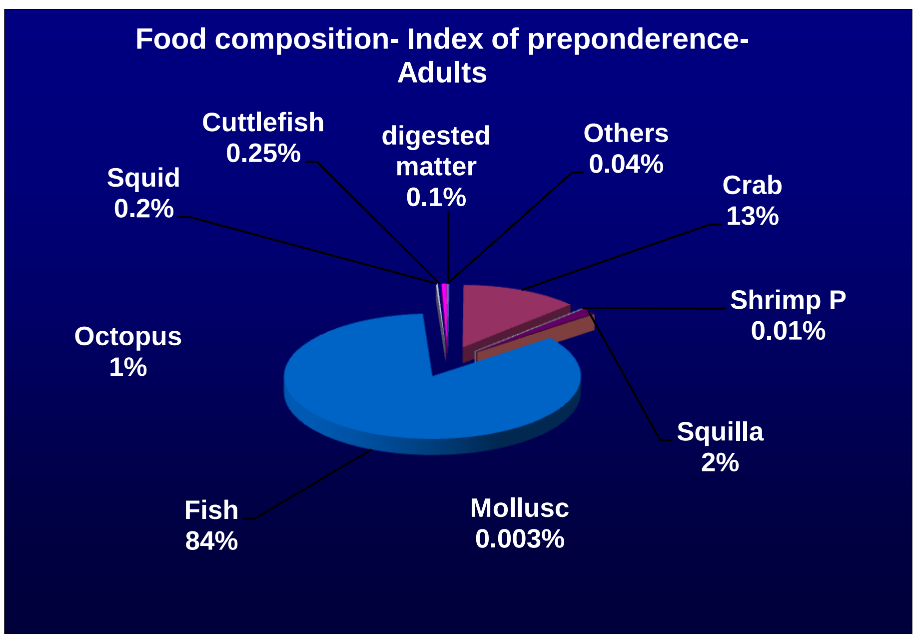

Fig. 12. Composition of gut contents of adult *Rachycentron canadum*

Table 6. Variation in composition of food expressed in percentage of juvenile and adult of *Rachycentron canadum*

Food component	Juvenile (22.6-64 cm)	Adult (65-151cm)
Fish	68.52	84.43
Crab	21.22	12.86
Squilla	4.63	1.56
Shrimp penaeid	1.67	0.01
Shrimp non penaeid	1.04	0.00
Squid	1.31	0.20
Cuttle fish	0.00	0.25
Octopus	0.00	0.53
Other Mollusca	0.03	0.00
Digested matter	1.29	0.11
Others	0.30	0.05

4.3.4. A. Fish

Percentage compositions of various fish species recorded from the gut contents of Cobia are furnished in Table 7, Fig.13 & Fig.14. More than twenty-five genera of fishes were encountered in the guts of Cobia. Tetradontids (Puffer fish) dominated among the fishes with 91.45% followed bu Mackerel (2.5%), Silver bellies (1.4) and Nemipterids (1.3%). Fishes found dominant among the gut contents of male during February – May, August and November. In female, similar dominance was noted during February, May and June. Size group wise, fishes occupied 81.52% and 68.52% of gut contents of adult and juveniles respectively. In general, Cobia prefers fishes to any other food items.

4.3.4. B. Crab

Four varieties of crabs namely *Portunus sanguinolentus*, *Portunus pelagicus*, *Charybdis feriatus* and *Charybdis smithii* were found in the guts of Cobia. Percentage compositions of crab were 27.67, 34.32 and 37.58 among the gut contents of male Cobia, female Cobia and Cobia pooled respectively. Month wise, crab dominated among the gut contents of male Cobia during January, June, July and December. In the case of female, crabs were the dominant food item during January, April, September and December. Percentage of occurrence of crab in the guts was more in the case of juveniles than adults.

4.3.4. C. Squilla

Squilla occurred 6.27% and 11.51% of gut contents of male and female Cobia respectively. Month wise, squilla was the main food item of female Cobia during March and August, but they were totally absent during September – December. Similarly, they were completely absent in the guts of male Cobia during September- February and April-May. Squilla occurred 4.63% of the gut contents of juvenile, but they occupied only 1.56% of gut contents in adults.

4.3.4. D. Shrimp- Penaeid

Commercially important penaeid shrimps like *Fenneropenaeus indicus, Penaeus monodon, Penaeus merguiensis, Metapenaeus dobsoni, Metapenaeus monoceros, Metapenaeus affinis, Solenocera crassicornis* and *Solenocera choprai* were encountered in the gut contents of Cobia. On an average penaeid shrimps occupied 1.04 and 0.70 percentages of gut contents of male and female Cobia respectively. Penaeid shrimps contributed to 1.67% of gut contents of juvenile, but their share was only 0.01% among the gut contents of adults. Month wise, maximum occurrence of penaeid shrimps were found during December (5.78%) followed by June (2.17) in both the sexes.

4.3.4. E. Shrimp- Non Penaeid

Non penaeid shrimps occupied 0.02 and 1.73 percentages of gut contents of male and female Cobia respectively. Commercially important non penaeid shrimps like *Nematopalaemon tenuipes, Exhippolysmata ensirostris, Acetes indicus, Acetes johni, Acetes sibogae* and *Acetes erythraeus* were found in the gut contents of Cobia. They occurred 1.04% of gut contents of juvenile Cobia but were totally absent in the guts of adults. Passive type movement of non penaeid shrimps may be the reason behind this disparity. This is an indication of the more active preying of the adults.

4.3.4. F. Squid

Squid occupied 1.07 and 3.0% of gut contents of male and female Cobia respectively**.** *Loligo duvaucelli, Doryteuthis sibogae* and *Loliolus investigatoris* are the squids found in the guts of Cobia. Squids contributed to 1.31% of gut contents of juveniles, but were found only 0.20 % in the guts of adult Cobia. Month wise, squids were completely absent in the guts of male Cobia during July to November. In the case of female Cobia, they were totally absent in the gut contents during August –January.

4.3.4. G. Cuttlefish

Sepia pharaonis, Sepia aculeata, Sepia elleptica and *Sepiella inermis* were the cuttlefishes found in the guts of Cobia. They were almost absent in the guts of male and contributed 0.55% of gut contents of female Cobia. Absence of cuttlefishes in the gut contents of juveniles is an interesting phenomenon.

Table 7. Percentage composition of fishes in the gut contents of *Rachycentron canadum* (pooled) -Index of preponderance value

Fish components	Percentage of composition
Tetradontids	91.45
Rastrelliger kanagurta	2.57
Leiognathids	1.41
Nemipterus spp.	1.30
Decapterus spp.	0.88
Eel	0.71
Therapon jarbua	0.20
Acropoma sp.	0.20
Other carangids	0.18
Elasmobranchs	0.17
Saurida spp.	0.15
Priacanthus spp.	0.14
Cynoglossuss spp.	0.08
Sphyraena spp.	0.04
Stolephorus spp.	0.02
Megalaspis cordyla	0.01
Platycephalus spp.	0.01
Harpodon nehereus	0.01
Sardinella spp.	0.01
Trichiurus sp.	0.01
Epinephelus diacanthus	0.004
Sciaenids	0.001
Ambassis spp.	0.0003
Alectis spp.	0.0002
Others	0.44

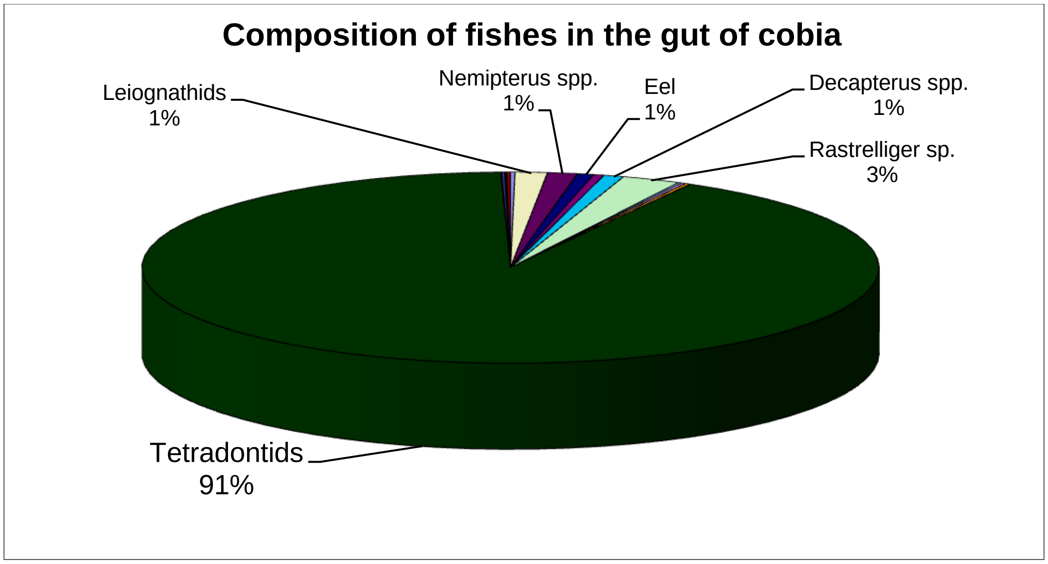

Fig. 13. Percentage composition of fishes in the gut contents of *Rachycentron canadum* (pooled)

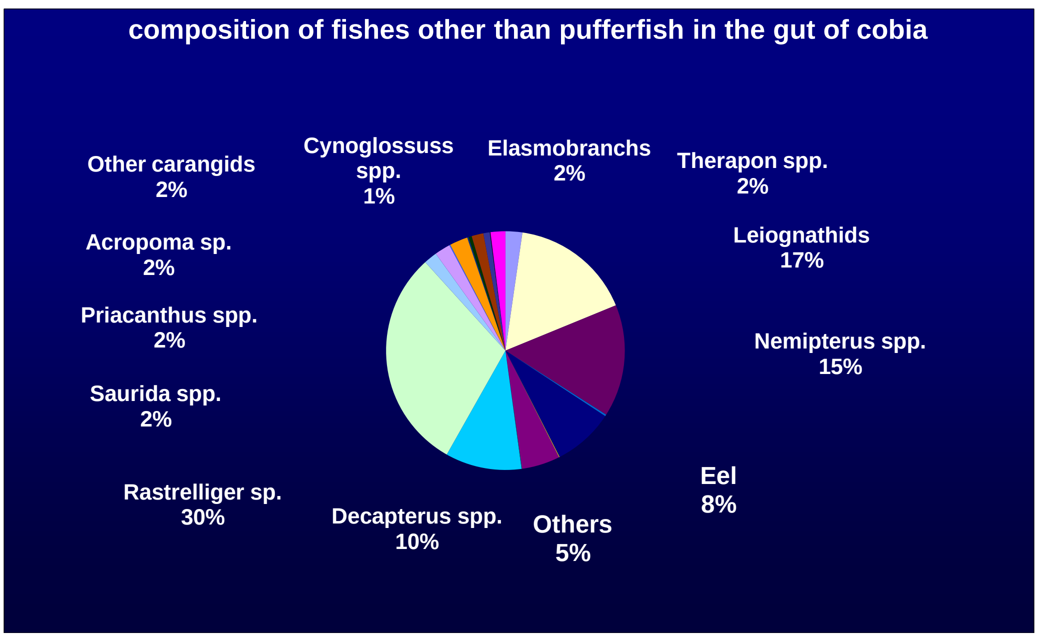

Fig.14. Percentage composition of fishes other than Tetradontids in the gut contents of *Rachycentron canadum* (pooled)

Meantime cuttlefishes occupied 0.25% of gut contents of adults. Month wise, except a 0.06% contribution noted in February, cuttlefishes were completely absent in the guts of male Cobia. They were found in the guts of female during February (0.08%) and June (6.55%) but were absent during the rest of the period.

4.3.4. H. Octopus

Octopus contributed 0.32 and 7.59% of gut contents of male and female Cobia respectively. They were completely absent in the guts of juveniles and occupied 0.25% of gut contents of adults. Month wise, octopus found only during February (0.02%) and May (3.81%) in the guts of male Cobia. In the case of females, octopus was the dominant food item during July (53.90%).They were also found in the guts of female Cobia during February –July period.

4.3.4. I. Other mollusca

Molluscan shells found in the guts of Cobia form this category of food items. They contributed 0.47% and 0.08% of gut contents of male and female Cobia respectively. They were present only in the guts of juveniles and were absent in the guts of adults.

4.3.4. J. Digested matter

Unidentifiable digested matters are put in to this category of digested matter. They occupied 8.5 and 5.7 percentage of gut contents of male and female Cobia respectively. During September all the gut samples of male Cobia were full of digested matter, similarly 60.83% of gut contents of female during November was also characterised by digested matter. They were recorded from both adult and juvenile guts.

4.3.4. K. Others

Occurrence of materials like lemon, wood piece, sand particle etc in the guts of Cobia was noticed sporadically. Others occupied 2-3% of gut contents of Cobia.

4.3.5. Feeding intensity

Monthly variation of stomach condition of Cobia in percentage of occurrence of stomach in different degree of fullness and feeding condition are given in Table.8. Fig.15 & Fig.16.From the percentage occurrence of actively fed fishes, it can be seen that Cobia actively fed during post monsoon period with a peak during December. Percentages of actively fed fishes were low during July and September. Share of empty stomachs was more during September and March. In general, 56% of fishes were found in either actively fed or moderately fed state. This is an indication of feeding intensity of Cobia inhabiting the north west coast of India.

Monthly percentage occurrence of stomach condition of male and female Cobia in different degree of fullness and feeding condition are presented in Table.9, Table 10, Fig.17 Fig.18, Fig. 19& Fig. 20. Except during April and July, male Cobia fed very actively. On an average, more than 52% of males are either active or moderately fed. Similar trend was noticed in the case of female Cobia, as 56% of female Cobia was found either active or moderately fed.

Variation in the feeding intensity of Cobia on lengthwise basis was analysed and results are presented in Table.11, Fig.21, Fig. 22 & Fig.23. Feeding intensity is invariably increases in proportion to length. Percentage of occurrence of empty stomachs shown a decreasing trend, when the fish grow. Except at the mid length of 135 cm, empty stomachs were absent in the case large sized Cobia. In general 55% of juveniles and 57% adults were found either in active or moderately fed condition.

Table. 8. Monthly variation of feeding intensity in percentage of *Rachycentron canadum* (pooled)

Month		Poor feeding		Moderate feeding	Active feeding			Number of Observations
	Empty	Trace	1/4th Full	1/2 full	3/4 full	Full	Gorged	
Jan	3.33	23.33	10.00	33.33	3.33	23.33	0.00	30.00
Feb	10.81	6.76	21.62	14.86	18.92	25.68	1.35	74.00
Mar	46.43	3.57	14.29	3.57	0.00	32.14	0.00	28.00
Apri	18.75	31.25	15.63	9.38	12.50	12.50	0.00	32.00
May	6.67	26.67	0.00	33.33	0.00	20.00	13.33	15.00
June	12.90	9.68	6.45	38.71	3.23	29.03	0.00	31.00
July	8.33	16.67	16.67	41.67	8.33	8.33	0.00	12.00
August	26.19	4.76	19.05	16.67	7.14	23.81	2.38	42.00
Sept	71.43	0.00	0.00	7.14	0.00	21.43	0.00	14.00
Oct	0.00	0.00	25.00	16.67	33.33	25.00	0.00	12.00
Nov	15.00	20.00	25.00	10.00	5.00	20.00	5.00	20.00
Dec	4.76	4.76	4.76	4.76	14.29	66.67	0.00	21.00
Total	17.82	11.78	14.80	18.43	9.67	25.98	1.51	331.00

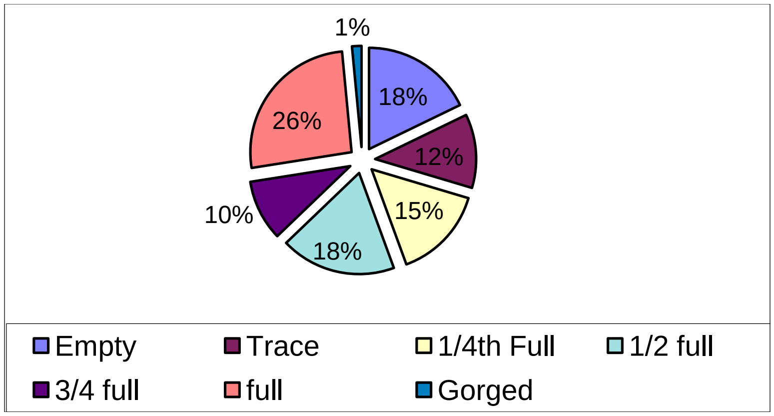

Fig.15. Feeding intensity in percentage of *Rachycentron canadum* (pooled)

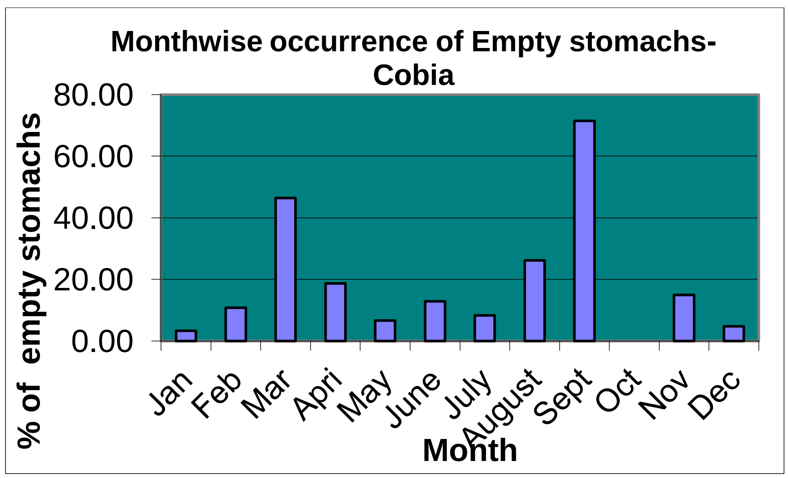

Fig. 16.Month wise percentage of occurrence of empty stomachs of *Rachycentron canadum* (pooled)

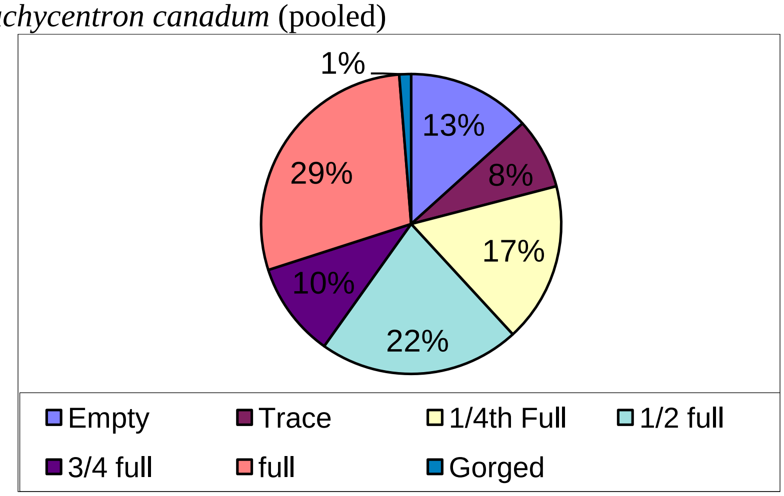

Fig. 17.Feeding intensity of male *Rachycentron canadum*

Table 9. Monthly variation of feeding intensity in percentage of male *Rachycentron canadum*

Month		Poor feeding		Moderate feeding	Active feeding			Number of Observations
	Empty	Trace	1/4th Full	1/2 full	3/4 full	Full	Gorged	
Jan	0.00	7.14	21.43	35.71	0.00	35.71	0.00	14.00
Feb	15.79	7.89	18.42	18.42	21.05	15.79	2.63	38.00
Mar	55.00	5.00	5.00	0.00	0.00	35.00	0.00	20.00
Apri	25.00	41.67	16.67	8.33	0.00	8.33	0.00	12.00
May	0.00	14.29	0.00	42.86	0.00	42.86	0.00	7.00
June	5.88	0.00	11.76	41.18	5.88	35.29	0.00	17.00
July	0.00	14.29	28.57	42.86	14.29	0.00	0.00	7.00
August	17.65	0.00	23.53	23.53	5.88	29.41	0.00	17.00
Sept	0.00	0.00	0.00	0.00	0.00	100.00	0.00	1.00
Oct	0.00	0.00	42.86	14.29	42.86	0.00	0.00	7.00
Nov	18.18	0.00	27.27	18.18	9.09	18.18	9.09	11.00
Dec	0.00	0.00	0.00	9.09	9.09	81.82	0.00	11.00
Total	16.05	9.23	20.77	26.15	12.31	34.62	1.54	162.00

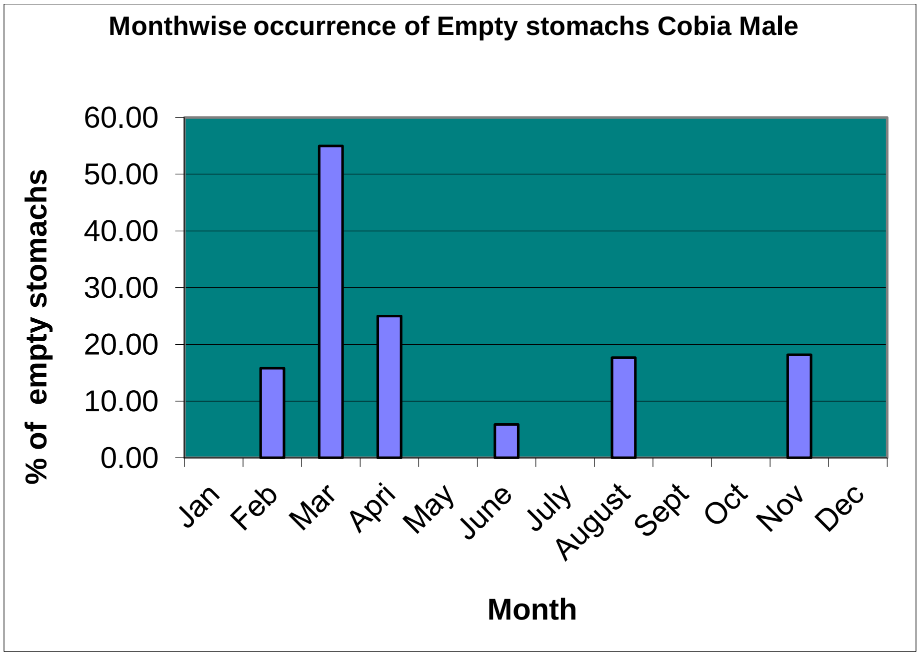

Fig. 18. Month wise occurrence of empty stomachs in percentage of male *Rachycentron canadum*

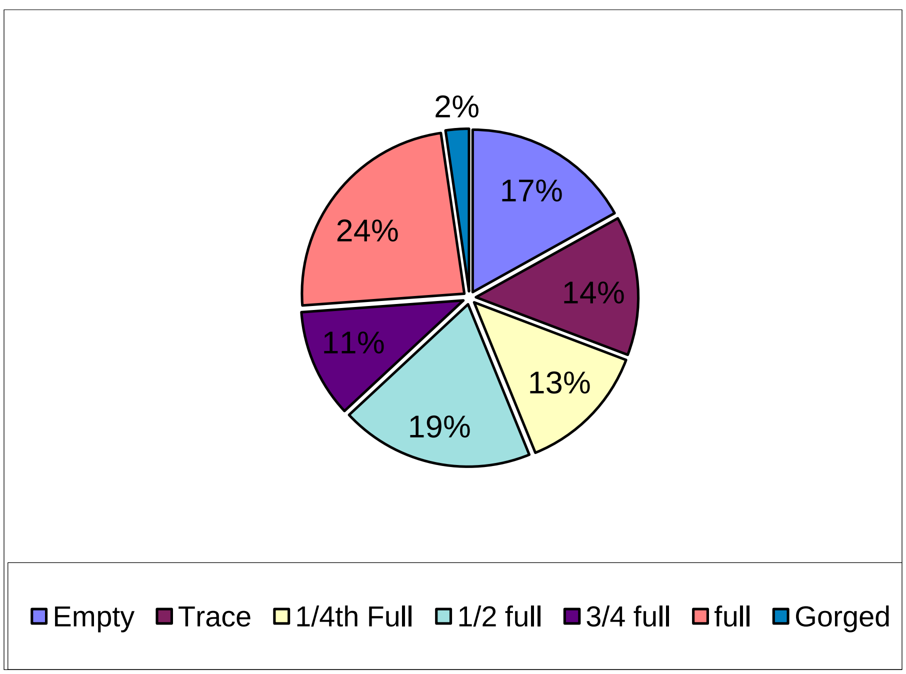

Fig. 19. Feeding intensity in percentage of female *Rachycentron canadum*

Table 10. Monthly variation of feeding intensity in percentage of female *Rachycentron canadum*

Month		Poor feeding		Moderate feeding	Active feeding			Number of Observations
	Empty	Trace	1/4th Full	1/2 full	3/4 full	Full	Gorged	
Jan	7.69	23.08	0.00	46.15	7.69	15.38	0.00	13.00
Feb	3.13	6.25	28.13	12.50	15.63	34.38	0.00	32.00
Mar	25.00	0.00	37.50	12.50	0.00	25.00	0.00	8.00
Apri	18.18	27.27	9.09	9.09	27.27	9.09	0.00	11.00
May	14.29	28.57	0.00	28.57	0.00	0.00	28.57	7.00
June	0.00	27.27	0.00	45.45	0.00	27.27	0.00	11.00
July	20.00	20.00	0.00	40.00	0.00	20.00	0.00	5.00
August	20.00	6.67	26.67	13.33	13.33	13.33	6.67	15.00
Sept	76.92	0.00	0.00	7.69	0.00	15.38	0.00	13.00
Oct	0.00	0.00	0.00	20.00	20.00	60.00	0.00	5.00
Nov	0.00	60.00	0.00	0.00	0.00	40.00	0.00	5.00
Dec	20.00	0.00	0.00	0.00	40.00	40.00	0.00	5.00
Total	16.92	13.85	13.08	19.23	10.77	23.85	2.31	130.00

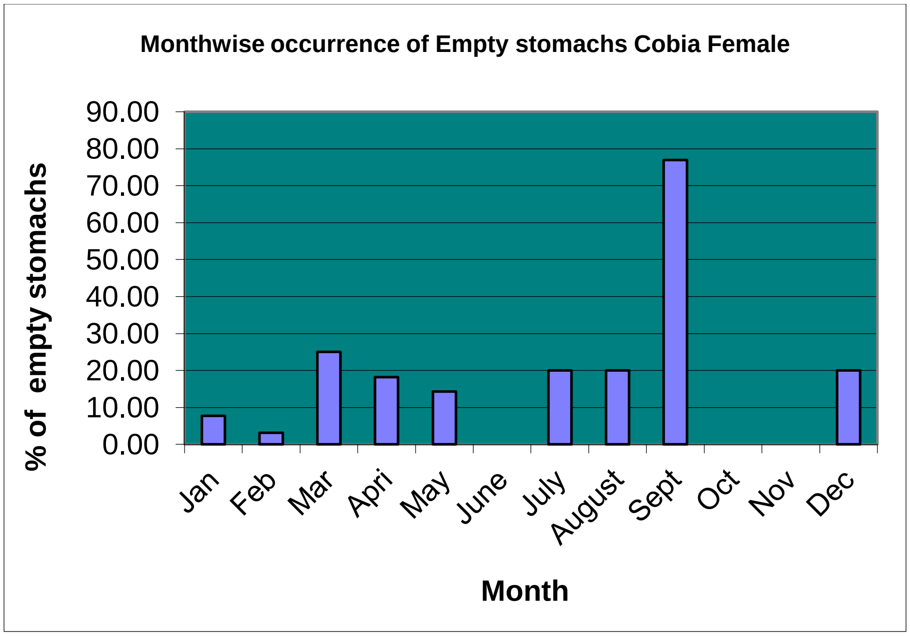

Fig. 20. Month wise occurrence of empty stomachs in percentage of female *Rachycentron canadum*

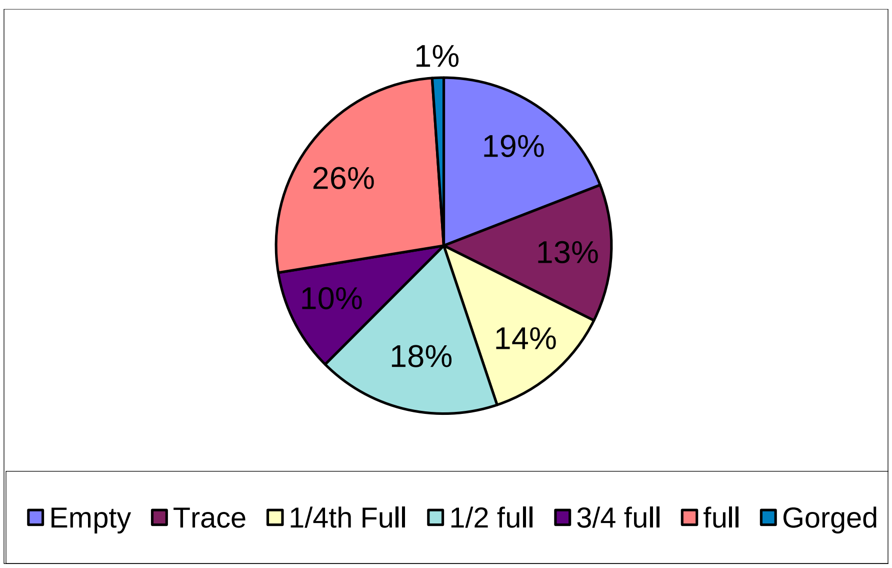

Fig. 21. Feeding intensity in percentage of juvenile *Rachycentron canadum*

Table 11. Length wise variation of feeding intensity in percentage of *Rachycentron canadum* (pooled)

Mid length of Length class (cm)		Poor feeding		Moderate feeding	Active feeding			Number of Observations
	Empty	Trace	1/4th Full	1/2 full	3/4 full	full	Gorged	
25	32.61	17.39	17.39	13.04	4.35	15.22	0.00	46.00
35	21.88	12.50	14.06	18.75	9.38	20.31	3.13	64.00
45	15.38	14.29	10.99	19.78	14.29	24.18	1.10	91.00
55	11.90	4.76	9.52	21.43	7.14	45.24	0.00	42.00
65	13.79	17.24	10.34	10.34	10.34	37.93	0.00	29.00
75	13.64	4.55	18.18	22.73	9.09	27.27	4.55	22.00
85	15.38	7.69	30.77	7.69	0.00	30.77	7.69	13.00
95	14.29	0.00	57.14	14.29	14.29	0.00	0.00	7.00
105	0.00	0.00	33.33	50.00	16.67	0.00	0.00	6.00
115	0.00	0.00	0.00	0.00	50.00	50.00	0.00	2.00
125	0.00	0.00	0.00	0.00	0.00	100.00	0.00	2.00
135	20.00	0.00	20.00	60.00	0.00	0.00	0.00	5.00
145	0.00	50.00	0.00	0.00	0.00	50.00	0.00	2.00
Total	17.82	11.78	14.80	18.43	9.67	25.98	1.51	331

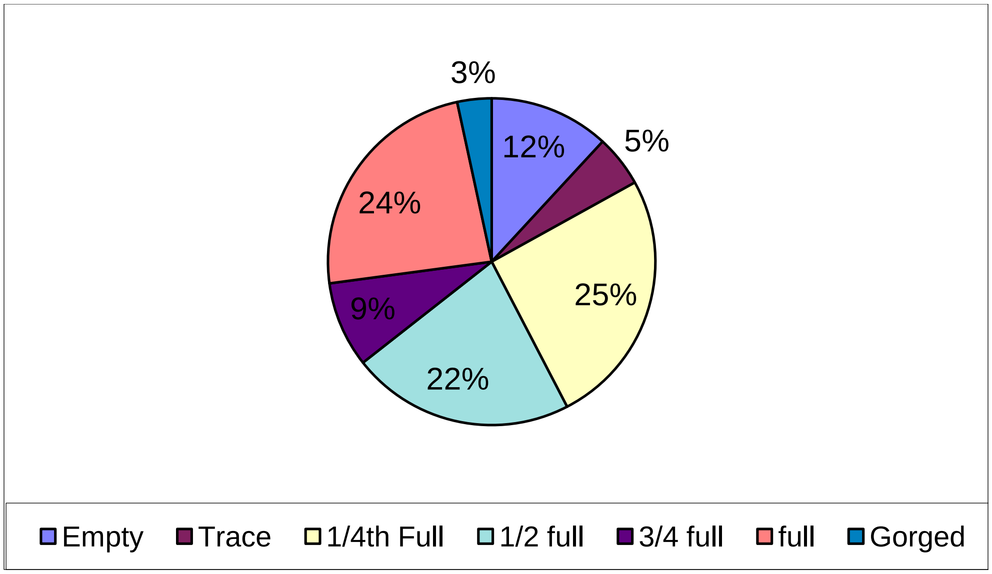

Fig. 22. Feeding intensity in percentage of adult *Rachycentron canadum*

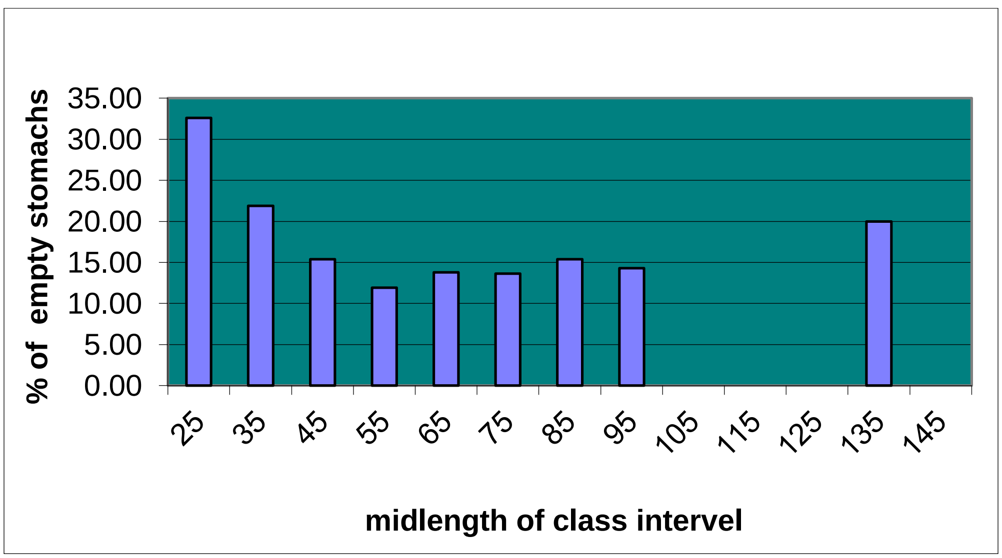

Fig. 23. Length wise occurrence of empty stomachs in percentage of *Rachycentron canadum* (pooled)

4.3.6. Mean Index of Feeding intensity (MIF) and Index of Fullness (IF).

Month wise Mean Index of Feeding intensity (MIF) and Index of Fullness (IF) values for male, female and pooled data are furnished in Table 12, Fig. 24, Fig.25 & Fig. 26. As illustrated, during most of the months, these fishes were well fed. In the case of male, low feeding intensity was recorded during April and July. Similarly, during March, April and July females were poorly fed. Values estimated for the pooled data also supports the above view. Similar trend was observed in the case of MIF and IF values, with some exception during certain months. In general, Cobia fed well during post monsoon periods and poor feeding activity was noticed during the month of July.

Lengthwise variation of the Mean Index of Feeding intensity and Index of Fullness values are furnished in Table 13 & Fig. 27. As shown in the Table 13 and Fig.27, length group with mid length 65 cm, 95 cm and 135 cm were poorly fed as both MIF and IF values recorded were low. MIF and IF values of juveniles were 4.62 and 3.96 respectively against 7.79 and 5.26 recorded for adults. This indicates that adults were fed well than juveniles.

4.3.7. Gastrosomatic Index (GSI)

Month wise Gastrosomatic index values for male, female and pooled are furnished in Table.14 & Fig. 28. As illustrated, male was found fed well than female. Most of the months GSI values of male were on higher side. This indicates the moderate or active feeding nature of male. In general, GSI value for the months of January, March and July were on lower side, which manifest the very low feeding intensity during the above period.

Lengthwise Gastrosomatic index values are furnished in Table. 15 and these values were compared with the Relative Condition Factor (Kn) values recorded for the length group (Fig.29). In general feeding intensity is more in larger sized groups except some decline noticed at the length group 91-100.

Table 12. Mean Intensity of Feeding and Index of fullness of *Rachycentron canadum* – Sex wise

Month	Male		Female		Pooled	
	Mean Index of fullness	Index of fullness	Mean Index of fullness	Index of fullness	Mean Index of fullness	Index of fullness
Jan	5.81	3.52	4.33	1.74	4.86	2.74
Feb	5.93	5.63	6.02	5.57	5.87	6.04
Mar	7.34	6.03	5.08	2.05	6.36	4.41
Apr	2.46	2.08	2.75	1.88	3.79	3.15
May	5.68	3.44	3.88	4.55	4.44	3.75
June	6.24	4.19	4.87	9.37	5.69	6.30
July	4.13	1.79	4.88	1.69	4.38	1.81
Aug	5.83	6.05	5.29	3.67	5.76	4.63
Sept	9.00	1.08	7.00	7.41	7.00	5.78
Oct	5.75	7.51	7.75	5.47	6.47	6.90
Nov	6.05	5.78	3.90	8.25	4.81	5.53
Dec	8.66	3.18	4.33	1.74	7.8	4.94
Average	6.07	4.19	5.01	4.45	5.60	4.66

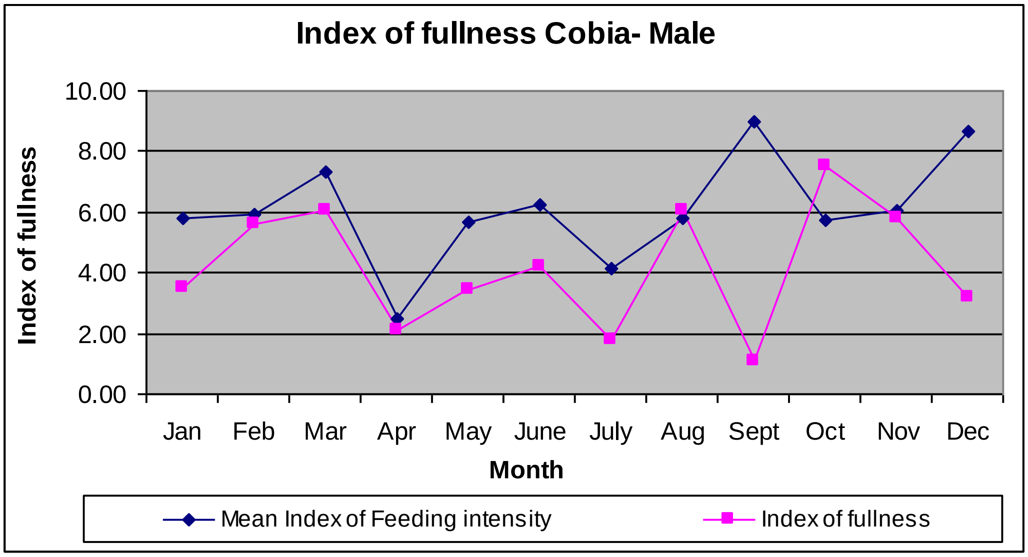

Fig.24. Mean Intensity of Feeding and Index of fullness of male *Rachycentron canadum*

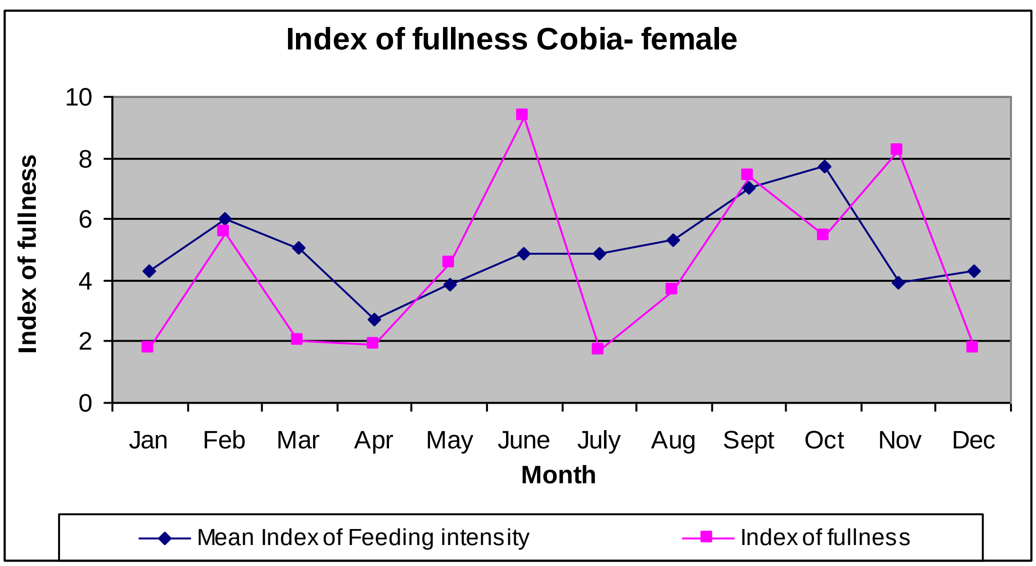

Fig. 25. Mean Intensity of Feeding and Index of fullness of female *Rachycentron canadum*

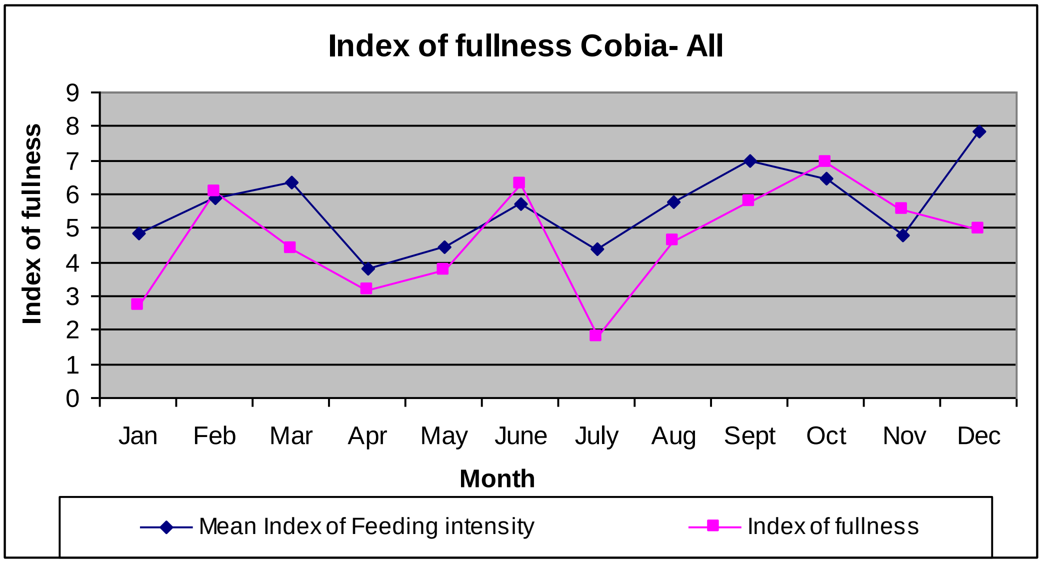

Fig. 26. Mean Intensity of Feeding and Index of fullness of *Rachycentron canadum* (pooled)

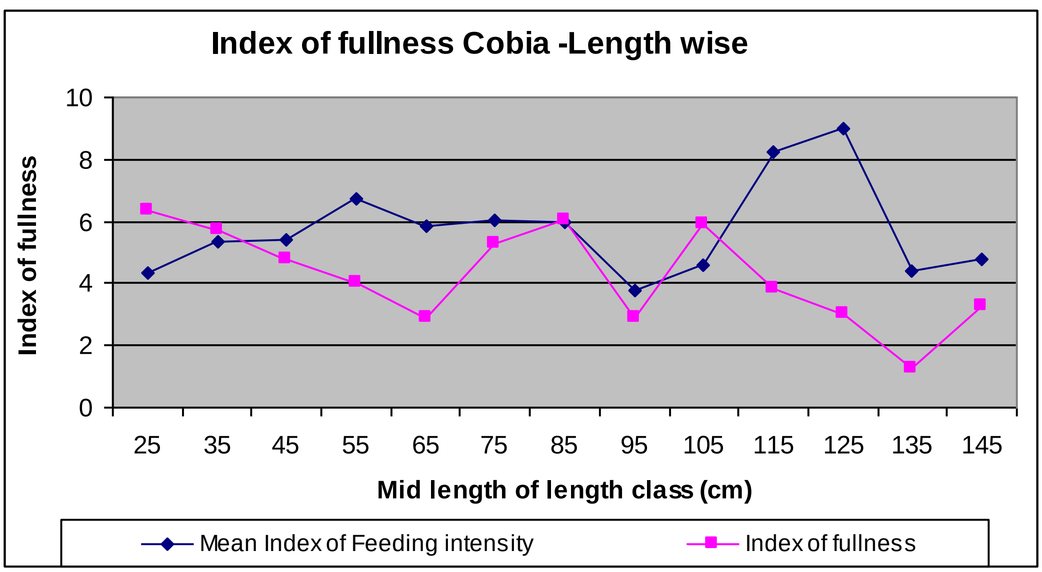

Fig. 27. Length wise Mean Intensity of Feeding and Index of fullness of *Rachycentron canadum* (pooled)

Table 13. Length wise Mean Intensity of Feeding and Index of fullness of *Rachycentron canadum* (pooled)

Mid length of Length class (cm)	Mean Index of fullness	Index of fullness
25.00	4.32	6.38
35.00	5.37	5.75
45.00	5.42	4.76
55.00	6.74	4.01
65.00	5.86	2.89
Juvenile	**4.62**	**3.96**
75.00	6.03	5.31
85.00	6.00	6.04
95.00	3.75	2.88
105.00	4.58	5.90
115.00	8.25	3.86
125.00	9.00	3.04
135.00	4.38	1.29
145.00	4.75	3.26
Adult	**7.79**	**5.26**

Table 14. Month wise Gastrosomatic Index (GSI) values of *Rachycentron canadum*

Month	Male	Female	Pooled
Jan	3.504621	3.722324	3.885312
Feb	6.106011	6.983732	6.822169
Mar	4.948783	2.299465	4.191835
Apr	4.295937	4.296833	5.01054
May	17.40401	5.089786	9.615837
June	4.913693	10.95673	6.741336
July	2.632137	2.100144	2.225052
Aug	6.605721	5.335547	5.777655
Sept	14.92308	4.796383	4.429263
Oct	13.45832	9.444797	11.78602
Nov	8.660547	9.802896	8.915973
Dec	4.564271	3.826311	7.39452
Average	7.668094	5.721246	6.399626

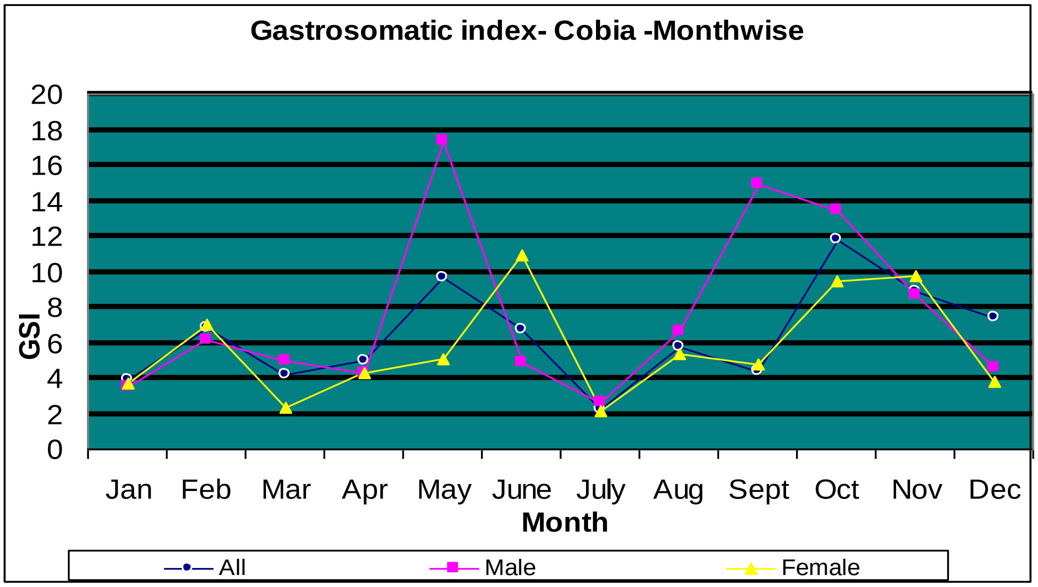

Fig. 28. Month wise Gastrosomatic Index (GSI) values of *Rachycentron canadum* -Sex wise

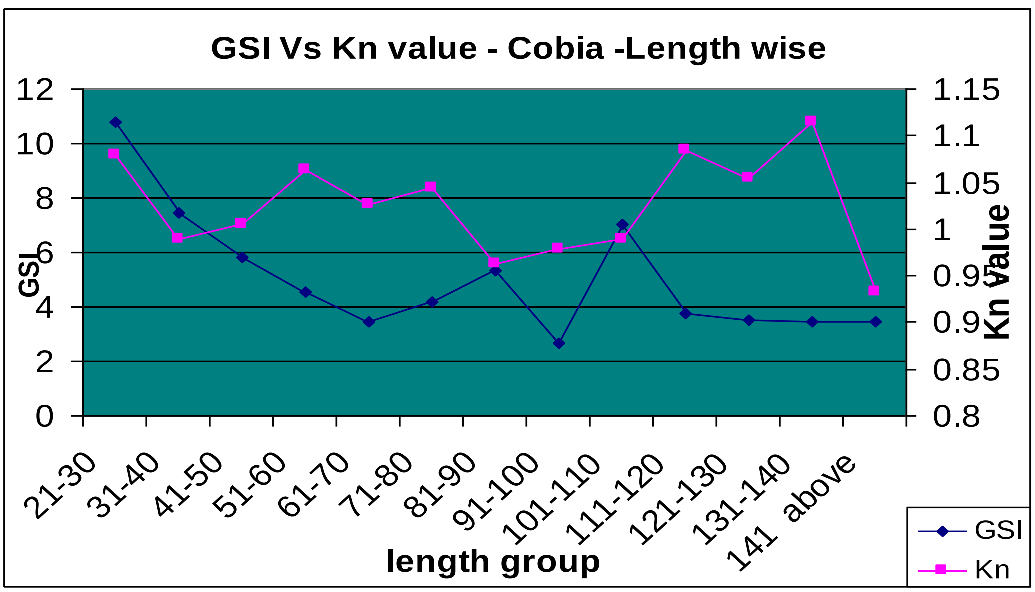

Fig. 29. Month wise Gastrosomatic Index (GSI) and Relative condition factor values of *Rachycentron canadum* (pooled)

Table 15. Length group wise Gastrosomatic Index (GSI) and Relative Condition Factor (Kn) of *Rachycentron canadum* (pooled)

Length group(in cm)	GSI	Kn
21-30	10.80789	1.07905
31-40	7.460408	0.989502
41-50	5.811431	1.004399
51-60	4.532708	1.063425
61-70	3.483862	1.026679
71-80	4.160187	1.043997
81-90	5.346044	0.962011
91-100	2.667711	0.979392
101-110	7.028214	0.988301
111-120	3.779545	1.084152
121-130	3.544643	1.054085
131-140	3.483601	1.115312
141 above	3.43943	0.932486

Table 16. Percentage composition and Trophic level values of food components of *Rachycentron canadum* (pooled)

Food components	Percentage composition	Trophic level	Reference
Tetradontids	42.721	3.86	Froese and Pauly (2011)
Rastrelliger kanagurta	1.201	3.1	Bathal (2005)
Leiognathids	0.659	3.24	Sea around us project (2011)
Nemipterus spp.	0.607	3.72	Sea around us project (2011)
Decapterus spp.	0.412	3.6	Bathal (2005))
Eel	0.331	4.1	Bathal (2005)
Terapon jarbua	0.093	3.9	Froese and Pauly (2011)
Acropoma sp.	0.093	3.26	Froese and Pauly (2011)
Other carangids	0.084	4	Bathal (2005)
Rays	0.079	3.7	Bathal (2005)
Saurida spp.	0.070	4.3	Sea around us project (2011)
Priacanthus spp.	0.065	3.81	Sea around us project (2011)
Cyanoglossuss spp.	0.037	3.29	Sea around us project (2011)
Sphyraena spp.	0.018	4.4	Sea around us project (2011)
Stolepherus spp.	0.009	3.25	Sea around us project (2011)
Megalaspis cordyla	0.005	4.39	Froese and Pauly (2011)
Platycephalus spp.	0.005	3.6	Froese and Pauly (2011)
Harpodon nehereus	0.0057	4.2	Sea around us project (2011)
Sardinella spp.	0.005	2.51	Sea around us project (2011)
Trichiurus sp.	0.005	4.3	Bathal (2005)
Epinephelus diacanthus	0.005	3.82	Froese and Pauly (2011)
Scianids	0.001	3.76	Sea around us project (2011)
Ambassis spp.	0.001	3.91	Froese and Pauly (2011)
Alectis spp.	0.00009	4.09	Froese and Pauly (2011)
Other fishes	0.205	3.5	Bathal (2005)
Crab	39.629	2.9	Bathal (2005)
Stromatopods	8.215	3.1	Bathal (2005))
Shrimp penaeid	0.7385	3.31	Sea around us project (2011)
Shrimp non penaeid	0.612	2.7	Bathal (2005)
Squid	2.0352	3.99	Sea around us project (2011)
Cuttlefish	0.074	3.6	Sea around us project (2011)
Octopus	1.898	3.58	Sea around us project (2011)
other mollusca	0.084	2.0	Bathal (2005)

4.3.8 Trophic level

Percentage of composition and trophic level values of food components of Cobia are given in Table. 16. Composition of food components assessed following index of preponderance method (Natarajan and Jhingran, 1961). Trophic value thus obtained for Cobia is 4.386. This shows that *Rachycentron canadum* is a top level predator in the ecosystem. Trophic level values of all the food components recorded from the guts of Cobia were at par or below that of the fish itself.

4.4. DISCUSSION

Different authors studied the food and feeding habits of Cobia, and the results showed that geographic differences exist in Cobia diet. Cobia feed on variety of prey items that are available in the vicinity and are considered as voracious feeder. Darracott (1977) reported undamaged crustaceans in the stomach of Cobia. Presence of undamaged prey items in the guts observed in the present study manifest that Cobia often engulf the prey and exhibits feeding absenteeism (Darracott, 1977). Large amount of benthic, demersal and pelagic fishes recorded from the guts of Cobia indicated that Cobia feed not only from near the bottom but also in the water column. Knapp (1951) also reported that Cobia feeds both near bottom and from near surface area.

Cobia is carnivorous, and feed extensively on fishes, crustaceans, cephalopods, and benthic invertebrates. They have been called as crab eaters in some parts of Australia due to the presence of large amount of crabs in their diet

(Wheeler, 1975; Randall, 1983). Major food items reported by different authors from different geographical locations are furnished in Table. 17. The preferential food of Cobia varied from region to region. Geographical differences in the availability of prey items and resultant differences in the Cobia diets (Arendt *et al.*, 2001) may be the reason for this variance.

Table 17. Preferential food items of *Rachycentron canadum* reported by various authors from different localities

Major food items	No. of observations	Area of study	Author/s
Crab and Penaeid shrimp	-	Texas Gulf coast	Knapp(1951)
Crustaceans	-	Western Indian Ocean	Darracott (1977)
Elasmobranches and Portunid crab	-	North Carolina	Smith (1995)
Fish (*Anchoa* sp.)	-	Northern Gulf of Mexico	Franks *et al.* (1996)
Crustaceans (Portunid crabs)	-	Northern Gulf of Mexico	Meyer and Franks (1996)
Fishes	100	Northern Gulf of Mexico	Franks *et al.* (1996)
Fishes	30	North west coast of India	Somvanshi *et al.*(2000)
Crab(Portunid crab)	78	Lower Chesapeake Bay	Arendt *et al*.(2001)
Fishes and crabs	318	North west coast of India	Present study

As far as north west coast of India is concerned, Somvanshi *et al*. (2000) reported that Cobia mainly fed on puffer fish (92.1%) followed by cephalopods (2.5%). Present study showed that 42.72% of gut contents is occupied by puffer fishes. Fish as a whole contributed 44.30% of the gut contents followed by 33.58% of crabs. Miles (1949) and Darracot (1977) are of the opinion that crabs are the major food item of Cobia. Crustaceans were reported to be occupying 70% and 100% of guts examined by Miles (1949) and Darracot (1977) respectively. In the present study crabs (33%) constituted the major food item of the female Cobia.

Meyer and Franks (1996) opined that there is no remarkable difference between the diets of male and female, but present study noticed variation in percentage composition of food items in the guts of male and female (Major constituent of male gut content was fish while crab was the major food content found in the gut of female Cobia). Findings of Somavnshi *et al.* (2000), who studied the food and feeding habits of Cobia inhabiting in north west coast of India is in agreement with the results of present study.

Seasonal variation in feeding habits and feeding intensity was noticed during the study. On an average, feeding intensity during July was low. Reduction in water temperature due to southwest monsoon, peak-spawning activity and less availability of prey items during the month may be attributed for this change of feeding intensity. Hassler and Rainville (1975) observed reduced feeding activity at a water temperature below 18^0 C while Richard (1977) opined that Cobia may cease feeding during spawning.

Trophic value estimated by utilizing the results of index of preponderance is 4.386. The trophic level values available in www.fishbase.org (Froese and Pauly, 2011) and www.sea.seaaroundus.org (Sea around us project, 2011) are 3.96 and 4.31 respectively, which are on a lower side than the value estimated in the present study. Geographic differences in the composition of gut content (Knapp, 1951; Darracott, 1977; Smith, 1995; Franks *et al.*, 1996; Meyer and Franks, 1996; Somvanshi *et al*., 2000; Arendt *et al*., 2001), variation in the availability of prey items (Arendt *et al.*, 2001) and differences in the feeding intensity (Hassler and Rainville, 1975) may be the reason for this variation.

5. LIFE HISTORY TRAITS

5.1. INTRODUCTION

The process of reproduction perpetuates a species. The ability of its members to reproduce successfully in a fluctuating environment ultimately determines the success of species (Moyle & Cech, 2000). Stability of population mainly depends on factors like recruitment, growth and mortality, of which, rate of recruitment of the stock is highly dependent on its reproductive potential. According to Bal and Rao (1984) reproductive aspects such as size at first maturity, spawning frequency, fecundity, sex ratio and recruitment are of great value in fishery prediction and for judicious exploitation and management of fishery resources. Detailed knowledge on reproductive biology of a species will lead to information on its life history traits. By understanding the life history traits, we can predict the changes that are likely to be occurring to its population.

The reproductive biology of commercially important fishes from Indian waters were studied notably by Kesteven (1947 a) Radhakrishnan (1957), Qasim & Qayyum (1963), James (1967), Khan (1972), Qasim (1973), Sreenivasan (1979), Gowda *et al.* (1988), Guha and Mukherjee (1991), Jayasankar and Alagarswami (1993), Das Gupta (2002), Doddamani *et al.* (2002) and Manojkumar (2005).

Pioneer study on the reproductive biology of Cobia is that of Day (1878). However, study of Goode (1884) is considered as a milestone in this field. Hildebrand and Schroeder (1928), Joseph *et al*. (1964), Richards, (1967), Erdman

(1968), Swingle(1971), Dawson (1971), Schwartz (1972, 1981), Finucane *et.al.* (1978), Franks *et al*. (1991), Dity and Shaw (1992), Biesiot *et al.* (1994), Smith (1995), Lotz *et al.* (1996), Franks *et al*. (1999), Brown-Peterson *et al.* (2001), Arnold *et al*. (2002), Kaiser and Holt (2004, 2005) and Tonya *et al*. (2010) reported detailed account on the maturation, spawning, reproductive behavior and dynamics of Cobia.

Information on spawning, maturity, fecundity and reproductive behavior of Cobia inhabiting the Indian waters are scanty. Rajan *et al.* (1968) and Somvanshi *et al*. (2000) and Pillai *et al.* (2009) provided some preliminary information on reproductive biology of Cobia inhabiting in Indian waters. The present study is an attempt to provide some vital aspects of reproductive biology of Cobia and thereby bridging the knowledge gaps in this field. Against this backdrop a detailed investigation on various aspects of reproduction like quantification of maturity stages, sex ratio, gonadosomatic index, size at first maturity, spawning season, spawning frequency and fecundity were carried out.

5.2. MATERIALS AND METHODS

Samples collected from the vessel *M.V. Matsya Nireekshani*, a survey vessel belonging to Mumbai base of Fishery Survey of India, Mumbai and samples collected from local landing centers at Mumbai were used for the present study. The study was conducted during January 2008 to December 2009. Frozen fish samples collected onboard the vessels were thawed at shore laboratory before examining the same for detailed analysis. Landing center samples were analysed in fresh condition itself.

In the laboratory, the sample was cleaned with fresh water and surface moisture was removed by using blotting papers. Total length of fish was measured to the nearest 1 cm and total weight to the nearest 1.0 g. Weight of ovary was recorded to the nearest 0.1g. As there is no sexual dimorphism in this species, the sex of individual specimen was determined by observing the gonads after dissecting the specimens. Sex of juveniles was identified by microscopic examination of gonads. Maturity stage of each gonad was recorded. The gonads were dissected out and preserved in 5 % formaldehyde for further studies (Philip, 1994).

Stages of maturity of gonads were determined based on morphological appearance. Five stages were identified through macroscopic observations on external appearance; extend of gonad in relation to body cavity, size of ova, shape and colour of gonad following Qasim (1973). Ovaries were fixed in 5 % formaldehyde for ova diameter and fecundity studies. Samples from anterior, middle and posterior side of gonads were taken for further analysis. Frequency of spawning was determined based on the modes of ova diameters in the mature ovaries following Jayabalan (1986). Ova diameter was measured using ocular micrometer. The entire range of ova measured were divided in to 50 micrometer division (μm) groups and plotted against percentage frequency to get frequency polygons. Spawning frequency was assessed based on the frequency polygons.

The relative ovary weight or Gonadosomatic index (GSI) was calculated applying the methods of June (1953) and Yuen (1955), using the formula:

G.S.I. = (w/ W) X 100………………………………………… (6)

Where as,

w = Weight of the gonad in gram

W = Weight of the fish in gram

GSI was calculated on monthly basis for both sex and results were utilized for determining spawning season. Distribution of different maturity stages of male and female during different months were also used for determining spawning season. Percentage of mature specimen during different months was plotted to demarcate the spawning season. Spawning season of the fish was inferred by using values of GSI and month wise percentage of mature specimen. Percentages of maturity stages were compared to the fullness of stomach to understand the feeding activity during the life history stages.

Fishes belonging to maturity stage III onwards were considered as mature fish and used for calculating the size at first maturity. Data recorded during same months during the 24 months period were pooled together to understand the month wise variations. Fishes were grouped in to different length class of 10cm length groups (Arendt, *et al.*, 2001). The percentage of the mature fish and immature fish in different size group was analysed. The length at which 50 % of fish were mature was considered as length at first maturity (Lm) of both sexes (Hodgkiss and Man, 1978).

Month wise and length wise sex ratio (M: F) calculated following Philip (1994). Fishes were further grouped in to juveniles (below the size at first maturity class) and adults to determine the sex ratio of fish in these life history stages. Sex ratio values were further tested for equality following Chi-square test (Snedecor, 1961; Snedechor and Cochran, 1967).

Fecundity was studied by examining mature preserved ovaries. Mature ovaries were weighed to the nearest milligram (mg) and samples representing anterior, middle and posterior parts of both lobes of ovaries were taken from the ovaries (Somvanshi, *et al.*, 2000). Three such duplicate samples were counted for each section to get average number of ova. Absolute fecundity was calculated using the formula:

$$F= (R\ (Fa+Fm+Fp)/(wa+wm+wp))+ L\ (Fa+Fm+Fp)/(wa+wm+wp))/\ 2X\ W \ldots\ldots(7)$$

Where as,

F = Absolute fecundity

R = Right ovary

L = Left ovary

W = total weight of ovary

Fa/ Fm/ Fp = No. of eggs in anterior/ middle/posterior sample

wa/ wm/ wp = weight of anterior/ middle/posterior sample

Fecundity index was calculated as absolute fecundity/ weight of ovary in gram.

Variations in feeding intensity during different maturity stages were assessed by recording fullness of stomach of the specimens in different maturity stages. Physical appearance of the fullness of stomach was the criteria used for categorization. All fishes were then categorised in to four groups namely 1.Empty, 2.Poor feeding (traces and ¼ th full stomach), 3.Moderate feeding (1/2 full stomach) and 4. Active feeding (3/4th full stomach, full stomach and gorged stomach). Values in percentages of feeding condition were plotted against maturity stages to understand the differential feeding habits of the fish in various maturity stages.

5.3. RESULTS

5.3.1. Classification of maturity stages

Cobia is gonochoristic. No external sexual dimorphism has been reported. Like most of other teleosteans, the reproductive glands (testes of males and ovaries in females) of *Rachycentron canadum* are typically paired structures.

The ovaries are paired structures, normally symmetrical, lying ventral to the air bladder suspended by mesenteries. When fully mature, ovary occupies more that 80% of the body cavity. In the earlier stages each ovary is a filamentous organ lightly pinkish or flesh coloured and they change to bright yellow to orange red as they become mature (Plate.1.D)

Testes in immature stage appears as slender, filamentous, translucent, light cream or white in colour. They grow anteriorly as maturity advances and become broad, fleshy and milky white in colour. When fully mature they occupy full length of body cavity and milt oozes out with slight pressure on abdomen (Plate.1.E).

Five stages were identified through macroscopic observations on external appearance; extend of gonad in relation to body cavity, size of ova, shape and colour of gonad. The stages so identified are 1 Immature; II. Maturing virgin/ recovered spent; III. Ripening; IV. Ripe and V. Spent.

Stage 1: Immature- Gonads usually translucent; occupy nearly one-fourth length of abdominal cavity. Ovaries thin, pinkish with innumerable tiny ova, which are invisible to the naked eye. The surface of the ovary smooth with no sign of blood vessels. Testis small and occupy nearly 20% of the length of body cavity. They are filamentous and white in colour.

Stage II: Maturing virgin/recovered spent- Gonads are either yet to develop or already been discharged. Occupy more than one third length of abdominal cavity, Ovary pinkish, translucent; eggs not visible to naked eye, but can be seen with the help of magnifying glass. Testis becomes little more thicker and creamy white in colour.

Stage III: Ripening- Gonads about two third length of body cavity, Eggs visible to naked eye. Ovary becomes bright yellow, blood vessels conspicuous with numerous blood capillaries. Testes enlarged, fleshy and whitish to creamy in colour.

Stage IV: Ripe – Gonad occupy about full length of body cavity. Ovaries orange red in colour, blood vessels prominent on the surface and contains large translucent eggs. Testis whitish- creamy, occupy nearly three fourth length of body cavity. On exerting slight pressure on the testis, milt oozes out.

Stage V: Spent- Gonads shrunken having loose walls. Ovaries contain few ripe darkened or translucent eggs. Testes usually dull white in colour and flabby.

5.3.2. Sex ratio

Month wise sex ratio of Cobia (M: F) arrived at is shown in Table 18. The average sex ratio between male and female observed during the period was 1: 0.80, showing dominance of male over the female. Dominance of male over female in numbers was observed during all the months, except during September, where sex ratio was 1: 1. Chi-square test performed to understand the significance of the ratio shown that there is no significant difference in the ratio of male and female.

Lengthwise sex ratio of Cobia (M: F) obtained during the study is furnished in Table19. Sex ratio between male and female observed for juveniles and adults were 1: 0.81and 1:0.74 respectively. Dominance of male over female was noticed during all the size class up to 100cm, except 40-50 cm size group. However, Chi-square test performed to understand the significance of the ratio shown that there is no significant difference in the ratio of male and female above 30 cm size group.

In the case of 20- 30 cm length group there is significant difference at 1% of confidence level in the sex ratio (1:0.32) of male and female. Dominance of female over male in size groups above 100 cm is quite visible. The faster growth rate recorded in female may be attributed as the reason for their dominance in large sized groups.

Table18. Month-wise sex ratio of *Rachycentron canadum* during January 2008-December 2009

Month	Total observations	Numbers		M: F	X^2 value
		Male	Female		
Jan	29.00	16.00	13.00	0.81	0.31
Feb	70.00	40.00	30.00	0.75	1.43
Mar	22.00	12.00	10.00	0.83	0.18
Apr	23.00	12.00	11.00	0.92	0.04
May	16.00	9.00	7.00	0.78	0.25
June	28.00	17.00	11.00	0.65	1.29
July	12.00	7.00	5.00	0.71	0.33
Aug	32.00	17.00	15.00	0.88	0.13
Sept	26.00	13.00	13.00	1.00	0.00
Oct	12.00	7.00	5.00	0.71	0.33
Nov	11.00	6.00	5.00	0.83	0.09
Dec	11.00	6.00	5.00	0.83	0.09
Total	292.00	162.00	130.00	0.80	3.51
1% (5%) table X2 value for 1 degree of freedom = 3.84(6.64)					

5.3.3. Size at first maturity

Sizes at first maturity of male and female estimated separately as there was differential growth rate observed for both sexes. To determine the size at which the fish attain the first sexual maturity, 150 males and 141 females were used. The percentage occurrence of matured individuals was plotted against different size group in male and female and the results are shown as Fig. 30 & Fig.31. All the fishes below 40cm are immature and seven male (18.45%) and six females (13.04%) in the length group 40-50 cm were observed as mature. Both male and female above 100 cm were found fully mature. More than 50 % of both male and female were found mature at the size group 60- 70cm total length (midpoint 65 cm) (Fig. 30 &31). The size of first maturity of male was estimated at 63 cm while in the case of female, it was 70 cm.

Table 19. Length-wise sex ratio of *Rachycentron canadum* during January 2008-December 2009

Mid length of length class in cm	Numbers		M:F	X^2 value
	Male	Female		
25	25	8	0.32	8.76*
35	24	22	0.92	0.09
45	37	46	1.24	0.98
55	22	19	0.86	0.22
Juvenile	128	105	0.81	2.27
65	19	10	0.53	2.79
75	15	7	0.47	2.91
85	8	5	0.63	0.69
95	5	2	0.40	1.29
105	2	4	2.00	0.67
115	1	2	2.00	0.33
125	2	3	1.50	0.20
135	1	1	1.00	0.00
145	1	1	1.00	0.00
Adult	34	25	0.74	1.37

* Sex ratio significantly different from 1:1 at 1% confidence level. 1% (5%) table X2 value for 1 degree of freedom = 3.84(6.64)

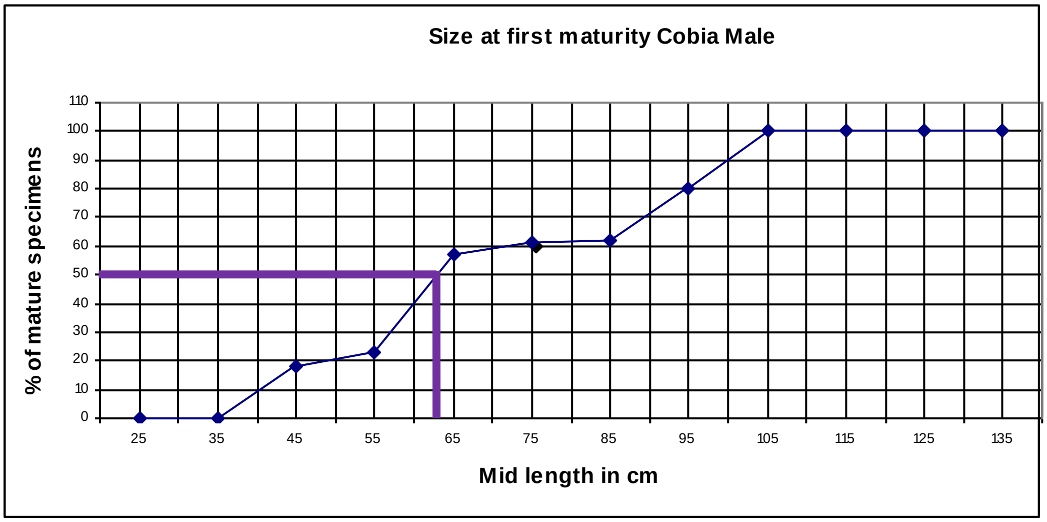

Fig.30. Percentage of occurrence of mature specimens in various size groups of male *Rachycentron canadum*

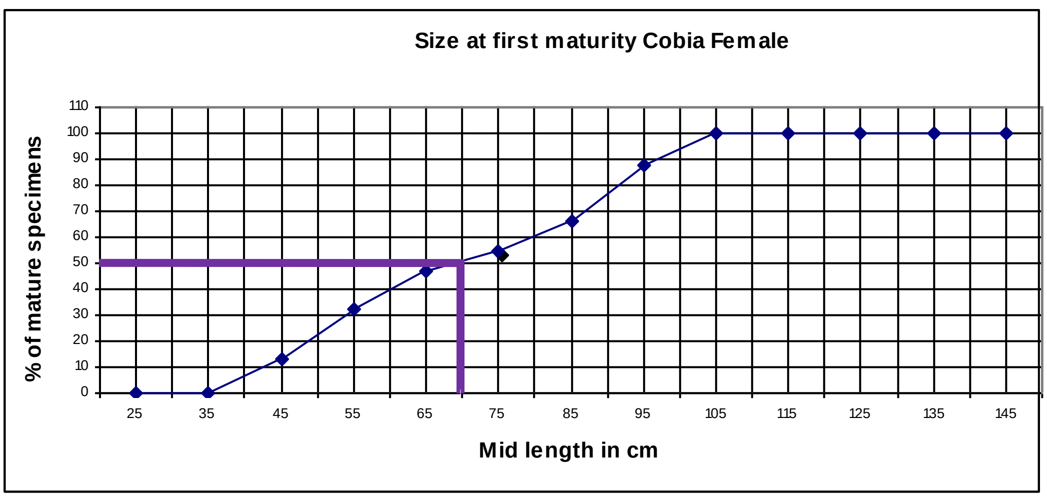

Fig.31. Percentage of occurrence of mature specimens in various size groups of female *Rachycentron canadum*

5.3.4. Spawning season

Spawning season was determined based on occurrence of different maturity stages in each month during the period from January 2008 to December 2009. Month wise pooled data on percentage of occurrence of mature specimens for the year 2008 and 2009 were plotted against each month (Fig. 32). Percentages of immature specimens (stage I) were not considered for the determination of spawning season. Mature specimens were observed throughout the year with minimum numbers during January, September and October. In contrast maximum percentage of occurrence of ripe specimens was observed during November and July. Spent individuals (stage V) were observed in small percentage during March, May and September. Stages with II and I were present throughout the year, which indicated a protracted spawning behavior of the species. From the results it can be inferred that Cobia breeds throughout the year with peak spawning activity during July-August and November- January along the north west coast of India.

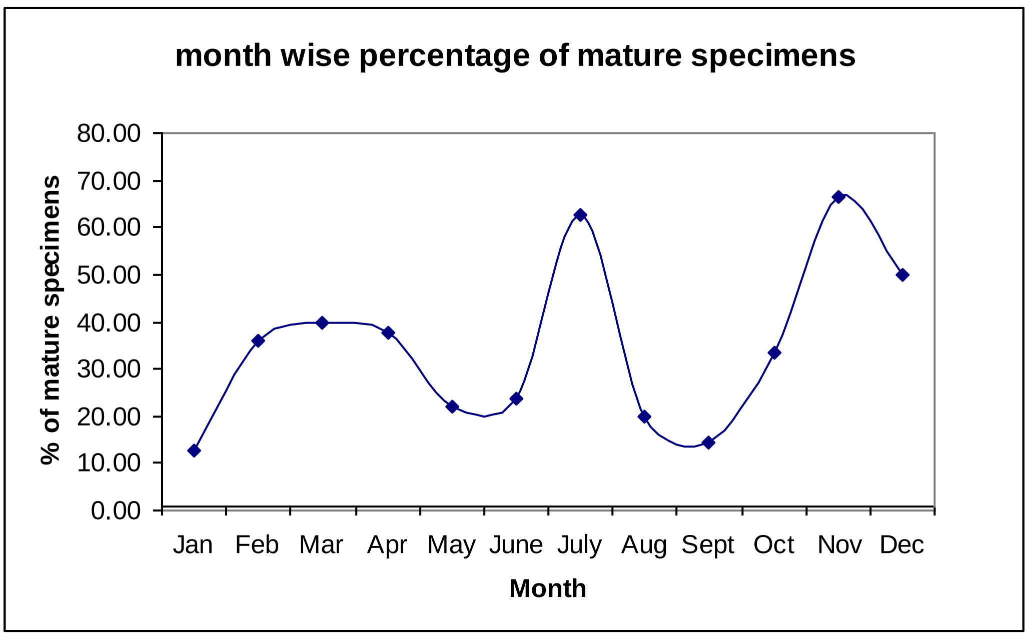

Fig.32. Month-wise occurrence of mature specimens - *Rachycentron canadum*

5.3.5. Gonadosomatic Index (GSI)

Month wise variation in Gonadosomatic index (GSI) values during the period from January 2008 to December 2009 is shown in Fig. 33. The mean monthly G.S.I. fluctuated between 0.05 (September and December) to 1.86(July). Maximum mean GSI value was recorded during July, followed by November, October and August. From May onwards GSI values were shown an increasing trend with two peaks during July and November. Fluctuations in the month wise GSI values almost synchronous with the fluctuation of month wise percentage of mature specimens. Moreover, peak value in G.S.I. coincided with peak spawning period.

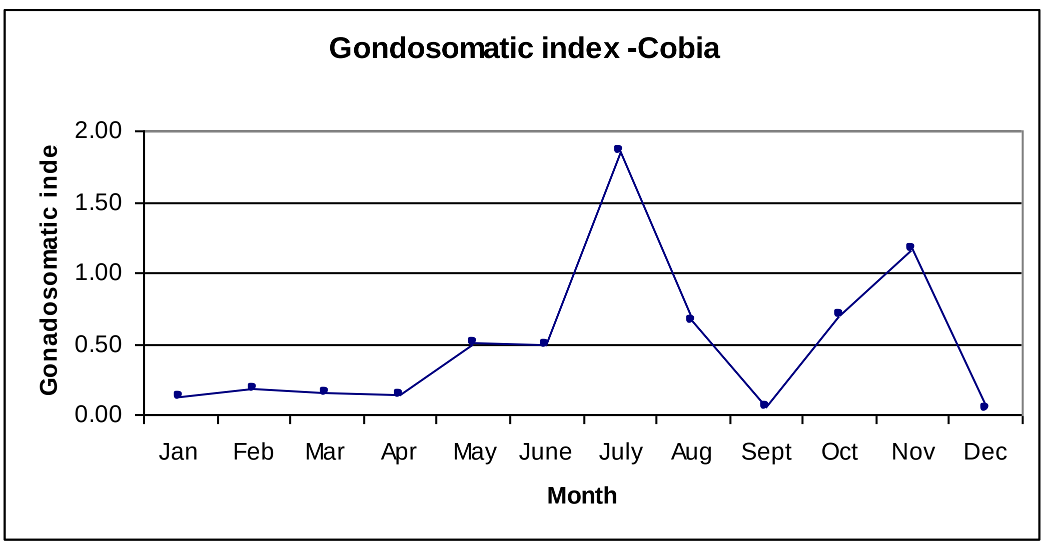

Fig.33. Month-wise Gonadosomatic index values of *Rachycentron canadum*

5.3.6. Spawning frequency

Ova diameter study of mature ovaries showed that ova diameter ranged from 250-1250 µm. Ova collected from anterior, middle and posterior parts of both lobes were pooled together and grouped into classes of 50 µm intervals and plotted against their percentage of frequency. Polygons obtained by plotting the ova diameter against frequency are depicted in Fig. 34. It can be seen from the Fig.34 that there are three polygons representing three groups of ova. They are 250-550 µm, 550-700 µm and 700-1250 µm. From these polygons, it was inferred that third group of ova ie. 700-1250 µm represents the mature group. Presence of different sizes of ova in the mature ovary clearly shows the spawning frequency of the fish.

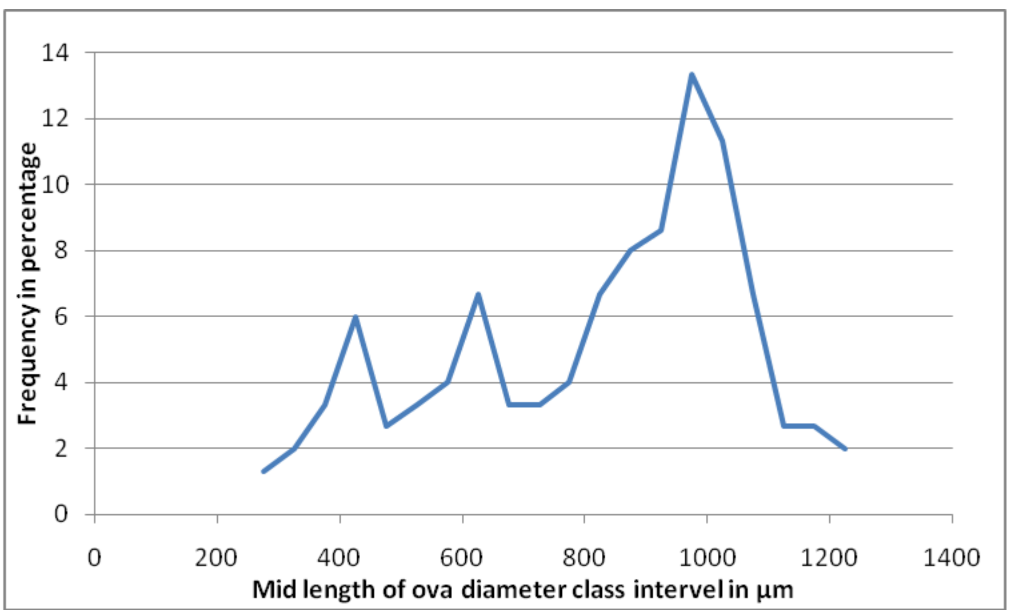

Fig.34.The ova diameter (in µm) frequency polygons of *Rachycentron canadum*

Results indicates that Cobia, *Rachycentron canadum* spawn more than once in a season, as its ovary contains three batches of ova namely ripe, ripening and immature ova. In between immature and ripe ova there is a batch of eggs in the ripening condition (intermediate maturing stock).From this it can be inferred that Cobia follows a protracted spawning season with the individual spawning more than once in a season.

5.3.7. Fecundity estimation.

Absolute fecundity obtained by the fecundity estimation studies ranged from 1,231,630 (125 cm TL) to 1,800,350 (147cm TL) numbers. Range of fecundity index obtained was from 2,123 to 2,372 eggs per gram ovary weight. Ova diameter frequency polygons illustrated in Fig. 34 shows that eggs of 700 μm and above were mature. This mature stock of ova occupies 69% of all yolked eggs.

5.3.8. Maturity stages and feeding condition

Percentages of feeding condition based on fullness of stomach of specimens of various maturity stages are given in Table.20 & Fig.35. Among the fully matured fishes (IV th stage of maturity) percentage of fishes with empty stomach and poorly fed fishes, were 16% and 50% respectively. Meantime, 75% of fishes in spent stage (V th stage of maturity) were either moderate or actively fed. In contrast to this, majority of maturing/recovered spent and ripening fishes (II nd and III rd stage of maturity) were found in well fed condition (moderate or actively fed). Feeding intensity of immature fishes was comparatively poor with percentages of 22% with empty stomach and 30% were poorly fed. This variation in feeding intensity shows that Cobia take very less food during their spawning period.

Table 20. Maturity stages Vs feeding condition in *Rachycentron canadum* during January 2008-December 2009

Maturity Stage	Feeding condition in percentage			
	Empty	Poorly fed	Moderately fed	Actively fed
I Stage	22	30	19	29
II Stage	17	17	22	44
III Stage	6	27	16	51
IV Stage	16	50	17	17
V stage	25	0	25	50

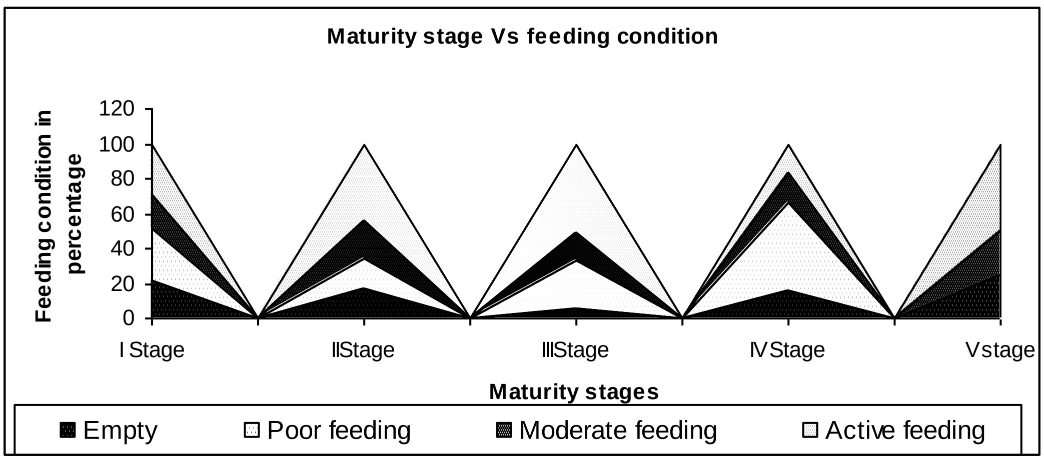

Fig.35. Maturity stages Vs feeding condition in *Rachycentron canadum*

5.4. DISCUSSION

5.4.1. Classification of maturity stages

Results of present study reveals that maturity stages of Cobia can be classified into five stages namely, immature, maturing virgin /recovered spent, Ripening, Ripe and spent. Richards (1967) followed a three-stage classification i.e. Immature, maturing and mature, for describing the maturity stages of Cobia inhabiting Chesapeake Bay and adjacent mid Atlantic waters. Above study did not considered maturity stage spent as a separate stage and considered maturing virgin/recovered spent and ripening stages as one stage. Geographical differences in the study area can be attributed as the major reason for this variance. Lotz *et al.* (1996) and Tonya *et al.* (2010) contradicts with the findings of Richards (1967), and they classified maturity stages of Cobia into six stages (five development categories and one post development category). Recovered spent included in the second stage in the present study has been considered as separate stage by the above authors. Tonya *et al.* (2010) carried out histological analysis of gonads, and observed that Cobia follows asynchronous reproduction and results of histological analysis supported the five maturity stage classification of Cobia.

Histological analysis is considered as most appropriate method for gonad maturity study. Macroscopic analysis has been carried out during the present study and the results are in agreement with the findings of histological analysis (Tonya *et al.*, 2010). Moreover, according to Quasim (1973) five stage maturation classification is more appropriate for fishes inhabiting in tropical waters.

5.4.2. Sex ratio

Results of sex ratio analysis and subsequent testing of statistical significance by following Chi-square test performed showed slight predominance of male over female.

Table 21. Sex ratio of *Rachycentron canadum* reported by various authors from different localities

Sex ratio(F:M)	Area of study	Author/s
26:74	Eastern Chesapeake Bay, USA	Richards (1967)
72:28	Western Chesapeake Bay, USA	Richards (1967)
2.1:1	Louisiana, USA	Thompson *et al.* (1991)
1:1	North Carolina, USA	Smith (1995)
1:0.36	North central Gulf of Mexico	Lotz *et al.* (1996)
2.7:1	Northeastern Gulf of Mexico	Franks *et al.* (1999)
1:1.5	North west coast of India	Somvanshi *et al. (*2000)
1:1.49	Northern water of Persian Gulf	Behnam *et al.* (2006)
2.18:1	Northeastern Australia	Tonya *et al.* (2010)
0.8: 1	North west coast of India	Present study

Sex ratio of Cobia reported by different authors from different localities of Cobia habitat is furnished in Table 21. Richards (1967), Behnam *et al.* (2006) and Somvanshi *et al.* (2000) observed a dominance of male over female and their observations are in agreement with the findings of the present study.

Richards (1967), Thompson *et al.* (1991), Lotz *et al.* (1996), Franks *et al.* (1999) and Tonya *et al.* (2010) reported a dominance of female over male Cobia. Richards (1967) studied sex ratio of Cobia along eastern and western Chesapeake Bay, USA reported dominance of male over female along eastern Chesapeake Bay and observed an opposite trend along western Chesapeake Bay. The author reported dominance of female Cobia over male along western Chesapeake Bay. Results of above study along the waters of Chesapeake Bay clearly indicate that, sex ratio of Cobia will vary according to the habitat.

Results of Somvanshi *et al.* (2000), who studied the sex ratio of Cobia inhabiting the waters of north west cost of India matches with the findings of present study. Here study area is identical to the present study and observation of male dominance over female Cobia is in close agreement.

5.4.3. Size at first maturity

Present study estimated size at maturity of female and male Cobia at 63 cm and 70 cm respectively, following L_{50} method. Occurrence of mature male and female specimens within the size group of 40-50 cm TL onwards was also observed during the study. Length of mature female specimen collected by Rajan, *et al.* (1968) from Chilka Lake (India) was 42.5 cm. These findings support the view that Cobia mature early.

Sizes at first maturity of Cobia reported by different authors from various localities are furnished in Table.22. Richards (1967), Lotz *et al.* (1996), Williams (2001), Kaiser and Holt(2005) and Tonya *et al.* (2010) are in full agreement with the finding of the study, that male Cobia mature at smaller length than female. Faster growth rate recorded for female Cobia can be attributed as one of the reasons for this difference in size at first maturity of both the sexes.

Size at first maturity reported by various authors reported from different waters differs from one another. According to Moyle and Cech (2000) size and age at first maturity depends on the nature of the environment in which the population of the species inhabits. Hence geographical difference, differences in physico chemical parameters of the habitat, differences in food availability etc can be considered as major reasons for this variation.

As far as Cobia occurring in Indian waters is concerned, present study is the premier one that estimated size at first maturity following L_{50} method.

Table 22. Size at first maturity of *Rachycentron canadum* reported by various authors from different localities

Sex	Length in cm	Total length (TL)/ Fork length (FL)	Area of study	Author/s
F	69.6	FL	Chesapeake Bay, USA	Richards (1967)
M	51.8	FL	Chesapeake Bay, USA	Richards (1967)
F	42.6	TL	Chilka lake, India	Rajan, *et al.* (1968)
F	70	FL	North Carolina, USA	Smith (1995)
F	83.4	FL	North central Gulf of Mexico	Lotz *et al.* (1996)
M	64.0	FL	North central Gulf of Mexico	Lotz *et al.* (1996)
F	84.5		Gulf of Mexico	Williams (2001)
M	64		Gulf of Mexico	Williams (2001)
F	83.4.	FL	Texas, USA	Kaiser and Holt (2005)
M	64.0	FL	Texas, USA	Kaiser and Holt (2005)
F	78.4	FL	Northeastern Australia	Tonya *et al.* (2010)
M	77.0	FL	Northeastern Australia	Tonya *et al.* (2010)
F	70	TL	North west coast of India	Present study
M	63	TL	North west coast of India	Present study

5.4.4. Spawning season

Results of month wise percentage of mature specimens and GSI values lead to the conclusion that Cobia breeds throughout the year with peak spawning activity during July-August and November- January. Peak spawning season of Cobia recorded by various authors from different geographical location is furnished in Table 23. Spawning season of Cobia occurring in different habitats varies from place to place (Table.23). However, literature on span of spawning period of Cobia is in agreement with the findings of the present study that Cobia follows a protracted spawning season.

In fishes, spawning usually occur at a time when environmental conditions are most favorable for larval survival and development (Moyle and Cech, 2000). This period of occurrence of favorable condition may differs from place to place and are affected by various environmental factors like water temperature, photoperiod, monsoon, food availability etc. Hence, spawning season of fish may vary from habitat to habitat. Peak spawning season of Cobia recognized by the present study coincide with the period of monsoon seasons (south west monsoon and northeast monsoon) along the northwest coast of India when the surrounding conditions are most favourable.

Longhurst and Pauly (1987) and Houde (1989) observed that coastal fishes in the tropics and sub-tropics are mainly serial spawners with a protracted spawning season, in contrast to species in temperate regions. This observation is true in the case of Cobia inhabiting the north west coast of India and also matches with the findings of present study.

5.4.5. Spawning frequency and fecundity

Investigation on ova diameter of mature ovaries of Cobia was identified three distinct groups of ova in the ovary. This elucidated that Cobia breeds more than once in a spawning season. Richards (1967), Lotz *et al.* (1996), Franks *et al.* (1999), Brown-Peterson *et al*. (2001) and Tonya *et al.* (2010) also reported occurrence of more than two distinct groups of ova and inferred that Cobia breeds more than once in a spawning season.

Table 23. Peak spawning season of *Rachycentron canadum* reported by various authors from different localities

Peak Spawning season	Area of study	Author/s
Mid June–mid August	Chesapeake Bay, USA	Joseph *et al.* (1964)
Late June -mid August	Chesapeake Bay, USA	Richards, (1967)
August	Puerto Rican waters	Erdman (1968)
Spring	Northern Gulf of Mexico	Dawson (1971)
July-September	Texas, USA	Finucane *et al.* (1978)
April-September	Gulf of Mexico	Tortonese (1986)
May-July	Louisiana, USA	Thompson *et al.* (1991)
Spring and summer	Northern Gulf of Mexico	Biesiot *et al.* (1994)
May-July	North Carolina, USA	Smith (1995)
April –October	North central Gulf of Mexico	Lotz *et al.* (1996)
April to September	Southern United States of America	Brown-Peterson *et al*. (2001)
April to October	Gulf of Mexico, Mexico	Franks and Brown-Peterson (2002)
September – June	Northeastern Australia	Tonya *et al.* (2010)
July-August and November-December)	North west coast of India	Present study

Range of ova diameter studied was 250-1250 µm, of which mature ova group was between 700-1250 µm. Somvanshi *et al.* (2000) and Brown-Peterson *et al*. (2001) also reported that ova diameter more than 700 µm as mature stock; hence agree with the findings of the present study. According to Richards (1967) and Lotz *et al.* (1996) ova diameter of mature stock are above 600 µm and 650 µm respectively.

Table 24. Fecundity estimates of *Rachycentron canadum* reported by various authors from different localities

Fecundity in numbers	Area of study	Author/s
1,900,000-5,400,000	Chesapeake Bay, USA	Richards, (1967)
2,600,000-191,000,000	North central Gulf of Mexico	Lotz *et al.* (1996)
1,955,264	North west coast of India	Somvanshi *et al. (*2000)
377,000- 1980,500	Gulf of Mexico	Williams (2001)
377,000-1,980,000 (Batch fecundity)	Southern United States of America	Brown-Peterson *et al*. (2001)
400,000-5,000,000	Texas	Jeffrey and Holt (2005)
1,684,954±118,990	Northern water of Persian Gulf	Behnam *et al.* (2006)
577,468–7,372,283	Northeastern Australia	Tonya *et al.((*2010)
1,231,630–1,800,350	North west coast of India	Present study

Present study estimated total fecundity of Cobia as 1.23 to 1.80 million(125 cm TL – 147 cm TL), which is more or less similar to the estimate of solitary study available from north west coast of India (Somvanshi *et al.,* 2000). Fecundity estimates of Cobia from different localities by various authors are furnished in Table 24. Values ranged from 0.37 million to 19.1 million eggs.

6. LENGTH -WEIGHT RELATIONSHIP AND CONDITION FACTOR

6.1. INTRODUCTION

Length-weight relationship studies of fishes are considered as an important tool for understanding of fish. Length is a linear measure (in centimeter) and the weight of a fish (in gram) is approximately equal to its volume (cubic centimeter). Hence, weight of a fish is a function of length. The relationship can be expressed by the hypothetical law $W= aL^3$. The value of exponent may considerably deviate from the value 3, as most fishes change their form or shape when they grow (Martin, 1949). This variation from expected weight to the actual weight of individual fish is assessed by analyzing the length-weight relationship

Length-weight relationship establishes the mathematical relationship between length and weight of fish (Beyer, 1987). Inter-conversions of these variables are required for setting up of yield equations, hence leads to information about the body forms of different groups of fishes and its growth pattern. Length-weight relationship also provides information on the changes in the well being of the fishes that happens during their life cycle. This can be estimated by comparing the expected weight estimated by using the length-weight relationship with actual weight of fish. Like other morphometric measurements, length-weight relationships may change during the events of life cycle like metamorphosis, growth and onset of maturity (Le Cren, 1951).

Length-weight relationships can be used as character for differentiation of taxonomic units. An already established length-weight relationship will be useful for assessing the data that contains only length frequency measurements. This relationship can be used in setting up of yield equations, estimate the number of fishes landed and for comparing the population over space and time (Beverton and Holt,1957).

The importance of variations in specific gravity of fish (Tester, 1940) in relations to conditions was discussed by Kesteven (1947b). Density of the fish is maintained as same as the density of its surroundings, hence changes in weight of fish to length are related to the changes in shape or volume and not to specific gravity. Variation from the general length-weight relationship is indicative of the overall condition and such changes in condition have been usually analysed by means of a condition factor or coefficient of conditions or ponderal index (Hille, 1936; Thompson, 1943).

Le Cren (1951) proposed the relative condition factor in preference to condition factor as the latter is influenced by many environmental and biological factors. Condition factor measures the deviation from a hypothetical ideal fish where as relative condition factor measures the deviation from the average weight or length of fish.

Various biological factors such as fatness, gonadal development, feeding and other environmental factor lead to fluctuations in the condition factor. Evaluation of the conditions at different body lengths can give valuable information regarding the maturation and spawning in the life span of the fish, whereas a close look at condition at different months can give definite clues regarding the breeding seasons.

Richards (1967), Hassler and Rainville (1975), Darracott (1977), Edwards *et al*, (1985), Bohnsack and Harper, (1988), Torres, (1991), Claro and García-Arteaga(1994), Burns *et al* (1998), Franks *et al.* (1999) and Williams(2001) contributed information on length-weight relationship of Cobia occurring along Chesapeake Bay and adjacent mid- Atlantic waters, off north Carolina, Tanzania, Gulf of Aden, southeastern United States, southern Africa, Chesapeake Bay, Gulf of Mexico, Gulf of Mexico and south Atlantic respectively. Most of the above studies were either based on limited number of specimens or for a limited period.

Somvanshi *et al*. (2000) and Abdurahiman *et al.* (2004) carried out length-weight relationship study of Cobia occurring in Indian waters, based on samples collected from research vessel and commercial fishery respectively. Somvanshi *et al*. (2000) arrived at the length weight relationship of Cobia based on 30 specimens collected during a single voyage of survey vessel, while Abdurahiman *et al.* (2004) established the relationship by utilizing 28 specimens collected from Karnataka coast of India. Both studies were carried out with limited sample size; hence have its own limitations. Hence, an attempt has been made to estimate the length-weight relationship of Cobia occurring along northwest coast of India by collecting samples from research vessel as well as from commercial landings.

Relationships established through the regression method are further used for understanding the well being of the fish by assessing the condition factor.

6.2. MATERIALS AND METHODS

Samples of Cobia, *Rachycentron canadum* were taken from the vessel *M.V. Matsya Nireekshani* belonging to the Fishery Survey of India, Mumbai during the period from January 2008 to December 2009. This was also supplemented by samples collected from landing centers viz. Sassoon dock and New ferry wharf at Mumbai. Landings were mostly from trawl, hook and line and gillnet fishery. Samples collected from landing centers were used in fresh condition, while frozen samples (Samples kept frozen at -20^0C) were thawed, cleaned and excess moisture removed before taking the length and weight(Philip,1994). Total length was taken from the tip of snout to the caudal fin end in cm and weight was taken in gram. A total of 285 specimens comprising 158 males and 127 females were used for study.

The length-weight relationship expressed as

$W= aL^b$ ……………………………………………………….. (8)

Logarithmic transformation of the above formula gives a linear equation, that is:

Ln W = ln a + b x ln L…..…………………………………….. (9)

Where

W = weight in gram;

L = total length in cm;

a and b are constants

The relationship was established for both male and female by linear regression of the natural logarithms of the length and weight data following Pauly (1983). Conversion of the resultant transformed equation to the original equation was achieved by rewriting the equation as

$W= e^{a} \times L^{b}$………………………………………………………… (10)

Confidence limit for slope (b) estimated following King (1995) and using the formula:

95% confidence limit = b ± t X Sb ……………….……….. (11)

Where,

b = slope in length weight relationship

t = table value of t (t test at 95 % confidence

$S_b^{2} = (1/ (n-2)) (S_y^{2} / S_x^{2}) b^{2})$ ………………………………..(12)

Where,

S_b^{2} = variance of slope

S_y^{2}=sum of square Y

S_x^{2}=sum of square X

n = number of observations

The regression analysis, Analysis of co variance(ANOCOVA) on the regression equations, t test on b and r value were carried out following standard statistical procedures (Snedecor, 1961;Snedecor and Cochran,1967).

Condition factor values were assessed for male, females and pooled data. Data analysed for various length group for different months to understand the well being of the species and also to infer information on reproductive behavior, feeding habits etc. (Froese, 2006). Condition factor/Ponderal index/Fultons condition factor (Fulton, 1904) was estimated using formulae:

$K = 100\ W/L^3$ ……………………………………………….. (13)

Where,

W = weight of fish in gram (gm)

L = length of fish in centimeter (cm).

Modified condition factor (Ricker, 1975) was estimated following formula:

Modified condition factor = $100\ W/\ L^b$ ………………………..….. (14)

Where,

W = weight of fish in gram (gm)

L = length of fish in centimeter (cm)

b is b value in length weight relationship.

Relative condition factor 'Kn' (Le Cren,1951) was estimated by using formulae

Kn = W / ^w ………………………………………..…………(15)

Where,

W = actual weight of fish in gram (gm)

^w = Expected weight

^w = Log W* = log a + b log L ………….………….………….. (16)

Where,

W* = Average of W

6.3. RESULTS

6.3.1 Length-weight relationships

The length-weight relationship of Cobia, *Rachycentron canadum* representing male, female and pooled (both sexes) are presented in Fig.36, Fig.37 & Fig. 38 respectively. The equations thus derived in respect of length-weight relationship are as follows:

Male: $W = 0.004381 \times L^{3.078}$ (r2 = 0.9803)

Female: $W = 0.003958 \times L^{3.1075}$ ($r^2 = 0.9635$)

Pooled: $W = 0.0042 \times L^{3.0895}$ ($r^2 = 0.9725$)

The corresponding logarithmic regression equation can be represented as follows:

Male: $\ln W = -5.4261507 + 3.078 \times \ln L$

Female: $\ln W = -5.53194833 + 3.1075 \times \ln L$

Pooled: $\ln W = -5.47046 + 3.0895 \times \ln L$

95% confidence limit estimated for the slope (b value) of length weight relationship of male, female and pooled data are:

Male: 3.0096 – 3.1464

Female: 3.0006-3.2134

Pooled: 2.9164 – 3.2635

The results of t test carried out to understand the significance of relationship and result is furnished in Table.25.

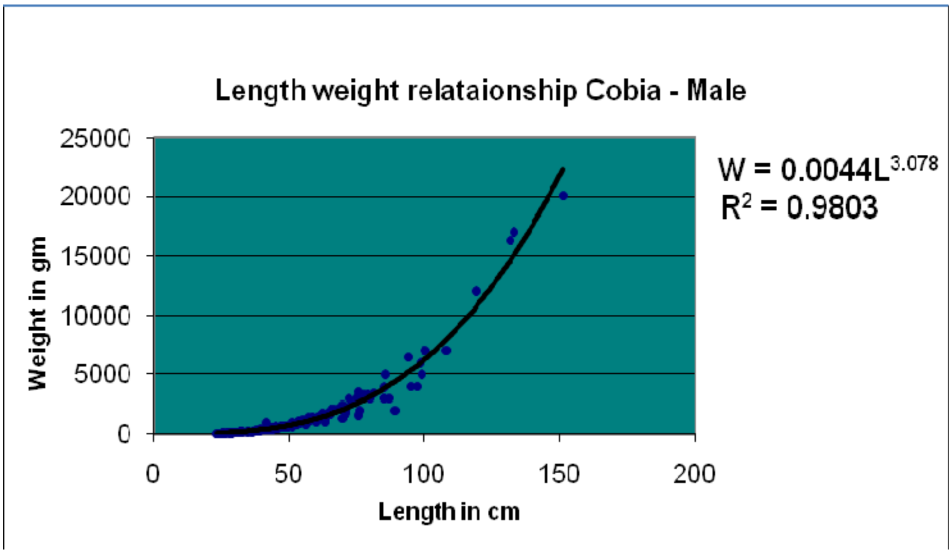

Fig.36. Length-weight relationship of male *Rachycentron canadum*

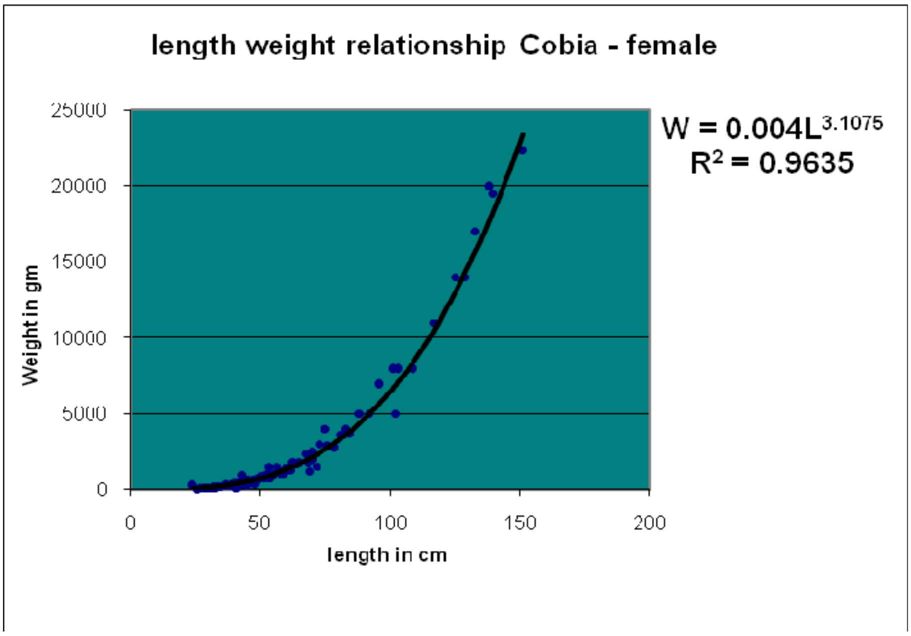

Fig.37.Length-weight relationship of female *Rachycentron canadum*

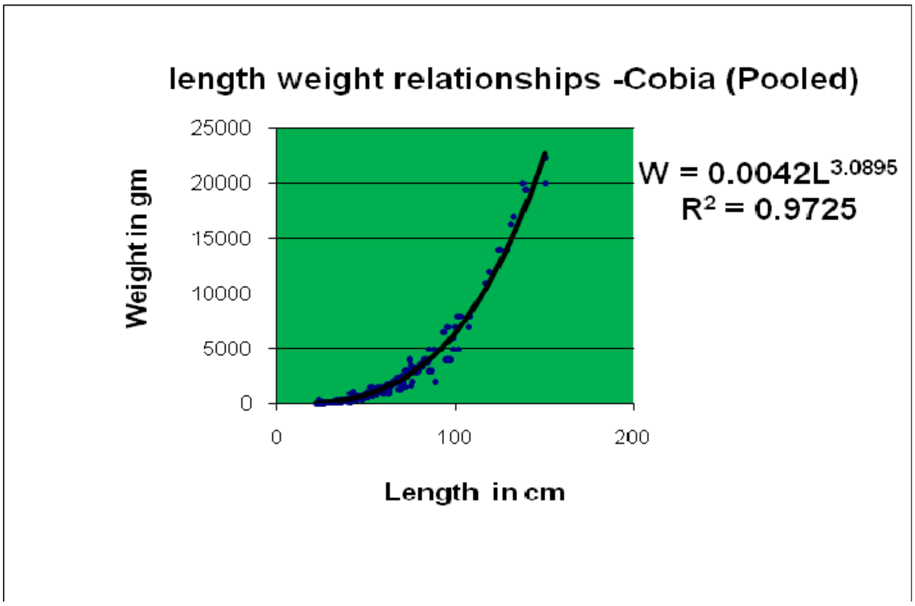

Fig.38. Length-weight relationship of *Rachycentron canadum* (pooled)

As shown in the table there is no significant difference between b value and the cube value in both the sexes and pooled data. This indicates that both the male and females follow isometric growth. r^2 values estimated in all the 3 cases were very close to 1, thus showing the accuracy of data and methodology followed for the estimation of relationship.

Table 25. Basic statistics in estimation of length- weight relationship of *Rachycentron canadum*

Parameters	**Male**	**Female**	**Pooled**
a value	0.004381	0.003958	0.004209
b value	3.077957	3.107482	3.08951
r^2 value	0.9803	0.9635	0.9725
T value (calculated)	0.464392	0.438682	0.6805068
Critical value at 1%	2.6	2.6	2.6
No. of observations(n)	158	127	285
Significance	Not Significant	Not Significant	Not significant

Table 26. Comparison of regression of length weight relationship of male, female and pooled data of *Rachycentron canadum* by ANOCOVA

Source	DF	SS X	SP	SSY	b	DF	SS	MS
Male	157	26.8159	82.5380	259.1563	3.078	156	5.108	0.03274
Female	126	19.2633	59.8603	193.0584	3.107	125	7.044	0.05635
Total						281	12.152	0.04324
Pooled W	283	46.0791	142.3983	452.2148	3.090	282	12.161	0.04313
Difference between slope						1	0.010	0.00977
Between	1	0.0525	0.1896	0.6850				
Pooled +Between (W+B)	284	46.1316	142.5879	452.8997	3.091	283	12.176	0.04302
Difference between corrected mean						1	0.014	0.01432
Comparison of slope F = 0.00977 (df. 1,281) = 0.23* Comparison of elevation F= 0.01432 (df. 1,282) = 0.33* * Not significant								

The results of the ANOCOVA on length-weight regression equation are given in Table 26. The results showed the F values are smaller than the table values at 5% level of significance. This indicates there is no significant difference between the length-weight relationship of male and female.

6.3.2. Condition factor

Month wise Fulton's condition factor, Relative condition factor and Modified condition factor for male are shown in Table 27 & Fig.39. The condition factor values of male ranged from 0.5 (October) to 0.75(July). Relative condition factor values were in the range of 0.86(October) -1.23 (July). Similar trend was seen in the case of modified condition factor, which ranged from 0.38(October) to 0.54 (July).

Table 27. Month wise condition factor of male *Rachycentron canadum*

Month	Condition factor	Relative condition factor	Modified condition factor
January	0.63	1.07	0.47
February	0.62	1.03	0.45
March	0.64	1.08	0.47
April	0.64	1.10	0.48
May	0.73	1.22	0.54
June	0.66	1.08	0.47
July	0.75	1.23	0.54
August	0.60	1.02	0.45
September	0.66	1.14	0.50
October	0.50	0.86	0.38
November	0.60	1.04	0.46
December	0.60	1.00	0.44

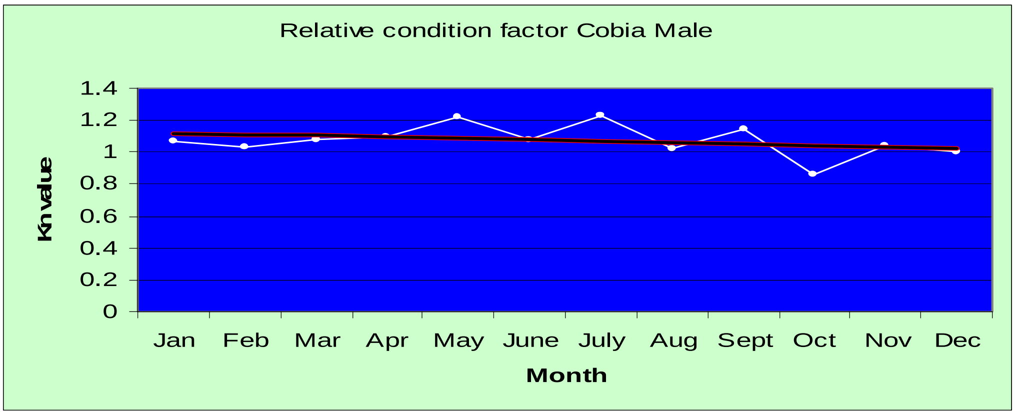

Fig.39. Relative condition factor of male *Rachycentron canadum*

Fulton’s condition factor, Relative condition factor and Modified condition factor for female during various months are shown in Table 28 & Fig. 40. The condition factor values of female ranged from 0.43 (November) to 0.75(September). Relative condition factor values were in the range of 0.74

(November) to 1.27(September). Similar trend was seen in the case of modified condition factor, which ranged from 0.29 (November) to 0.5 (September).

Table 28. Month wise condition factor of female *Rachycentron canadum*

Month	Condition factor	Relative condition factor	Modified condition factor
January	0.60	1.01	0.40
February	0.68	1.10	0.44
March	0.67	1.08	0.43
April	0.58	0.82	0.39
May	0.58	0.97	0.38
June	0.58	0.96	0.38
July	0.65	1.01	0.40
August	0.51	0.86	0.37
September	0.75	1.27	0.50
October	0.56	0.96	0.38
November	0.43	0.74	0.29
December	0.65	1.06	0.42

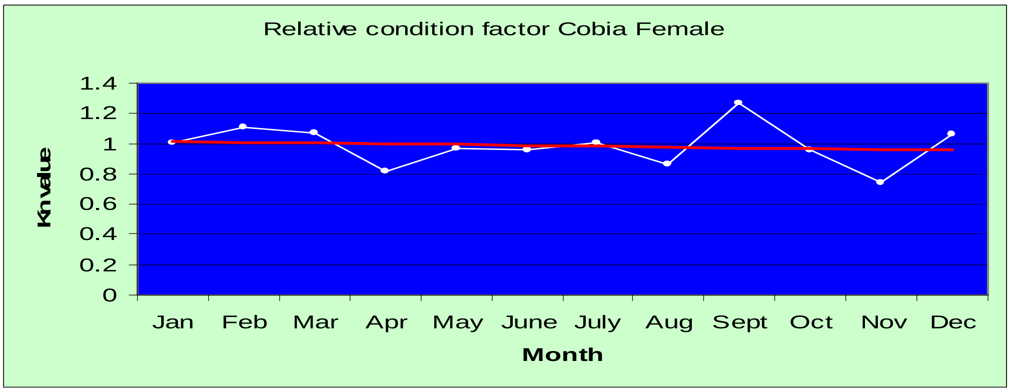

Fig.40. Relative condition factor of female *Rachycentron canadum*

Condition factor values were analysed on various length group basis to understand the well being of the fish in respect of pooled data and the results are shown in Table 29 & Fig. 41. Condition factor values were above 0.56 and ranged between 0.57and 0.7.3. Relative condition values were in the range of 0.93 to 1.12, while modified condition values ranged between 0.39 and 0.47.

Table 29. Length wise condition factor of *Rachycentron canadum* (pooled)

length class (in cm)	Condition factor	Relative condition factor	Modified condition factor
21-30	0.61	1.08	0.45
31-40	0.57	0.99	0.42
41-50	0.59	1.00	0.42
51-60	0.64	1.06	0.45
61-70	0.63	1.03	0.43
71-80	0.65	1.04	0.44
81-90	0.60	0.96	0.40
91-100	0.62	0.98	0.41
101-110	0.63	0.99	0.42
111-120	0.70	1.08	0.46
121-130	0.68	1.05	0.44
131-140	0.73	1.12	0.47
141 above	0.62	0.93	0.39

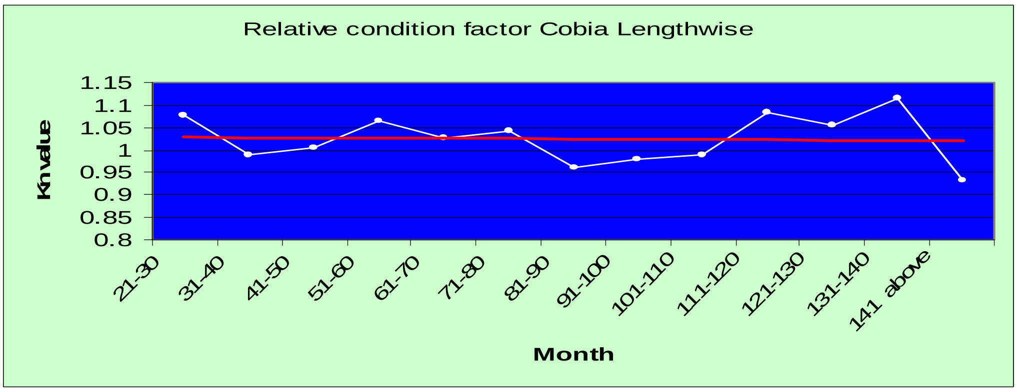

Fig.41. Length wise Relative condition factor of *Rachycentron canadum* (pooled)

6.4. DISCUSSION

6.4.1 Length-weight relationships

The results of statistical analysis of length weight relationships showed that the value of exponent (b value) of the length weight relationships was not significantly different from the cube value (3) in both the sexes. This indicates that both male and female Cobia follows isometric growth pattern. Results of

ANOCOVA showed that curvilinear relationships of male and female cobia are same.

Length weight relationships of Cobia reported by various authors from different parts of the world are furnished in Table 30. Value of exponent (b value) assessed by different authors are very close to 3, similar to the values obtained in the present study. Richards (1967), Franks *et al.* (1999) and Williams (2001) reported similar curvilinear relationship in both the sexes of Cobia. These findings are in agreement with the results of present study. However, Burns *et al.* (1998) established the length-weight relationship of Cobia collected from different coastal areas of Gulf of Mexico reported that the curvilinear relationship differs from coast to coast. They attributed geographical difference of the area of study as one of the major reasons for this difference

Present study estimated the exponent (b value) of length weight relationships of male and female cobia as 3.078 and 3.1075. Somvanshi *et al.* (2000) and Abdurahiman *et al.* (2004) established length-weight relationship of Cobia of Indian waters and the results showed that b value is higher in female than male. Present study agrees with the above findings. Both studies were based on a smaller sample size and not attempted to establish the statistical significance of the values. Significance of the curvilinear relationship tested by standard statistical procedures in the present study is highly useful in understanding the dynamics of the Cobia population.

Table 30. Length-weight relationship of *Rachycentron canadum* reported by various authors from different localities

Sex	Length (TL/FL)	No. of specimens	a value	b value	Area of study &Author/s
Pooled	FL	288	0.003	3.088	Chesapeake Bay Richards (1967)
Male e	FL	9	0.0064	3.15	Tanzania Darracott (1977)
Femal		9	0.027	2.79	
Pooled	FL	-	0.0010	3.500	Gulf of Aden Edwards *et al.* (1985)
Pooled	FL	-	0.0027	2.812	Southern Florida Bohnsack and Harper(1988)
Pooled	FL	-	0.0056	3.160	Soth Africa,Torres, 1991
Pooled	TL	915	0.0015	3.428	Northeastern Gulf of Mexico Franks *et al.* (1999)
Male	TL	18	0.0096	2.874	North west coast of India Somvanshi *et al.* (2000)
Female		12	0.0036	3.1603	
Pooled	FL	-	10.8×10^{-8}	2.97	Gulf of Mexico Williams, 2001
Male		16	0.010	2.876	South west coast of India Abdurahiman *et al.* (2004)
Female		22	0.004	3.092	
Male	TL	158	0.004381	3.078	North west coast of India Present study
Female		127	0.003958	3.107	
Pooled		285	0.0042	3.090	

6.4.2. Condition factor

Table 27 & Fig. 39 showed that except during October, all the three values of Fulton's condition factor, Relative condition factor and Modified condition factor of male Cobia were above 0.56, 1 and 0.4 respectively. Fishes with condition factor value above 0.56 are considered as in good condition (Bennet, 1970). Results indicated that male Cobia was in good condition throughout the period except during October, in which they were in average condition.

As shown in Table 28 & Fig. 40 condition factor values for female Cobia during November, August and October were below 0.56, which manifest that females were in average condition during the above months and were in good condition during the rest of the period. Relative condition values during January-March, July, September and December were above one. This indicated that fish is in good condition during the above-mentioned periods and was in average condition during the rest of the period. Similar trend was seen in the case of modified condition factor values in female Cobia.

Table29 & Fig. 41 showed that relative condition values of Cobia (pooled) were above 1 or close to 1; this indicated that fish is in good condition in all the size groups from 20 cm to 140 and above. Modified condition factor values (0.39 to 0.47) also followed similar pattern in respect of all the size groups. Condition factor values did not follow any specific pattern of increase or decrease according to the size increase, hence it can be inferred that in general Cobia is in good condition throughout its juvenile to adult stage.

Three different methods of condition factor were employed for estimation of growth indices or well being of Cobia. Results obtained by all the three methods were almost complementary; this indicated that Cobia is in good condition throughout its life cycle. Difference in the availability of prey items, changes in the environmental condition etc. may be reflected on well being of fish; hence there were minor variations during certain months and in different size groups.

7. AGE AND GROWTH

7.1. INTRODUCTION

Growth in simple terms can be defined as change in length or weight over time. Fish continue to grow throughout their life and growth rate is not constant over the years. The growth rate is variable because it is greatly dependent on a number of biotic and abiotic factors. Major biotic factors affecting growth rate are age, maturity, ingested food quality and predators. It is also influenced by abiotic factors such as temperature, photoperiod, dissolved oxygen and salinity. All these factors interact with each other to influence the growth rate (Moyle and Cech, 2000).

The age of fish can be determined by rearing the fish in tanks or aquaria or by tagging. Age also can be determined following indirect methods like length frequency method and also by interpretation of the growth rings on the hard parts. The hard parts that are usually used for age determination are the scales, otolith, vertebral centra, dorsal and pectoral spines, opercula, etc. However, the growth rings are known to be more distinct and clear on the otolith than in other structure of the fish. This method of aging is based on the principle that successive rings are formed as the fish grows in age (Pannela, 1971).

Despite the long-term global use of otolith annuli as age indicators, the factors influencing their formation are not clear-cut. Each annulus is comprised of an opaque and translucent zone, which in many species corresponds to fast and slow growth respectively. In general, the opaque zone seems to be formed during periods of increasing water temperatures, while the translucent zone is formed during periods of reduced growth, or in association with spawning. In tropical waters, this demarcation between zone of reduced growth and fast growth is not clear (Menon, 1953). The methods based on length frequency data have been widely applied in the tropics, because of their simplicity as well as availability of adequate data.

The knowledge of age and growth of a fish is essential for understanding the age composition of the stocks and the role of various year classes in the fisheries. These provide valuable information on stock composition, age at maturity, longevity, mortality, growth and yield. Accordingly, knowledge of age and growth is of vital importance in fisheries resource management.

Cadenat (1950) and Joseph *et al*. (1964) provided preliminary information on age and growth of Cobia. Richards (1967) estimated age of Cobia inhabiting Chesapeake Bay and adjacent mid-Atlantic waters, by scale methods and growth estimates by von Bertalannfy's. Thompson *et al.* (1991) studied the age and growth of Cobia occurring along Louisiana waters and Franks *et al*. (1991) provided information on Cobia along northeastern Gulf of Mexico through tagging and recapture studies. Smith (1995), Franks *et al*. (1999), Williams (2001) and Fry and Griffiths (2010) studied the age and growth parameters of Cobia along north Carolina waters, northeastern Gulf of Mexico, territorial waters of United States and Australia respectively.

As far as Cobia occurring in Indian waters is concerned but for a preliminary investigation by Somvanshi *et al.* (2000) no other studies have been made till date. Age and growth studies of a fish will provide basic inputs for fishery management. Hence, an attempt is made to provide information on age and growth of Cobia inhabiting the northwest coast of India.

7.2. MATERIALS AND METHODS

1261 specimens of total length ranging from 22.6 cm to 181cm collected from the vessel *M.V. Matsya Nireekshani*, the survey vessel belonging to Mumbai base of Fishery Survey of India, Mumbai and from local landing centers at Mumbai were used for estimation of age and growth. All fishes collected during the period January 2008 to December 2009 were grouped in to length class of 10 cm interval. To ensure uniformity of length frequency, the entire data were pooled as one-year data and analysed using FAO-ICLARM Stock Assessment Tools (FiSAT) (Gayanilo *et al.*, 2005).

7.2.1. Estimation of growth parameter L_∞ and K

The von Bertalanffy growth equation (VBGF) (Bertalanffy, 1957) was used to describe the growth. The simplest version of VBGF is

$L_t = L_\infty$ (1 - EXP (-K (t - t_o) ……………………………………...(17)

For growth in length and for weight

$W_t = W_\infty$ (1 – EXP (-K(t - t_o)……………………………….……(18)

Where

L_∞ = asymptotic length

W_∞ = asymptotic weight

K = growth coefficient

t_o = the age the fish would have at length or weight zero if they grow as per equation

Lt = predicted length at age t

Wt = predicted weight at age t.

The analysis was carried out in the following stages:

1) Analysis of the data using Electronic Length Frequency Analysis (ELEFAN I). to estimate K value and L_∞ (Pauly and David, 1981; Pauly, 1982; Pauly and Morgan, 1987) and Shepherd's method (Shepherd, 1987; Isaac, 1990) to find out K value by fixing L_∞

2. Analysis of data using Powel-Wetherall plot (Powell, 1979; Pauly, 1986; Wetherall, 1986) to find out z/k value and L_∞

3. Model class progression analysis following integrated method (Pauly, 1982, 1983)

4. Estimation of K value and L_∞ following Ford-Walford Plot (Ford, 1933: Walford, 1946) and Gulland and Holt (1959) plot method

5. Estimation of t_o following Beverton's method as well as by von Bertalanffy plot

6. Fitting of von Bertalanffy growth equation.

Electronic Length Frequency Analysis (ELEFAN I) identified the growth curve that "Best" fits the length-frequency data, using the value of Rn as a criterion. "Best" growth curve was identified by scan of K-values. Initial sample mid length has been taken as starting length. Length frequency data were reconstructed to generate "peaks" and "troughs", and the goodness of fit index (Rn) is defined by

$R_n = 10^{ESP/ASP}/10$ ……………………………………….……..(19)

Where,

ASP ("Available Sum of Peaks") = sum of the 'best' values of the available 'peaks'

ESP ("Explained Sum of Peaks") = sum of all the peaks and troughs "hit" by a growth curve of the form,

$L_t = L_\infty (1 - EXP(-K(t - t_o) + St_s + St_o)$…………………………..(20)

Where,

$St_s = (CK/2\pi) \cdot \sin (2\pi(t-t_s))$,

$St_o = (CK/2\pi) \cdot \sin (2\pi(t_o-t_s))$, and

L_t = the length at time t.

Shepherd's method was performed by K scanning with fixed L_∞. The score (S) for Sheperd's method is defined following:

$S = (s_A^2 + s_B^2)^{½}$)……………………………………….……(21)

Where,

s_A = goodness-of-fit scores (stz) obtained with the origin of the VBGF in calendar time (tz) set to 0

sB = the goodness-of-fit scores (stz) obtained with the origin of the VBGF in calendar time (tz) 0.25.

Stz is defined by:

$$Stz = \sum T_1\sqrt{N_1} \ldots\ldots(22)$$

Where,

N_i = frequency for length group i

$T_i = D \cdot \cos 2\pi\ (t\text{-}t_i)$

$D = (\sin\pi \cdot (\Delta t)/\pi(\Delta t))$

$t = \Delta t/2$

$D_t = t_{max} - t_{min}$

$t_i = t_z - (1/K)\cdot \ln(1-(L_i/L_\infty))$

$t_z = (1/2\pi) \cdot \tan^{-1}(s_B/s_A)$.

Estimated L_∞ and Z/K estimates by using Powel-Wetherall plot. Here smallest length L', or cut-off length is the smallest length fully recruited by the gear. Then

$$(\bar{L} - L') = a + b * L' \ldots\ldots(23)$$

Where

$$\bar{L} = (L_\infty + L') / (1+Z/K) \ldots\ldots(24)$$

$L_\infty = -a/b$

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

Modal class progression analysis (MPA) refers to a methodology that infers growth from the apparent shift of the modes or means in a time series of length-frequency samples. The mean was estimated following Bhattacharya's method (Bhattacharya, 1967). Here decomposition of composite distribution has been done by subjective identification of mean and linking of cohort. Utilizing the above decomposed data growth parameters were assessed following Gulland and Holt plot method (Gulland and Holt, 1959; Pauly, 1984) using the following equation:

$\Delta L / \Delta t = a + b * L^{-}$ ……………………………………………..(25)

Where,

$\Delta L = L_r - L_m$

$\Delta t = t_r - t_m$

$L = (L_r + L_m)/2$.

L_m = the length at marking (initial reading),

L_r = length at recapture

t_m = age at marking

t_r = age at recapture.

From these, growth parameters estimated

$L_\infty = -a / b$ ………………………………………………………...(26)

$K = -b$…………………………………………………………………...(27)

The growth parameters were simultaneously assessed following Ford-Walford plot, which is a modified version of VBGF:

$L_{t+1} = a + b L_t$ ……………………………………….…………….(28)

This can be rewritten as

$L_{t+1} = L_\infty (1 - EXP\text{-}K) + EXP\ K * Lt$ ……………….………….(29)

Or $L_{t+1} = a + b\ Lt$………………………………………….……….....(30)

L_∞ and K Estimated by following the formula:

$L_\infty = a/(1\text{-}b)$ ………………………………………………….…….(31)

$K = -\log_e b$ ……………………………………………...…..(32)

7.2.2. Estimation of growth parameter t_o

Growth parameter t_o was calculated following von Bertalanffy plot.

$to = t_{(l)} + (1/k \ln (1\text{-}Lt/ L\infty)$...(33)

The parameters L_∞ and K used in the above formula were obtained from Ford-Walford plot. The growth parameters thus arrived at was fitted in the VBGF to obtain growth model for the fish samples. By substituting the values of size at first maturity (male and female) in cm estimated in the present study(Chapter.5), age at first maturity of male and female was estimated following the equation:

$t = to\text{-}(1/K) \ln(1\text{-}Lt/ L_\infty)$ ………………………………………..(34)

7.3. RESULTS

7.31. Growth parameters L_∞ t_o and K

Monthly Length frequency distribution of Cobia for the period from January 2008 to December 2009 and ELEFAN curve are shown in Fig. 42& 43. Cobia reported throughout the period of study and stock was represented by different year classes. This is more clearly shown in ELEFAN curve (Fig.43).

K value and L_∞ estimated following three methods of direct fit of length frequency (ELEFAN, Shepherd's method and Powell and Wetherall method). K values plotted against score function following ELEFAN and Shepherd's methods and the results are depicted as Fig. 44 & 45.

Relationship between K value and score function followed similar trend in ELEFAN and Shepherd's methods. Above relationship was used to estimate the K value and L_∞. Difference of mean length and cut of length (mean L- L') against cut of length (length at which fish recruit to gear fully) is shown in Fig. 46. Cut of length identified by using pseudo catch curve available with the software.

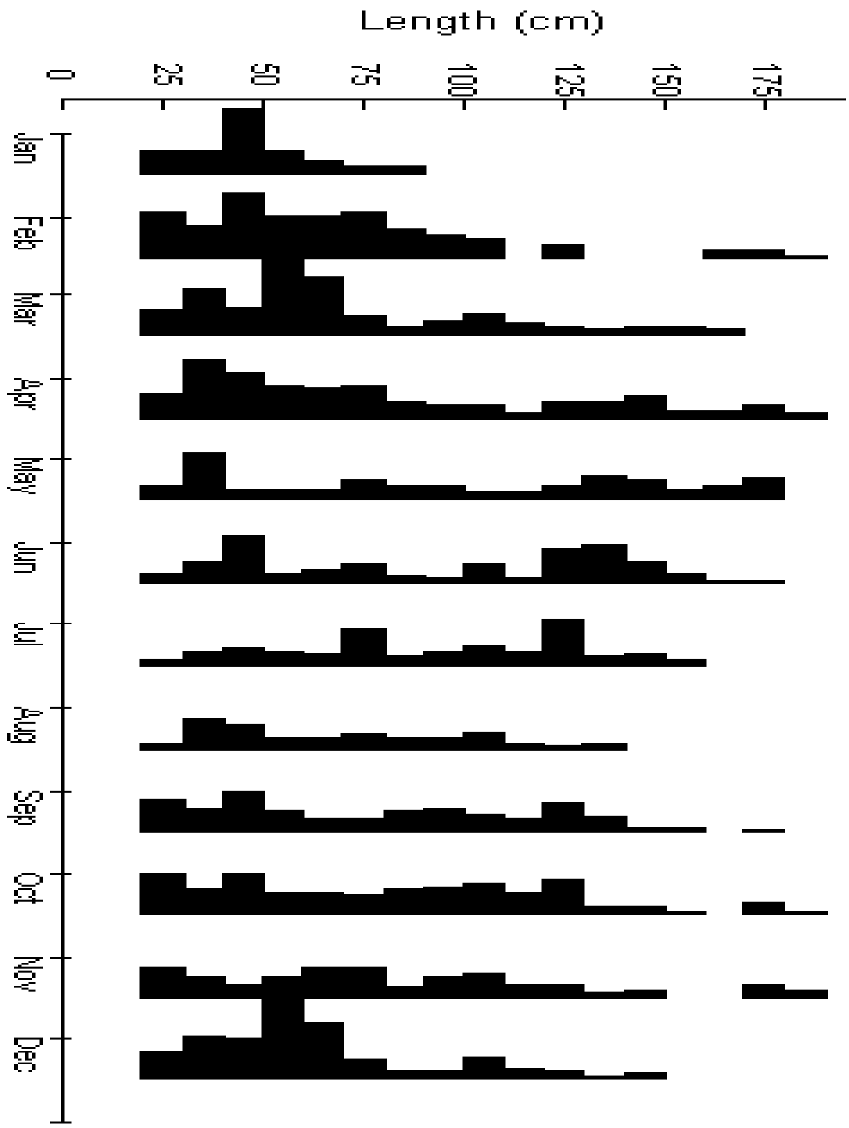

Fig.42. Monthly length frequency distribution of *Cobia Rachycentron canadum*

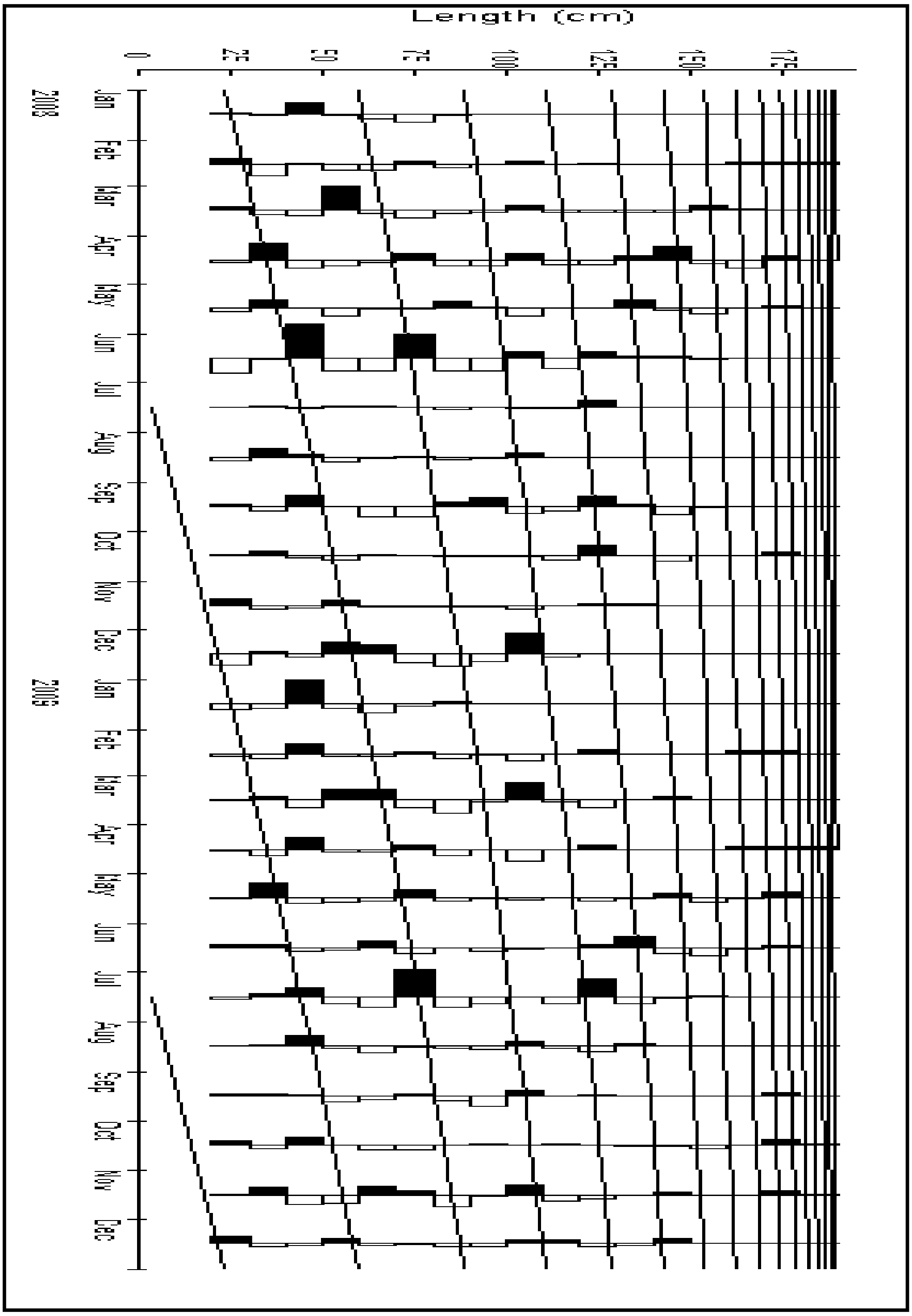

Fig. 43. ELEFAN I curve of Cobia *Rachycentron canadum*

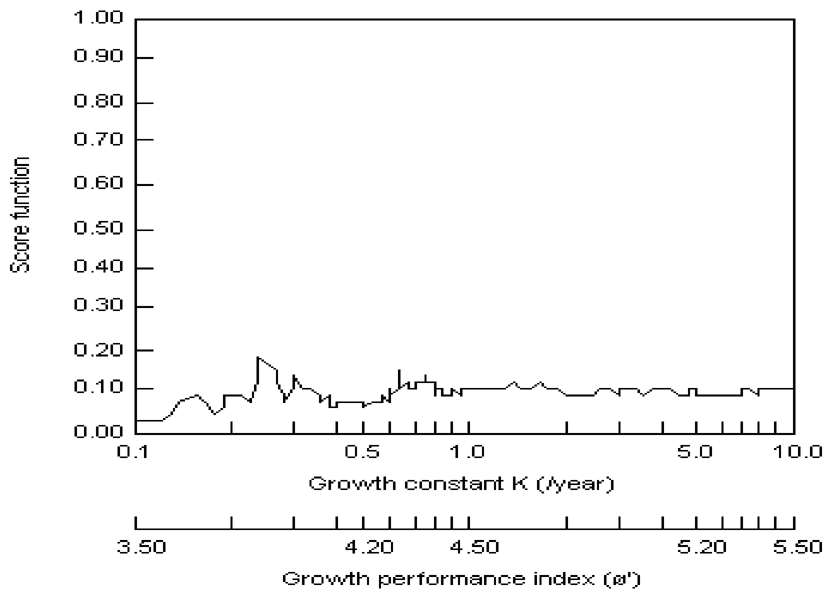

Fig.44. Non parametric scoring of VBGF fit using ELEFAN I

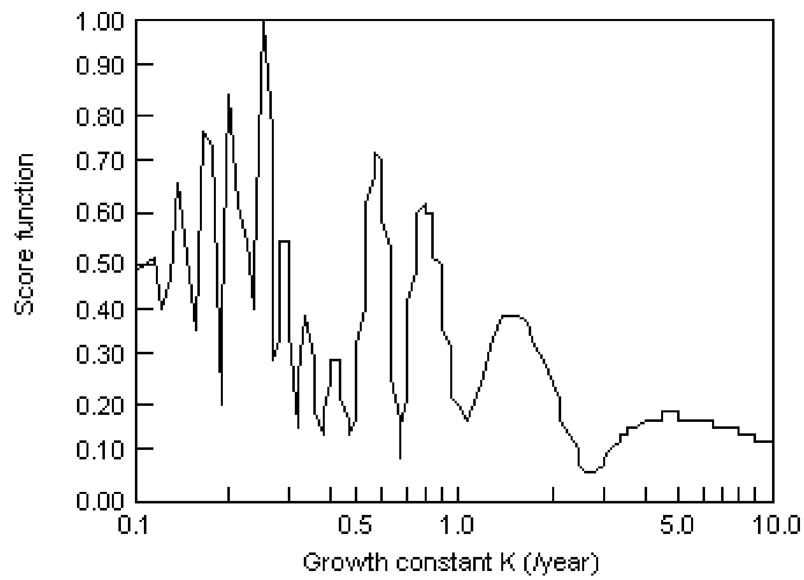

Fig.45. Maximising non parametric scoring of VBGF fit using Shepherd's method

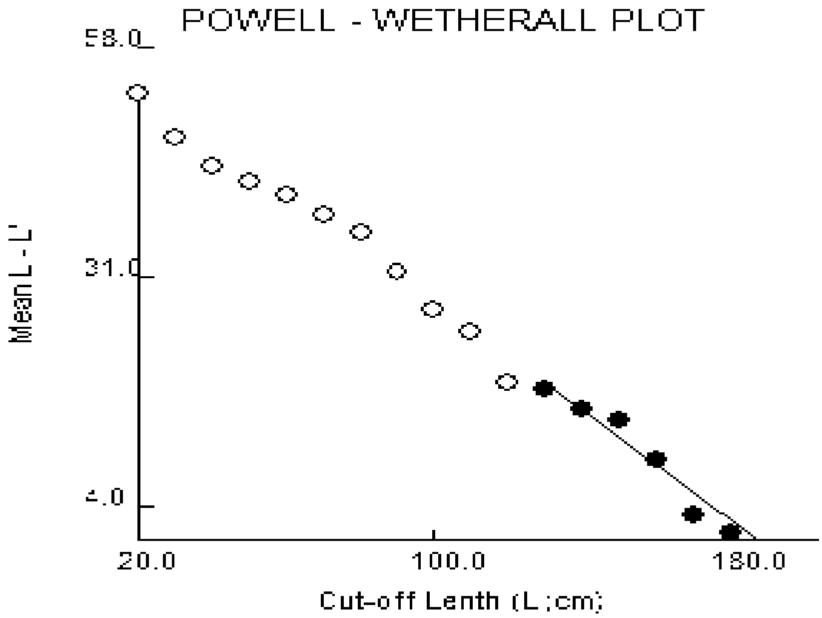

Fig.46. Powell-Weatherall plot for estimation of Z/K value and L_∞ of *Rachycentron canadum*

Results obtained by all the three methods of direct fit of length frequency were furnished in Table 31. Parameters estimated by all the three methods were almost similar. However, L_∞ in cm and K value estimated by ELEFAN was used for further analysis as ELEFAN is considered as free from subjectivity than other methods.

Table 31. Growth parameter L_∞ and K of *Rachycentron canadum* obtained by direct fit of length frequencies

Methodology	L_∞ in cm	K value in K/yr
ELEFAN	194.25	0.24
Shepherd's method	194.25	0.25
Powell and Wetherall	199.85	0.23

Decomposition of composite distribution has been done for subjective identification of mean and linking of cohort. Mean lengths of cohorts recorded in different months during the study obtained by Bhattacharya's method is furnished in Table 32. Two to three cohorts occurred throughout the period with mean ranging between 34.58 cm and 174.73 cm. Sample represented specimens from all the size groups of 10 cm interval between 30- 180.

Results of growth increment study are furnished as Table 33. Growth rate ranged from 1.25 cm per month to 7.5 cm per month. Table 33 showed faster growth rate in juveniles, and also indicated seasonal difference in growth rate. Identification of cohort by linking of mean is furnished in Fig.47. Seven cohorts were visible in the figure and this indicated occurrence of multi age stock of the species. By using the above length at age data, L_∞ and K estimated following Gulland and Holt plot method.

Growth rate was plotted against mean length and percentage of deviation of growth during different season is furnished as Fig. 48 & 49. L_∞ and K estimated were 194.20 cm and 0.299 respectively. Fig. 49 indicates that seasonal growth oscillation is significant. Lengths at age data derived by model progression analysis are further utilized for Ford Walford plot and estimated growth parameters as L_∞ and K as 194.25 and 0.24.Graph plotted length against length +1 is depicted in Fig. 50.

Table 32. Mean length of *Rachycentron canadum* obtained during the study by Bhattacharya's method

Month	Mean length in cm		Standard deviation	
	1	2	1	2
January	40	91.4	14.28	18.57
February	46.31	74.47	9.54	11.56
	170		9.54	
March	57.17	101.73	7.66	12.71
	151.01		14.55	
April	37.76	68.77	9.32	13.73
	136.79	174.73	12.88	7.67
May	34.58	76.25	6.12	10.56
	136.8		15.69	
June	43.5	73.07	6.57	9.05
	105.51	130.9	6	14.85
July	42.48	75.01	11.67	5.85
	124.14		5.81	
August	38.95	74.53	7.24	17.38
	105.13		6.69	
September	44.48	93.22	9.37	16.39
	127.98		6.17	
October	44.48	122.49	9.37	7.16
	170		8.49	
November	71.18	106.85	20.63	8.24
	170		13.99	
December	105.92	57.11	7.67	10.67

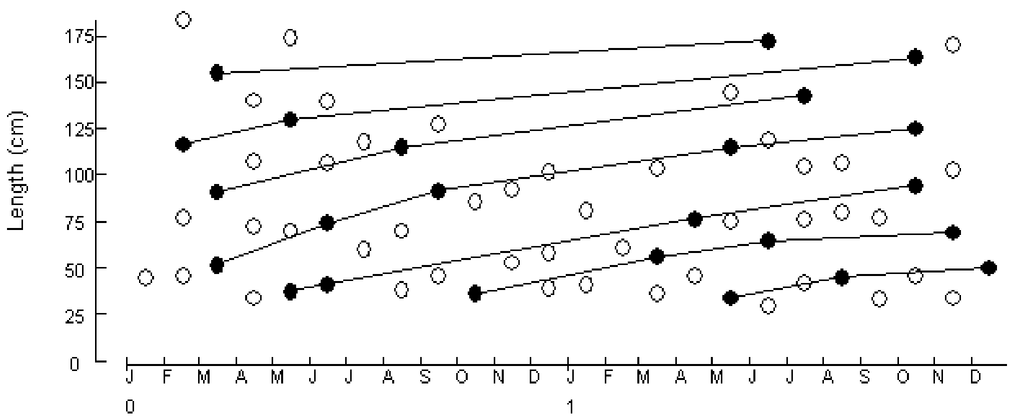

Fig.47. Linking of mean length of *Rachycentron canadum* by Bhatacharyas method

Table 33. Growth increment data of *Rachycentron canadum* during the study following Bhattacharya's method.

Initial length in cm			**Final length in cm**			**Growth rate in cm per month**
Month	**Year**	**Length in cm**	**Month**	**Year**	**Length in cm**	
February	2008	46.17	March	2008	51.63	5.46
February	2008	116.67	May	2008	130	4.44
March	2008	51.63	August	2008	70.07	3.69
April	2008	34	May	2008	37.3	3.30
April	2008	72.7	September	2008	91.74	3.81
April	2008	107.5	August	2008	115.05	1.89
May	2008	37.3	June	2008	41.25	3.95
May	2008	130	October	2009	163.33	6.67
June	2008	41.25	September	2008	45.69	1.48
August	2008	70.07	January	2009	80.93	2.17
August	2008	115.05	July	2009	143.09	2.55
September	2008	45.69	March	2009	56.11	2.08
September	2008	91.74	March	2009	103.75	2.00
January	2009	80.93	October	2009	94.61	1.52
March	2009	56.11	November	2009	69.06	1.62
March	2009	103.75	October	2009	125.21	3.07
June	2009	30	August	2009	45	7.50
August	2009	45	December	2009	50	1.25

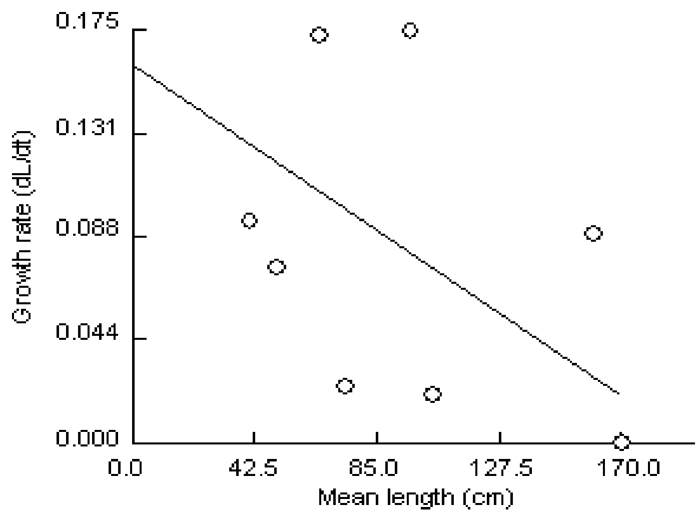

Fig.48. Gulland and Holt plot for estimation of K value and L_∞

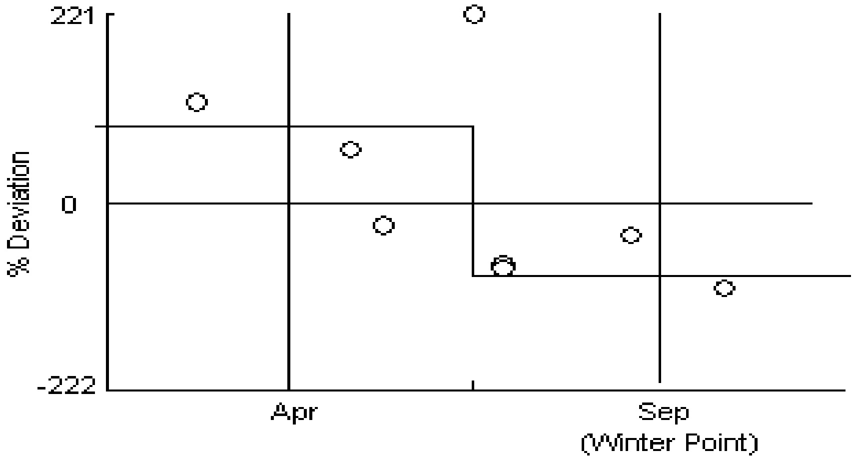

Fig.49. Gulland and Holt residual plot analysis of seasonal growth of *Rachycentron canadum*

The parameter t_0 was estimated following von Bertalanffy plot. Here L_∞ and K estimated by Ford Walford plot were used as input parameter and substituted in to the equation by utilizing the length at age data derived by model progression analysis, t_0 thus obtained is –0.1567. Negative value so arrived at indicates that Cobia juveniles grow faster.

7.3.2. Fitting of von Bertalanffy's Growth equation

Length at age derived by the utilizing data based on linking of mean are depicted in Fig. 51. The VBGF equation was fitted using various parameters estimated following Ford Walford plot (L_∞ and K) and von Bertalanffy plot (t_0).

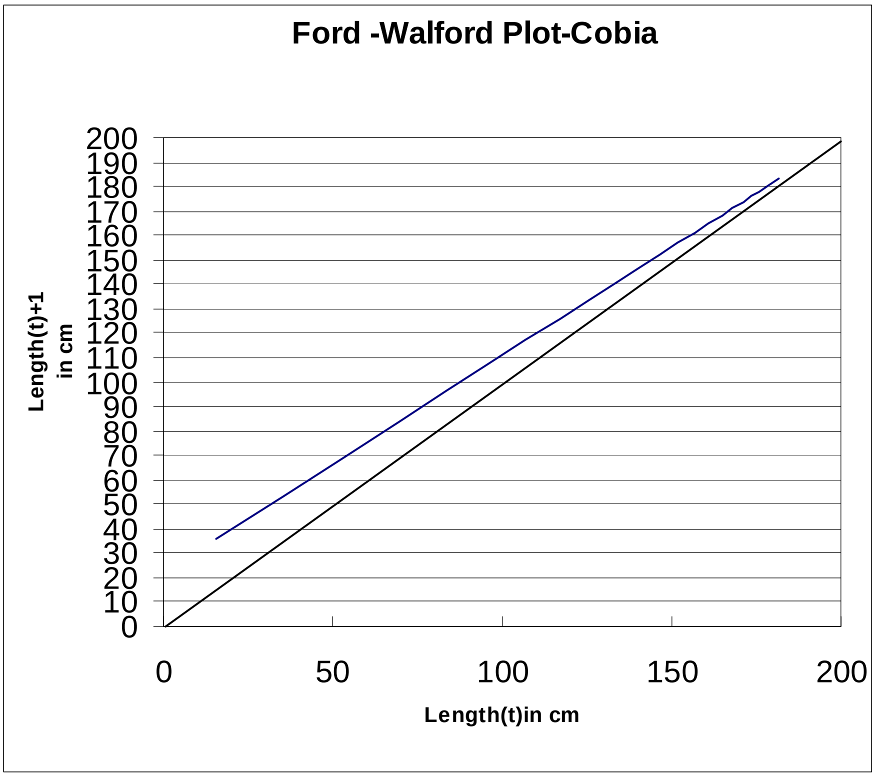

Fig.50. Ford Walford plot of *Rachycentron canadum*

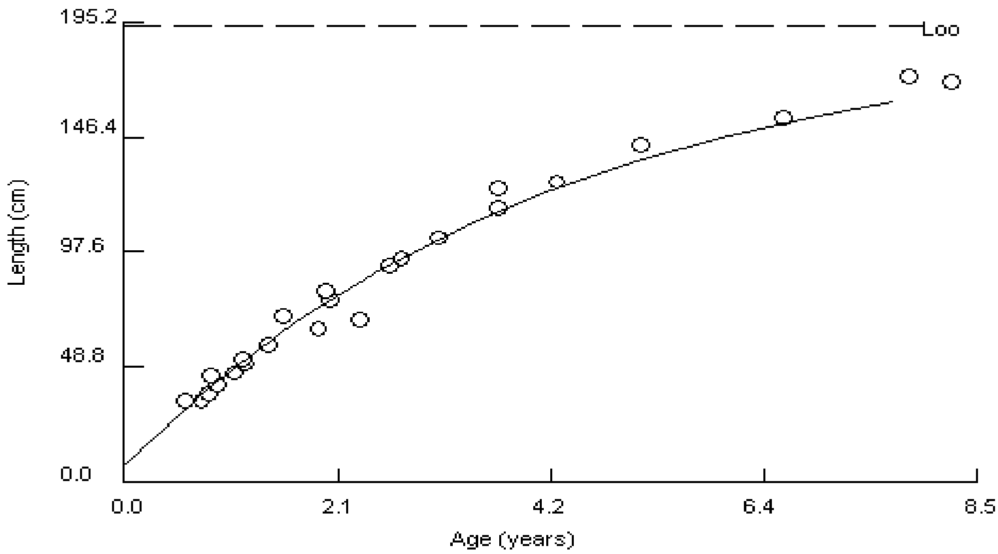

Fig.51. Analysis of length at age of *Rachycentron canadum*

Table 34. Age and length of *Rachycentron canadum* inhabiting along northwet coast of India

Age length derived by linking of mean		Age and length by VBGF	
Age	Length in cm	Age	Length in cm
0.613	33.92	0.5	15.36
0.768	34	1	35.59
0.85	37.3	1.5	53.53
0.866	45	2	69.44
0.935	41.25	2.5	83.56
1.094	46.17	3	96.07
1.173	51.63	3.5	107.18
1.2	50	4	117.02
1.436	58.19	4.5	125.76
1.593	70.07	5	133.50
1.935	64.66	5.5	140.37
2.012	80.93	6	146.46
2.052	77.37	6.5	151.89
2.354	69.06	7	156.66
2.635	91.74	7.5	160.91
2.76	94.61	8	164.68
3.131	103.75	8.5	168.02
3.718	125.21	9	170.99
3.724	116.67	9.5	173.62
4.308	127.55	10	175.95
5.138	143.09	10.5	178.02
6.565	155	11	179.86
7.817	172.37	11.5	181.48
8.236	170	12	182.92

The VBGF equation so arrived at is

$$Lt = L_{\infty}\ (1\text{- } e^{-K\,(t\text{-}to)})$$

It can be rewritten as

$$Lt = 194.25\ (1\text{-}e^{-0.24(t—0.1567})$$

Length of fish derived by linking of mean and values obtained by fitting the VBGF equation is given in Table 34. Present study estimated the length at first maturity of male and female as 63cm and 70cm respectively. By Fitting these length to the VBGF equation and age at first maturity of male and female was estimated as1.48(rounded to 1.5) and 1.71(rounded to 1.75) years respectively.

7.3. DISCUSSION

Growth parameters L_∞ and K were estimated following five methods. Out of the five methods employed L_∞ and K value estimated by ELEFAN method and Ford Walford plot are the same. Subjectivity is at minimum in the case of ELEFAN method, while parameters estimated are generally in agreement with other methods; hence they were used for further analysis. Age at zero length t_o estimated following von Bertalanffy plot was –0.157. Negative t_o value indicated the faster growth rate of fish in their juvenile stage (Ford, 1933; Walford, 1946).

Growth parameters estimated by different authors from various localities are furnished in Table 35. Somvanshi *et al.* (2000) and in the present study the 'total length' (TL) of fish was used for estimation but in all others study 'fork length' (FL) was used for this purpose. L_∞ estimated by the present study was on higher side when compared to other estimations except Burns *et al.* (1998), Williams (2001) and Behnam *et al.* (2006). Torres and Pauly (1991) reported maximum length of Cobia as 200 cm and while comparing to the present estimate of L_∞ with Torres and Pauly (1991) appears to be reasonable.

K value estimates ranged between 0.09 to 0.63 and present estimate concur with Richards (1967, 1977) and Torres and Pauly (1991) and may be more reliable due to higher sample size used for the study

Table 35. Growth parameters of *Rachycentron canadum* reported by various authors from different localities

L_∞ in cm (Pooled)M/F	K value in L/yr (Pooled) M/F	t_0 in yr (Pooled)M/F	Location and Author/s
49/59	0.21/0.10	-0.67/0.80	Chesapeak Bay Richards (1967)
121/164	0.28/0.22	0.06/0.08	Chesapeak Bay Richards (1977)
(160)	(0.09)	(0.01)	Gulf of Aden Edwords *et al.*(1985)
(141)	(0.21)	-	South Africa Torres and Pauly (1991)
(183.9)	(0.125)	(-3.621)	Texas Burns *et al.* (1998)
117/155	0.432/0.272	-1.150/-1.254	Northeastern Gulf of Mexico Franks *et al.* (1999)
(135.16)	(0.17)	-	North west Indian EEZ Somvanshi *et al.* (2000)
114.8/185.2	0.38/0.125	-1.05/-3.07	Gulf of Mexico Williams (2001)
(168.65)	-	(-0.97)	Northeastern Persian Gulf Behnam *et al.* (2006)
(116)	(0.63)	(-0.21)	North and Eastern Australia Fry and Griffiths (2010)
(194.25)	(0.24)	(-0. 1567)	North west Indian EEZ Present study

Similarly, t_0 value ranged between –3.6 to 0.67. Except Richards (1967, 1977) and Edwords *et al.* (1985), invariably all previous workers reported negative t_0 value. This indicates the faster growth rate of Cobia in their juvenile stage.

Model progression analysis, linking of mean of length class modes as a part of model progression analysis identified seven cohorts in the sample. This shows the occurrence of multi- age groups in the Cobia stock. Results of previous study furnished in Table 35 concur with the results of the present study. Length of fish in different age groups estimated by model progression analysis and VBGF are of similar pattern. This shows the correctness of the present estimates.

Age at maturity estimated for male and female Cobia was 1.5 and 1.75 years respectively. Richards (1967, 1977) estimated the age at maturity of Cobia inhabiting in Chesapeake Bay as 2 years and 3 years for male and female respectively. Geographical difference of study area is an important factor for this variance.

8. STOCK ASSESSMENT AND DISTRIBUTION

8.1. INTRODUCTION

Fish Stock assessment is the search for the exploitation level that in the long run gives the maximum yield from the fishery (Sparre and Venema, 1993). Fish resources are renewable and depend on both fishery independent and dependent factors. Fishery dependent factors like level of exploitation; size at capture etc. can be controlled to ensure the health of the stock. Sound knowledge about distribution and abundance is a pre requisite for the sustainable exploitation of any resources. The knowledge about these resources helps the scientists and planners to recommend a sustainable yield and the effort required to exploit the above stock.

Several studies have been carried out in different parts of the world to understand the distribution and abundance of Cobia stock. Major works in this regard are Jordan and Seale (1906), Nichols and Breder (1926), Springer and Bullis (1956), Briggs (1958, 1960), Bearden(1961), Richards, (1967), Lindberg and Krasyukova (1971), Dawson (1971), Monod (1973), Relyea (1981), Menni *et al*. (1984), Golani and Ben-Tuvia (1986), Shaffer and Nakamura, (1989), Bohlke and Chaplin (1993), Huang (2001) and Williams (2001). These pioneering data now provided are vital in understanding the distribution and abundance of Cobia occurring in different parts of the world except India.

Cobia *Rachycentron canadum* is distributed widely in tropical and subtropical waters except in the eastern Pacific and the Pacific Plate (Butsch, 1939; Briggs, 1960; Carlsson, 1974; Shaffer and Nakamura, 1989; Fricke, 1999). Along the western Atlantic they are distributed from Scotian shelf in Canada to Argentina including the Gulf of Mexico and entire Caribbean (Robins and Ray, 1986; Scot and Scot, 1988; Cervigón, 1993; Smith**,** 1997).

In the eastern Atlantic they are distributed from Morocco to South Africa (Smith, 1965; Monod, 1973; Quero, 1990; Khalaf, 2005; Galil, 2007). In the Indian Ocean they are distributed from east Africa to Australia and in Pacific from Hokkaido, Japan to Australia and East Indies (Jordan and Seale 1906; La Monte 1952; Hatchell 1954; Fourmanoir, 1957; Ueno 1965; Lindberg and Krasyukova 1971; Grant, 1972; Ivankov and Samylov, 1979**;** Relyea 1981; Aprieto and Villoso, 1982; Masuda *et al*., 1984; Bianchi, 1985; Smith, 1986; Fisher *et al*., 1990; Edward and Shaher, 1991; Hermes, 1993; Fouda and Hermosa, 1993; Shao *et al*., 1993; De Bruin, *et al*., 1995; Sommer *et al*., 1996; Mohsin and Ambak, 1996; Al Sakaf and Esseen, 1999; Allen and Adrim, 2003; Letourneur *et al*., 2004; Kim *et al*., 2005). Except for possible strays from the Red Sea through the Suez Canal Cobia do not occur in the Mediterranean waters (Golani and Ben-Tuvia, 1986).

Chacko (1949), Munro (1955), Rajan *et al*. (1968), GOK (1968), Talwar and Kacker **(**1984) and Kapoor *et al*. **(**2002) reported occurrence of Cobia in different maritime states and lakes of India. Pillai (1982) documented landing details of Cobia along maritime States of India during 1969- 80.

Compared to predominant smaller pelagics like oil sardine and mackerel, Cobia landings are of low magnitude, however high price and increased demand in the local market elevate their status as a major resource. Except for a little information on occurrence of Cobia no other data is available on distribution and abundance of Cobia. Hence, an attempt has been made to understand the spatio-temporal distribution of Cobia by utilizing historical resource survey data collected by the Fishery Survey of India. Present study provides first hand information on biomass of the Cobia stock along east and west coast of India. Bathymetrical and spatial distribution of Cobia and its abundance will help the managers to formulate exploitation strategy.

8.2. MATERIALS AND METHODS

The Fishery Survey of India (FSI) conducted exploratory fishing surveys in the continental shelves and offshore regions of Indian EEZ. Survey and assessment of fish stocks and charting of fishing grounds in the Indian EEZ and adjoining area is an important mandate of the organization. Exploratory surveys carried out during the past provided a lot of information about the characteristics of fishery resources of our country. Exploratory fishing data of the trawlers attached to FSI (Table 36) along both east and west coasts carried out during January 1985 to December 2007 is the source of data base of this study.

Exploratory data collected by the FSI fleet along the coastal belt from 30-200m has been utilized for the study. Trawlers attached to the FSI carried out exploratory survey along the west coast between Lat. 07^{0}.00’ and 22^{0}.00’N.

Similarly, they covered area between 10^0.00’ and 20^0.00’N along the east coast. 34 m fish trawl, 45.6 m expo model fish trawl and 27 m fish trawl were the fishing gears used for survey.

Table 36. Specifications of survey vessels, fishing gears and area of operation

Name of Vessel	Vessel Type	Overall length (m)	Gross tonnage (t)	Break horse power (BHP)	Area of operation (Latitude)	Fishing gear used
Matsya Nireekshani	Stern trawler	40.5	329.26	2030	18^0-22^0 N (West coast)	34 m Fish trawl
Matsya Mohini	Stern trawler	42.5	345	1100	18^0-22^0N (West coast)	45.6 m Expo model fish trawl
Matsya Vishwa	Stern trawler	36.5	327.18	825	10^0-18^0N (West coast)	27 m Fish trawl
Sagarika	Stern trawler	28.8	189	650	10^0-18^0N (West coast)	27 m Fish trawl
Matsya Varshini	Trawler-cum-Purse-seiner	36.5	268.80	1160	07^0-10^0N (West coast)	45.6 m Expo model fish trawl
Matsya Jeevan	Stern trawler	36.5	327.18	825	10^0-16^0N (East coast)	27 m Fish trawl
Samudrika	Stern trawler	28.8	189	650	10^0-16^0N (East coast)	27 m Fish trawl
Matsya Shikari	Stern trawler	39.5	352	1740	16^0-20^0.’N (East coast)	34 m Fish trawl

8.2.1. Sampling method

Area under study i.e. between latitude 07^0.00’ and 22^0.00’N along west coast and 10^0.00’ and 20^0.00’N along east coast from 0- to 200 m depth zone was divided into 54 strata based on the latitude and depth contours of 50 m, 100 m, and 200 m. Each 1^0 lat. x 1^0 long. was further divided in to 100 squares of 6’x 6’area. Hauls were allocated to these 6’x 6’ squares following the stratified random sampling procedure. Previous exploratory data and area available for trawling were considered for allocation of hauls. Trawling operation was carried out at a speed of 3 knots for 90 minutes duration in each haul. Cobia catches were sorted out immediately after each haul and weight was recorded.

8.2.2. Distribution and Biomass estimation

Catch recorded onboard the vessel were converted to catch per unit effort by dividing the quantity in kg with effort in hours (actual haul duration). Catch/effort data thus obtained was recorded and average catch per unit effort from each stratum estimated and presented in tabular form. Bathymetric distribution of depth stratum 0-50 m, 50-100m and 100-200 m were estimated by pooling the catch and effort data of concerned strata. Similarly latitude wise abundance was also estimated for understanding the geographic distribution. Seasonal variations in abundance of Cobia along both coasts were estimated by taking monthly average of catch per unit effort.

Biomass of Cobia from the study area was estimated by using the 'swept area method' (Gulland, 1975). 'Swept area' or the 'effective path swept' by the trawl net during the haul was calculated by using the formula

$a = D * h * x_2$, ……………………………………………….………(35)

$D = V * t$ ..……………………………………………………………(36)

Where,

a = the swept area

V = the velocity of the trawl over the ground when trawling

h = the length of the head rope

t = the time spent for trawling

x_2 = that fraction of the head rope which is equal to the width of the path swept by the trawl, (the 'wing spread', h * x_2).

In south-east Asian waters, values for x_2 ranging from 0.4 (Shindo, 1973) to 0.66 (SCSP, 1978) have been used. Pauly (1980 a) suggests $x_2 = 0.5$ as the best compromise. Somvanshi *et al.* (2004) based on some experiments have arrived at the value of $x_2 = 0.4$ to be the best compromise for the FSI vessels, and has been used for the present study. Velocity of the trawl over the ground when trawling was 3 knots. Catch per unit area is obtained by dividing the catch per hour by the area swept per hour by trawl. Based on this, the average catch per unit area (ACPUA) in sq.km was worked out for each stratum and biomass of demersal stocks in each stratum was estimated from the relationship.

$B = (cpua) * A / x_1$ ....(37)

Where,

B = the Biomass; A = the area of the stratum

x_1 = the fraction of the biomass in the effective path swept, which is actually caught.

The value of x_1 was actually chosen between 0.5 and 1. For trawlers used in southeast Asia a value of $x_1 = 0.5$ was commonly used in survey work (Isarankura, 1971; Saeger *et al.*, 1976). Dickson (1974), on the other hand, suggests $x_1 = 1$. There are some evidences that $x_1 = 0.5$ might in fact be realistic (Pauly, 1979). In the present study also the value of x_1 was considered as 0.5. Biomass for each stratum was estimated separately and then summed up to find out the total biomass of the area (Sparre *et al.*, 1989).

8.2.3. Estimation of maximum sustainable yield

Maximum sustainable yield or potential yield estimated following the Cadima's formula (Sparre *et al*., 1989).

MSY= 0.5 x Z x B……………………………………………..(38)

Where,

Z = total mortality;   B = biomass of exploited stock

8.3. RESULTS

8.3.1. Distribution

Latitude-wise and depth-wise abundance of Cobia based on trawl catches recorded during the period January 1985 to December 2007 from west and east coast are furnished in Table 37 & 38.Catch per effort recorded from different depth zone from west coast are depicted as Fig. 52 to 55. Similarly distributions along east coast are furnished as Fig.56 to Fig.59.

As showed in Table 37, Fig 52- 55 stratum of Lat.17^{0}N and 0-50 m depth zone recorded the maximum catch/hour of 1.27 kg/hr for Cobia along the west coast, followed by Lat.8^{0}N and 100-200 m depth zone. In general, better catch rates were recorded from the northern latitudes.

Along the east coast, stratum of Lat.20^{0}N and 0-50 m depth zone recorded maximum catch rate of 2.11 kg/ hr. Similar to west coast better catch rates were recorded from northern latitudes along east coast of India.

To understand the geographical difference in the distribution, catch per effort recorded during the period were pooled on latitude basis and results are furnished in Table 39 & 40. Graphical representations are shown in Fig. 60 & 61. Along the west coast better catch rates were recorded from northern latitudes, with maximum catch rate from Lat.17^{0}N. In general, the dominance of Cobia was more along the north west coast. Similar trend was recorded from east coast of India and maximum catch rate was recorded from the Lat.20^{0}N.

Bathymetrical distribution of Cobia along west and east coast is furnished in Table 41. Depth zone 0-50 m was found to be more productive along both the coasts followed by 50-100m. Depth zone 100-20m along west coast recorded better catch rates than east coast.

Table 37. Latitude wise and depth wise catch per unit effort (kg/hr) of *Rachycentron canadum* – along west coast of India.

Latitude	Depth zone in m		
	30-50	50-100	100-200
7^{0}N	0.35	0.3	0.15
8^{0}N	0.35	0.13	1.05
9^{0}N	0.11	0.07	0.06
10^{0}N	0.22	0.17	0.03
11^{0}N	0.04	0.29	0.19
12^{0}N	0.12	0.11	0.24
13^{0}N	0.21	0.18	0.11
14^{0}N	0.17	0.26	0.11
15^{0}N	0.16	0.38	0.13
16^{0}N	0.12	0.26	0.37
17^{0}N	1.27	0.19	0.37
18^{0}N	0.44	0.47	0.71
19^{0}N	0.04	0.14	0.2
20^{0}N	0.1	0.19	0.57
21^{0}N	0.16	0.45	0.17
22^{0}N	0.44	0.34	0.28

Table 38. Latitude wise and depth wise catch per unit effort (kg/hr) of *Rachycentron canadum* – along east coast of India.

Latitude	Depth zone in m		
	30-50	50-100	100-200
10^0N	0.45	0.3	0.3
11^0N	0.39	0.04	0.04
12^0N	0.05	0.02	0.2
13^0N	0.1	0.09	0.09
14^0N	0.06	0.25	0.25
15^0N	0.04	0.03	0.03
16^0N	0.14	0.04	0.04
17^0N	0.02	0.03	0.03
18^0N	0.13	0.17	0.17
19^0N	0.21	0.06	0.06
20^0N	2.11	0.26	0.26

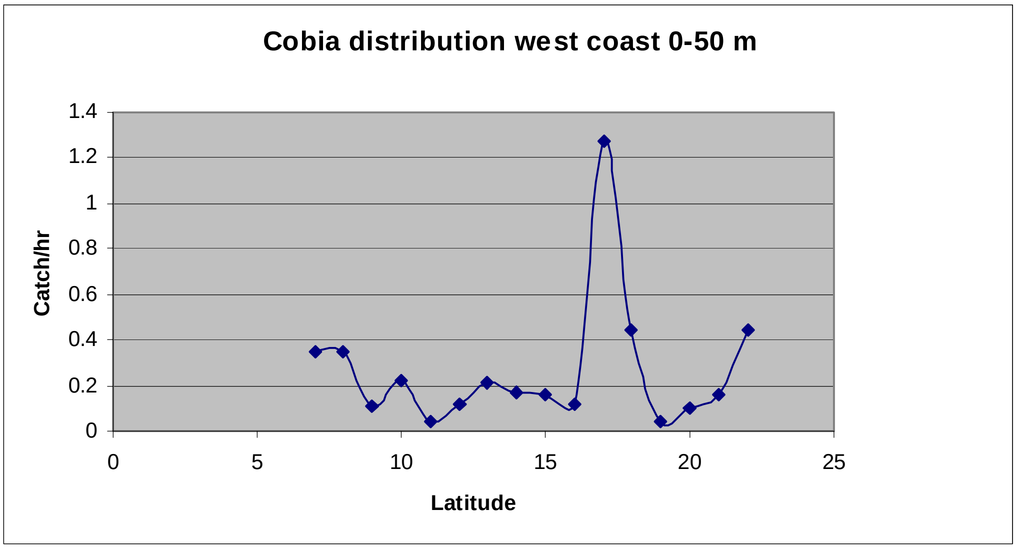

Fig.52. Catch per unit effort in kg/hr of *Rachycentron canadum* recorded from 0-50 m depth zone along west coast of India

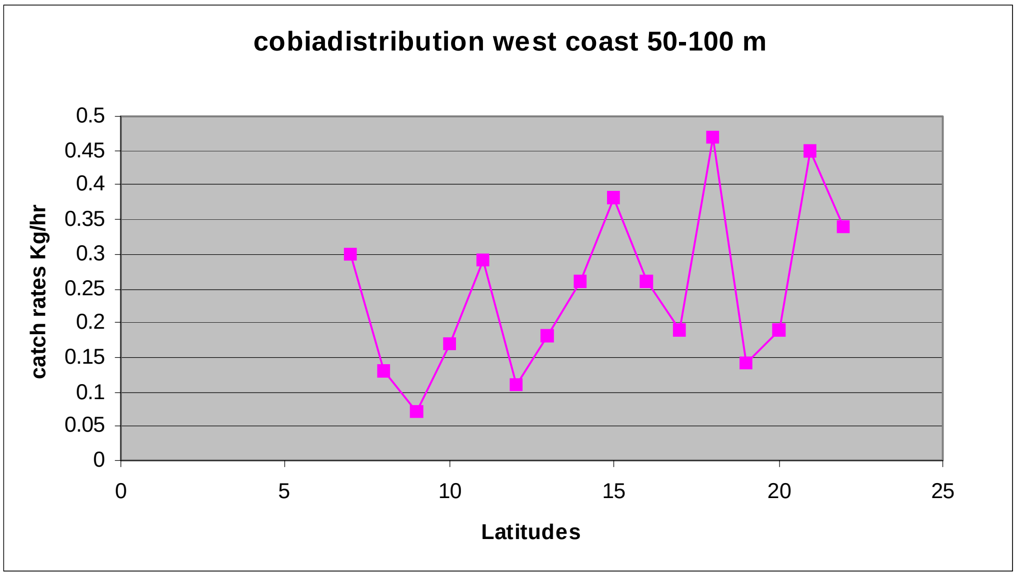

Fig.53. Catch per unit effort in kg/hr of *Rachycentron canadum* recorded from 50-100 m depth zone along west coast of India

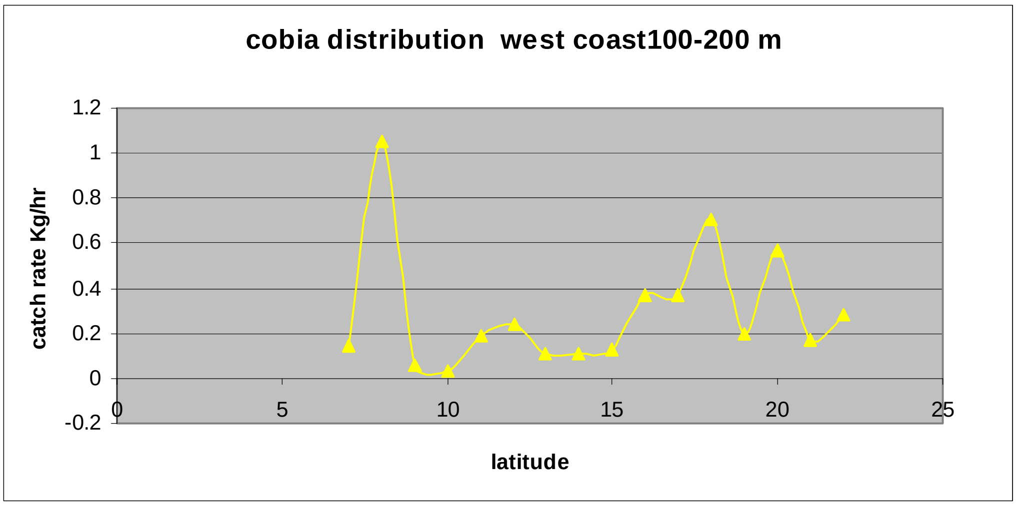

Fig.54. Catch per unit effort in kg/hr of *Rachycentron canadum* recorded from 100-200 m depth zone along west coast of India

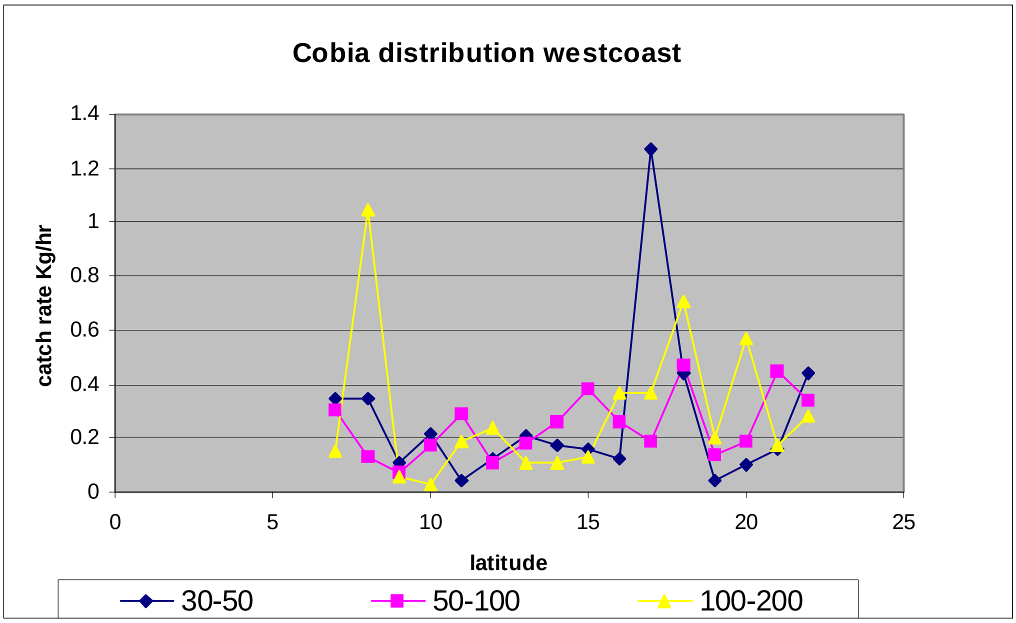

Fig.55. Catch per unit effort in kg/hr of *Rachycentron canadum* recorded from west coast of India

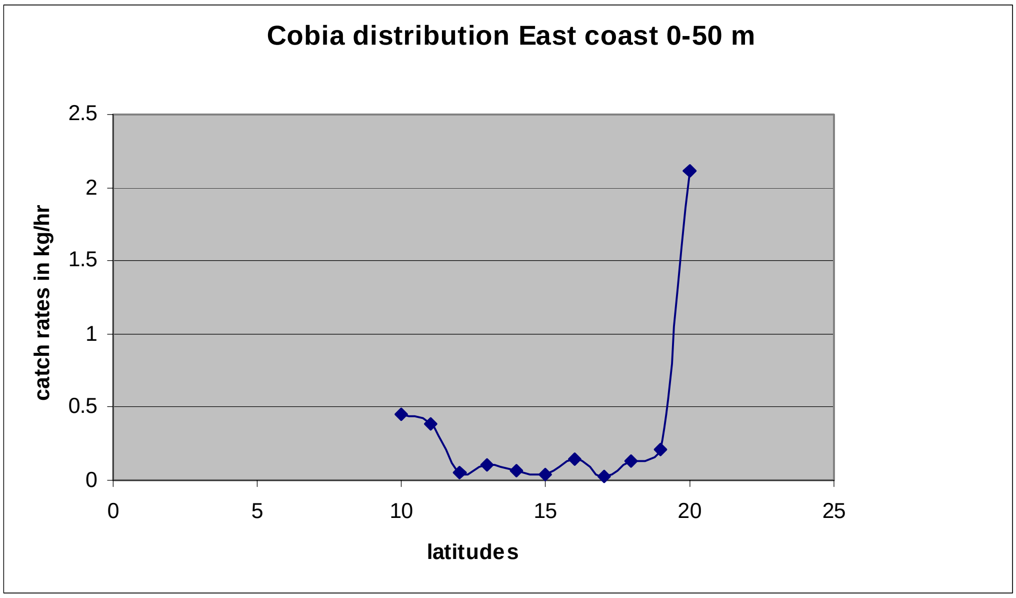

Fig.56. Catch per unit effort in kg/hr of *Rachycentron canadum* recorded from 0-50 m depth zone along east coast of India

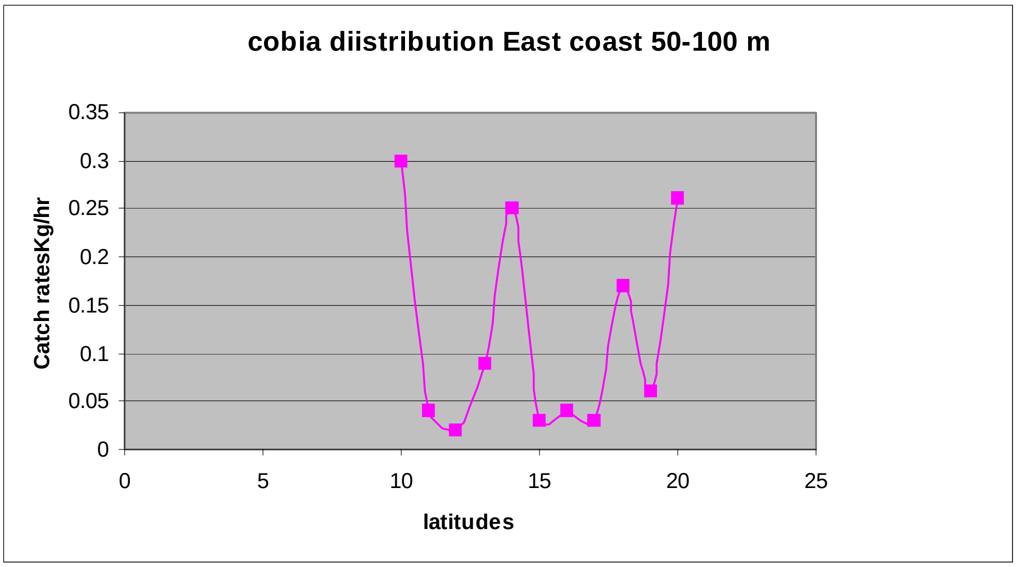

Fig.57. Catch per unit effort in kg/hr of *Rachycentron canadum* recorded from 50-100 m depth zone along east coast of India

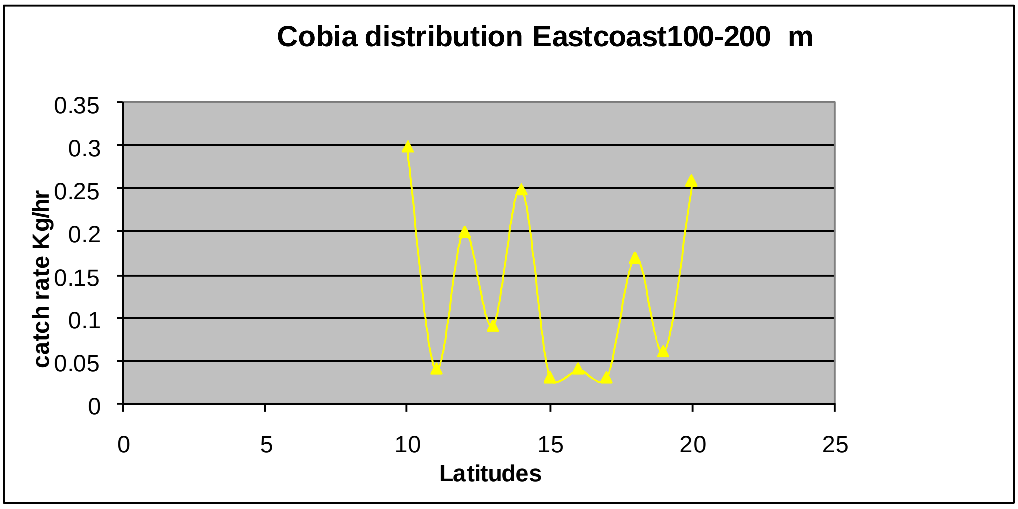

Fig.58. Catch per unit effort in kg/hr of *Rachycentron canadum* recorded from 100-200 m depth zone along east coast of India

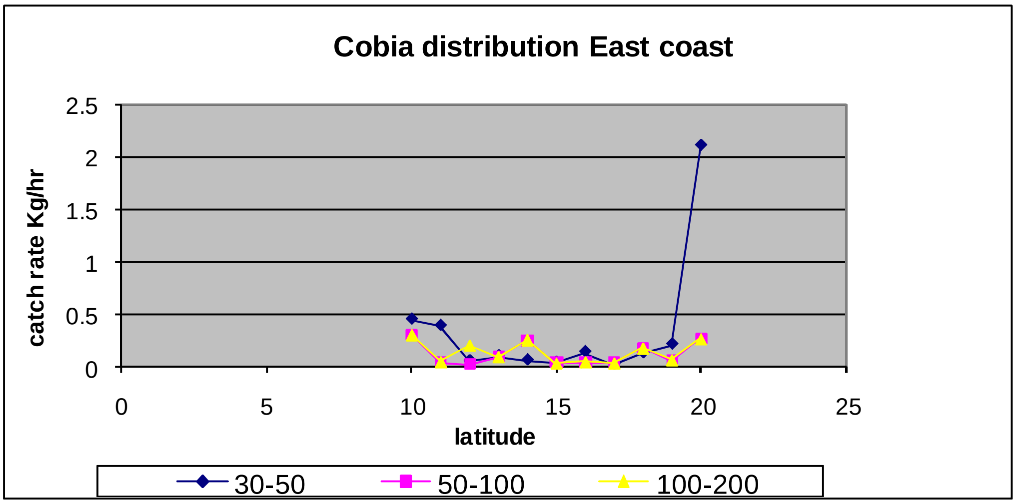

Fig.59 Catch per unit effort in kg/hr of *Rachycentron canadum* recorded from east coast of India

Table 39. Latitude wise catch per unit effort (kg/hr) of *Rachycentron canadum* along west coast of India

Latitude	Effort in hr	Catch in kg	Catch/ Effort kg/hr
7^0N	545.69	86	0.157599
8^0N	3718.44	743	0.199815
9^0N	6535.51	594	0.090888
10^0N	2013.46	356	0.17681
11^0N	1182.304	218	0.184386
12^0N	2120.14	323	0.152348
13^0N	1895.05	345	0.182053
14^0N	5053.2	947	0.187406
15^0N	6850	1527	0.22292
16^0N	4924.47	1132	0.229872
17^0N	3281.1	1919	0.584865
18^0N	6573	3029	0.460825
19^0N	1181.15	115	0.097363
20^0N	4727.55	990	0.209411
21^0N	3831.67	1237	0.322836
22^0N	1391.14	484	0.347916

Table 40. Latitude wise catch per unit effort (kg/hr) of *Rachycentron canadum* along east coast of India.

Latitude	Effort in hr	Catch in kg	Catch/ Effort kg/hr
10^0N	1395.16	372	0.266636
11^0N	870.9	286	0.328396
12^0N	3964.07	135	0.034056
13^0N	17845.95	243	0.013617
14^0N	1645.08	184	0.111849
15^0N	1864.59	54	0.028961
16^0N	1449.75	105	0.072426
17^0N	4190.9	88	0.020998
18^0N	3126.5	443	0.141692
19^0N	2372	273	0.115093
20^0N	1685.68	1370	0.812728

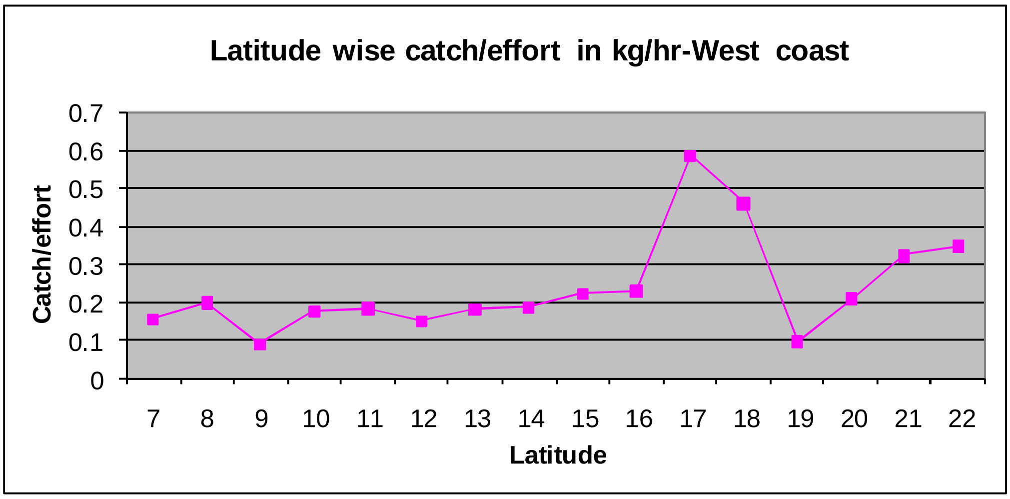

Fig.60. Latitude wise catch per unit effort in kg/hr of *Rachycentron canadum* recorded from west coast of India

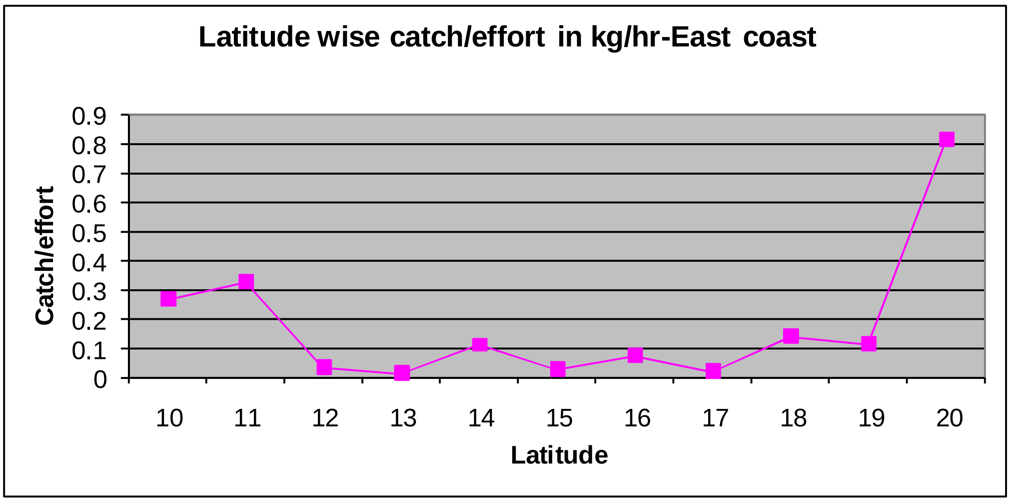

Fig.61. Latitude wise catch per unit effort in kg/hr of *Rachycentron canadum* recorded from east coast of India

Table 41. Depth wise catch per unit effort (kg/hr) of *Rachycentron canadum* along west and east coast of India

Depth range in m	Effort in hr	Catch in kg	Catch/effort kg/hr
West coast			
0-50	22354.19	5660	0.253196
50-100	24027.69	6442	0.268107
100-200	9441.99	1943	0.205783
East coast			
0-50	27588.28	2656	0.096273
50-100	9393.78	855	0.091018
100-200	3428.52	42	0.01225

Seasonal abundance of Cobia along Indian water was assessed by pooling catch per effort recorded during the respective months. Results are furnished in Table 42 & 43and Fig.62 & 63. Cobia was caught throughout the year along both the coasts. Peak fishing season for Cobia along west coast starts from May and extended up to December. Along east coast peak fishing season was during the last quarter of the year i.e. from October to December.

Table 42. Month wise abundance of *Rachycentron canadum* along west coast of India

Month	Effort in hr	Catch in kg	Catch/ Effortkg/hr
January	551	107	5.149533
February	408	120.5	3.385892
March	401	68.5	5.854015
April	357	94.5	3.777778
May	273	34	8.029412
June	86	22.5	3.822222
July	77	4.5	17.11111
August	9	3.5	2.571429
September	80	12	6.666667
October	70	8.5	8.235294
November	319	55.5	5.747748
December	265	57.5	4.608696

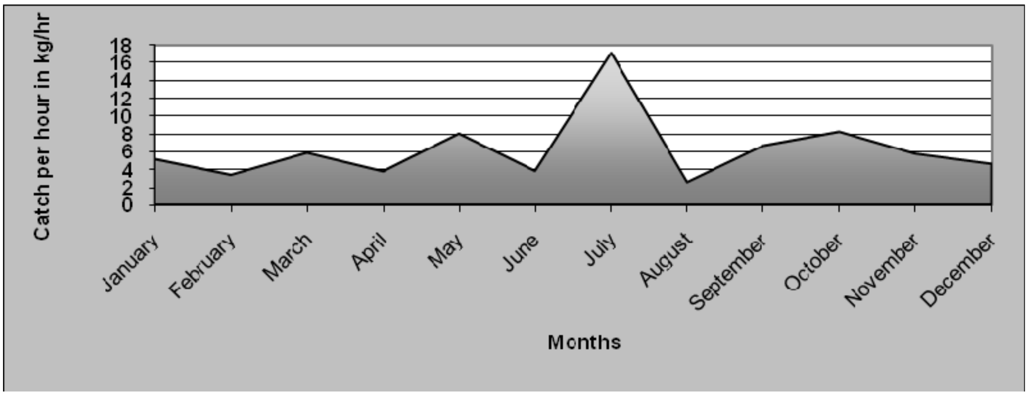

Fig.62. Month wise catch per unit effort in kg/hr of *Rachycentron canadum* recorded from west coast of India

Table 43. Month wise abundance of *Rachycentron canadum* along east coast of India

nth	Effort in hr	Catch in kg	Catch/ Effort kg/hr
January	92	366	3.97826087
February	127.5	426	3.341176471
March	96.5	371	3.844559585
April	47	148	3.14893617
May	66.5	269	4.045112782
June	45	196	4.355555556
July	43.5	112	2.574712644
August	33	126	3.818181818
September	35	125	3.571428571
October	46.5	240	5.161290323
November	52.5	1400	26.66666667
December	89	437	4.91011236

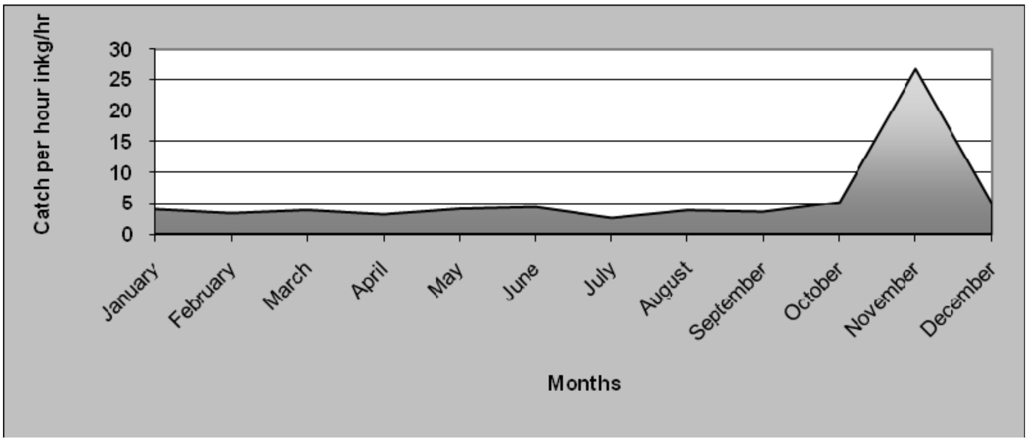

Fig.63. Month wise catch per unit effort in kg/hr of *Rachycentron canadum* recorded from east coast of India

To understand the changes to the Cobia stock due to fishery dependent and independent factors, catch per unit effort recorded since 1985 were pooled (1985-1990; 1991-2000; 2001-2005) and results are shown in Fig. 64 & Fig.65 as average catch per unit effort. As showed in the graphs, generally catch per effort showed a decreasing trend along the west coast. But catch rates increased during 90's along east coast and then showed a down ward trend during 2000's.

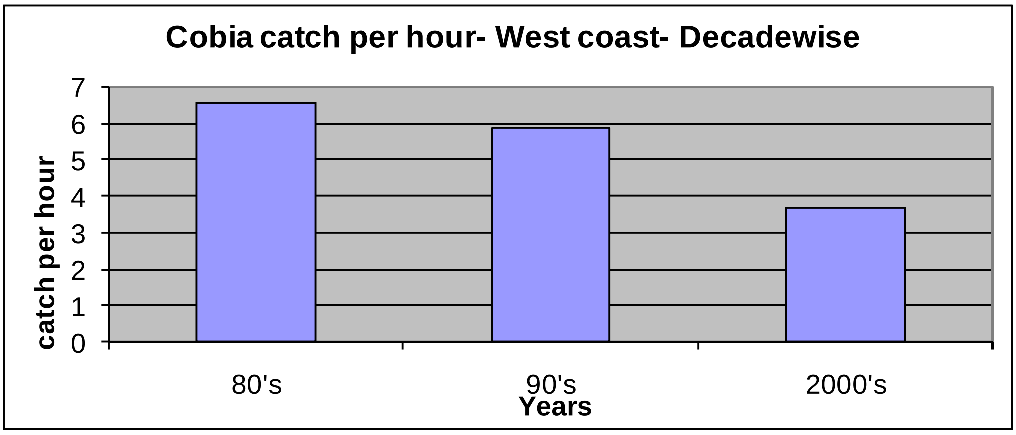

Fig.64. Decade wise catch per unit effort in kg/hr of *Rachycentron canadum* recorded from west coast of India

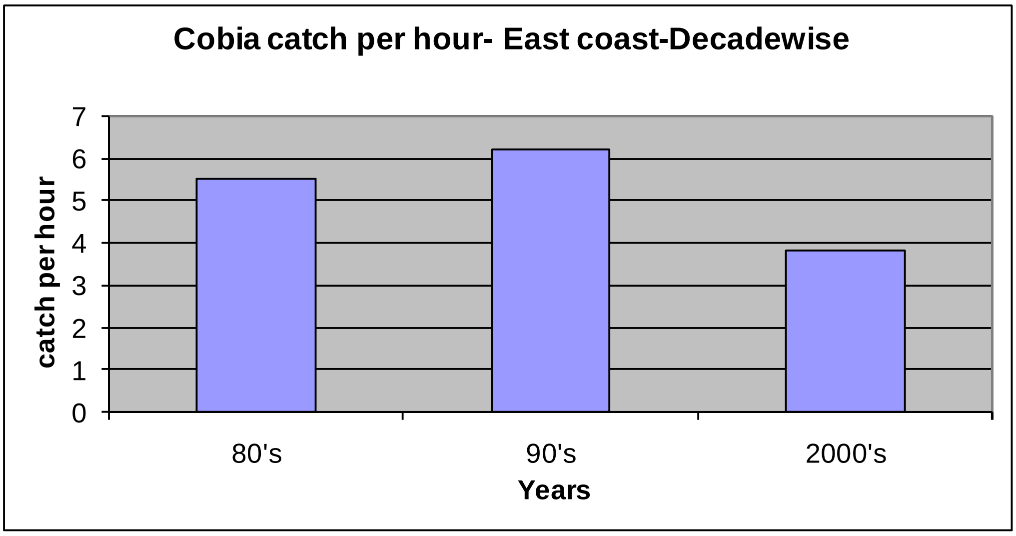

Fig.65. Decade wise catch per unit effort in kg/hr of *Rachycentron canadum* recorded from east coast of India

8.3.2. Biomass and sustainable yield

Biomass of *Rachycentron canadum* estimated following swept area method along west and east coast were 1709.744 and 496.377 metric tonnes respectively. Total biomass of Cobia obtained by summing up of estimated biomass from both the coast was 2,209.514 metric tonnes. Percentage compositions of Cobia biomass along east and west coasts are shown as Fig.66. The results showed that west coast of India supports 77 percentage of Cobia stock.

Maximum sustainable yield (MSY) of Cobia occurring in India was estimated following Cadimas formula (Sparre *et al.*, 1989). Total mortality estimated in the present study was 0.76. By applying this value of total mortality, MSY of Cobia was estimated at 839.6 metric tonnes.

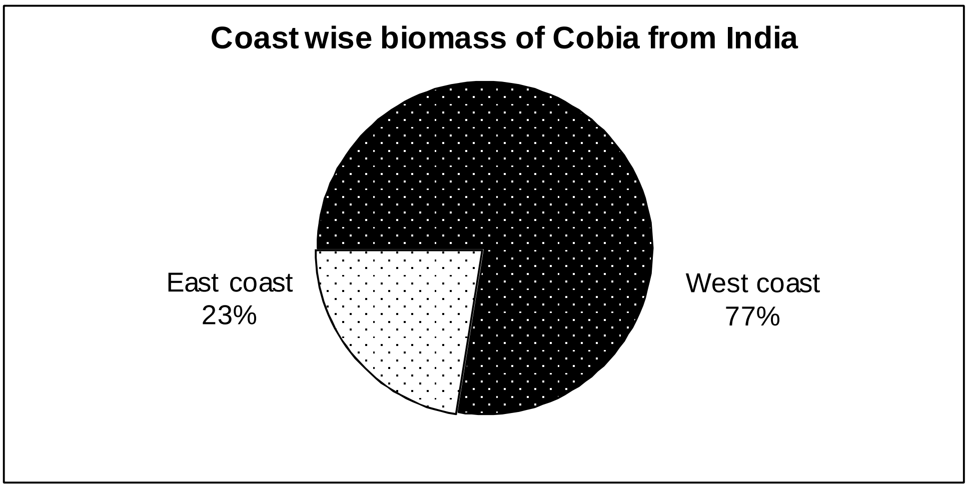

Fig.66. Biomass of *Rachycentron canadum* in percentage occurring along west and east coast of India

8.4. DISCUSSION

8.4.1. Distribution

Analysis of catch and effort data of Cobia recorded by FSI fleet revealed that Cobia occur along both east and west coast of India. Latitude wise, they were available in all the latitudes surveyed. In general, Cobia was more abundant in northern latitudes along both coasts, a distribution pattern similar to that of spotted Spanish mackeral *Scomberomorus guttatus* (Sudarsan *et al.,* 1989). Bathymetrically, they were caught between 33m to 229 m. Like other pelagic fishes, Cobia also found to be more abundant along near shore water i.e. depth zone 0-50 m. Near shore water is more productive than any other depth zone, this may be the reason for rich concentration of Cobia along near shore waters.

Study on fishing season of Cobia revealed that they are available throughout the year. Fluctuation in their abundance during different season and coast was noticed. Results of the present study indicated that peak fishing season of Cobia along west coast start with May and extends up to December. Similarly peak season along east coast start from October and continues up to December. Peak fishing season coincided with south west monsoon along west coast and north east monsoon along east coast.

Due to upwelling and resultant increased food availability along the near shore water, Cobia may move towards this area for feeding. Rich inflow of river water which contains lot of flotsam to coastal waters and river mouth is a common phenomenon during monsoon period. Concentration of Cobia near floating objects was reported by many authors (Baughman, 1950; Carr, 1987; Shaffer and Nakamura, 1989). Presence of such floating objects in the near shore water during monsoon season and abundance of prey items can be attributed as reasons for their abundance during monsoon period.

Analysis of catch and effort data on time indicates that Cobia catch rate recorded during the present decade from both west and east coast is less than the catch rate recorded during 80's. This may be due to heavy fishing pressure exerted on the stock.

8.4.2. Biomass and sustainable yield

Biomass of Cobia occurring in India is estimated by the present study as 2209.514 metric tones. 77% of biomass was from west coast and 33% along east coast. Above estimate was based on bottom trawl survey, hence fishes found in the bottom column only came in the purview of estimation. Cobia being a pelagic, neretic species occurring all along the water column, total biomass of the species will be more than the one estimated by the present study. Compared to the biomass of other pelagic fishes occurring in Indian waters, quantum of Cobia is less, but there is a high demand in the market for this fish. This high demands and better unit cost of the fish makes them an important resource.

Cobia in India is caught by various gears like hook and line, troll line, drift gill net and trawlers (Pillai, 1982). In bottom trawls they are caught as by-catch and most of the fishes caught by trawlers are of smaller size. Due to high unit price in the local market most of the fishes are sold fresh in local market. Being a good table fish they are susceptible to high fishing pressure and hence exploited heavily.

Information on sustainable yield of Cobia available in Indian water is meager. MOA (2000) estimated the sustainable yield of Cobia at 727 tonnes. Present study estimated the potential yield of Cobia from Indian waters as 839.6 metric tonnes. Both studies considered that fishes are vulnerable to bottom trawling; hence the actual potential may be more than this. A concerted effort to assess the biomass and potential of Cobia vulnerable to pelagic gears is the need of hour to ensure the sustainable exploitation of Cobia available in the Indian EEZ.

9. MORTALITY AND EXPLOITATION

9.1. INTRODUCTION

Stock size of a fish depends on recruitment, growth and mortality. The biomass of fish in the usable stock is getting increased by the reproduction and growth. Concurrently, due to loss of individuals from the population, the stock will be reduced in numbers and weight. The losses of individual in a population through death are due to various reasons, which are independent of each other.

Many factors in the marine environment contribute to the death of fish. To list a few are adverse conditions, lack of food, competition, predation, etc. Death of individuals in a population due to above said natural reasons are called as natural mortality (M). In an exploited stock, stock size further reduces due to human interference notably by fishing and hunting. Removal of individual fishes from the stock due to fishing and hunting is called as fishing mortality (F). The instantaneous rate of total mortality rate (Z) is the sum of the instantaneous rate of fishing mortality and the instantaneous rate of natural mortality.

Information on mortality rate is essential for formulation of exploitation strategy and thereby exploit and mange the fishery resources at optimal levels. Mortality estimates have been done in almost all major exploited fish stocks with a view to arrive at optimum levels of exploitation. Mortality estimates of Cobia inhabiting Chesapeake Bay, Gulf of Mexico and Australia were carried out by Richards (1967), Williams (2001) and Fry and Griffiths (2010) which provided basic information on the dynamics of the Cobia stock. However, no information is available on mortality and exploitation of Cobia occurring in Indian waters.

Cobia is exploited world wide both by commercial and recreational fishery. In the commercial fishery they are generally caught as incidental catch in various fishery. Pakistan, Taiwan, Philippense, Viatnam, United State of America, Gulf of Mexico, Australia and India are major Cobia fishing nations. Cobia are mainly exploited by handlines, bottom trawls, driftnets, floating gillnets, drift gill nets, troll lines, pound nets, purse-seine and trawl nets (Freeman and Walford,1976; Aprieto and Villoso, 1979; Pillai 1982; Manooch, 1984; Bianchi, 1985; Aprieto, 1985; Rountree, 1990). In India, Cobia is caught as incidental catch by hand lines, bottom trawls, drift gill nets, troll lines, purse-seine and trawl nets both along west and east coast of India.

Compared to major fishery resources that support marine fishing industry in India, landings of Cobia is very less, but their unit price and increased attention due to culture prospective make them an important fishery resource. In the present study, mortality rates of Cobia were estimated and the dynamics of recruitment and exploitation pattern exist in India have been examined with an aim to propose sustainable management measures to ensure rational exploitation and improve sustainability of the stock.

9.2. MATERIALS AND METHODS

1261 specimens having total length ranging from 22.6 cm to 181cm of Cobia collected during the period January 2008 to December 2009 were grouped in to length class of 10 cm interval and analysed using FAO-ICLARM Stock Assessment Tools (FISAT) (Gayanilo *et al.*, 2005).

9.2.1. Natural mortality estimation

The instantaneous rate of natural mortality (M), was estimated following Pauly' empirical formula (Pauly, 1980 b, 1984) and Cushing formula (Cushing, 1980).

9.2.1. A. Pauly's empirical formula

Pauly (1980 b) established relationship of growth parameters (L_∞ (in cm) or W_∞ (in g) and K (year^{-1}), mean annual habitat temperature (T in °C) and natural mortality. The relationship was derived by utilizing 175 sets of independent sets of mortality estimates and predictor value for the tropical fishes. The equation used was:

$$\ln(M) = -0.0152 - 0.279 \ln L_\infty + 0.6543 \ln(K) + 0.463 \ln(T) \ldots\ldots(39)$$

Where,

L_∞ and K are von Bertalanffy growth parameters

T = the mean annual habitat temperature in °C.

von Bertalanffy growth parameters estimated by ELEFAN method/ Ford – Walford plot was used for the estimation. The mean annual habitat temperature recorded during the study was 28 °C.

9.2.1. B. Cushing formula

Cushing (1968) proposed a method by which M can be calculated based on longevity of the fish by applying equation:

$M = (\ln .100)/ t_{max}$……………………………………………..(40)

Where,

t_{max} = the age at L_{max}

Here natural mortality estimated based on the assumption that 99% of the animals in a population die before attaining $L_{max.}$ Maximum length of fish (L_{max}) in a population was estimated following Foramacion *et al.* (1991). This method is based on the assumption that the observed maximum length of a time series of samples does not refer to a fixed quantity but, rather represent a random variable which follows a probabilistic law.

L'_{max} was estimated from a set of n extreme values (L*, the largest specimen in each sample of a file) using the (Type I) regression:

$L^* = a + 1/\alpha \cdot P$………………………………………………...(41)

Where,

P = the probability associated with the occurrence of an extreme value

$1/\alpha$ is a measure of dispersion

L'_{max} = the intercept of the regression line with the probability associated with the n^{th} observation (note that the scale used for P is non-linear, i.e., corresponds to that used for extreme value probability paper).

P is computed for any extreme value following Gumbel (1954 probability P obtained from the formula:

$P = m/(n+1)$ ……………………………………………...……..(42)

Where,

m = the position of the value, ranked in ascending order

n = the number of L* values.

9.2.2. Total mortality estimation

The instantaneous rate of total mortality (Z) estimated following the Beverton and Holt model (Beverton and Holt, 1956) and length converted catch curve method (Pauly, 1984, 1990).

9.2.2. A. Beverton and Holt model

Beverton and Holt (1956) assumed that growth follows the VBGF and mortality can be represented by negative exponential decay. Here instantaneous rate of total mortality (Z) was obtained from the formula:

$Z = K \cdot (L_{\infty} - \bar{L})/(L_{\infty} - L')$……………………………………..….(43)

Where,

Z = instantaneous rate of total mortality.

$\bar{L}$ = Mean total length in cm, L' = cut of length

9.2.2. B. Length converted catch curve method

The method essentially consists of a plot of the natural logarithm of the number of fish in various age groups (N_t) against their corresponding age (t), which gives the linear relation.

$\ln(N_i/Dt_i) = a + b \text{ X } t_i$……………………………………………..(44)

Where,

N_i = the number of fish in length class i,

Dt_i = the time needed for the fish to grow through length class i,

t_i = the age (or the relative age, computed with $t_o = 0$) corresponding to the mid length of class i,

b= with sign changed is an estimate of Z.

Following estimation of Z, the routine used to estimate M using Pauly's M equation and F, from the equation:

F = Z – M…………………………………………………….…(45)

Where,

F = instantaneous rate of fishing mortality

And the exploitation ratio (E) from formula

E = F/Z………………………………………………………..(46)

9.2.3. Probability of capture

Probability of capture of fishes L_{25} (length at which 25 % of fishes caught), L_{50} (length at which 50 % of fishes caught) L_{75} (length at which 75 % of fishes caught) were estimated from length-converted catch curves by backward extrapolation of the catch curve and comparison of the numbers actually caught with those that "ought" to have been caught. Catch curve analysis extended to an estimation of probabilities of capture by backward projection of the number that would be expected if no selectivity had taken place (N'), using the formula

$N_{i-1}' = N'_I$ X EXP (ZDt_i)………………………………………..(47)

Where,

Dt_i as defined above in equation 44

$Z = (Z_i + Z_{i+1})/2$,…………………………………………………...(48)

Where,

$Z_i = M + F_i$; $F_{i-1} = F_i - X$, and $X = F$ / (no. of classes below P_1 +1)

Where,

P_1 = the first length group with a probability of capture equal to 1.0, and whose lower limit is an estimate of L'. From this, probabilities of capture by length were computed from the ratios of N_i/N'_i.

Values obtained were again tested following trawl type selection (Pauly, 1984). Three points of logistic plots were selected and subjected to regression analysis. Then L_{25}, L_{50} and L_{75} were estimated following the equation:

ln ($1/P_L$)-1) = S1 - S2 X L…………………………………………(49)

Where,

P_L = the probability of capture for length L,

S1 and S2 = variables used for estimating the probability of capture under the logistic model

L_{25} = (ln (3)-S1)/S2…………………………….……..……..(50)

L_{50} = S1/S2……………………………………………………..(51)

L_{75} = (ln (3) +S1)/S2………………………………………………(52)

9.2.4. Sample weight estimation, growth performance indices and life span

In order to understand the sample weight of the specimens used for study and to use as an input parameter for models, sample weight was estimated following Beyer (1987). Sample weight of length group and mean weight of sample were estimated by using the formula:

$WS^{-} = \sum (W_i^{-} X\ Ni) / \sum Ni)$ ……………………………….…….(53)

Where,

WS^{-} = mean weight of the sample s computed

N_i = the frequency count,

Wi = the mean weight of the fish in class i computed from

$W^{-}i = (1/Li + 1 – Li)\ X\ (a/b+1)\ X\ (Li + 1^{\ b+1} + Li^{\ b+1})$………....(54)

Where,

a and b = the coefficients of the length-weight relationship

L_i = the lower limit of length class i

L_{i+1} = the upper limit of length class i

The growth performance index ø' (Pauly, 1979) estimated from asymptotic length from the formula:

$ø' = \log_{10}(K) + 2 \cdot \log_{10}(L_\infty)$………………………………………..(55)

Where,

L_∞ = asymptotic length in cm

K = VBGF curvature parameter - $year^{-1}$)

The oldest individual in an unexploited stock are often about 95 percent of the species' asymptotic length (L_∞). It means that life span (t_{max}) is defined as the time required for fish to reach 95 per cent of the species asymptotic length (King, 1995). Life span is estimated following the equation:

$t_{max} = (-1/K) \ln (1-(0.95 L_\infty)/ L_\infty)$...(56)

Following equation is also used for estimation of life span:

$t_{max} = 3/K$ …………………………………………………………(57)

Where,

L_∞ and K are growth parameters explained above in equation 56

t_{max} = maximum age (life span)

9.2.5. Recruitment pattern and Virtual Population Analysis (VPA)

Seasonal pattern of recruitment is assessed by backward projection, along a trajectory defined by the VBGF of the frequencies in to the time axis of a time-series of samples (Pauly, 1983; Moreau and Cuende, 1991). Model is based on two assumptions and they are (i) all fish in the sample grow as described by a single set of growth parameters and (ii) one month out of twelve always has zero recruitment. Here restructured data has been used so that the temporal spread reduces and thus probably better reflects the actual seasonality of recruitment.

Length structured virtual population analysis (Pauly, 1984) is a modified version of Jones and van Zalinge (1981). Here length frequency, L_∞ and K are used as input parameter. This routine provides information on survivors, natural mortality and fishing mortality in each length group. The initial step is to estimate the terminal population (Nt) given the inputs, from equation:

$N_t = C_t \cdot (M + F_t)/F_t$……………………………………………(58)

Where,

Ct = the terminal catch (i.e., the catch taken from the largest length class). Then, starting from N_t, successive values of F are estimated, by iteratively solving,

$C_i = N_{i+Dt} \cdot (F_i/Z_i) \cdot (\exp(Z_i X Dt_i)-1)$……………………………..(59)

Where,

$Dt_i = (t_{i+1} - t_i)$,

$t_i = t_o - (1/K) X \ln(1-(L_i/L_¥))$………………………………..…..(60)

Population sizes (N_i) were computed from

$N_i = N_{i+Dt} X \exp(Z_i)$……………………………………………….(61)

The last two equations are used alternatively, until the population sizes and fishing mortality for all length groups have been computed.

9.2.6. Relative Yield/Recruitment (Y/R) and Biomass/ Recruitment (B/R) analysis

Using knife-edge selection, relative yield-per-recruit (Y'/R) was computed from:

$Y/R = EU^{M/K}(1- \quad (3U/ 1+m) + (3 U^2 /1+2M) - (3U^3 /1+3M)$..(62)

Where,

$U = 1-(L_c/ L_\infty)$ …………………………………………………….(63)

$m = (1-E)/(M/K) = (K/Z)$ ……………………………………………(64)

$E=F/Z$………………………………………………………..…...(65)

Relative biomass-per-recruit (B'/R) is estimated from the relationship

$B'/R = (Y'/R)/F$, ………………………………………..……….(66)

E_{max}, $E_{0.1}$ and $E_{0.5}$ are estimated by using the first derivative of this function.

Plots of Y'/R vs E (=F/Z) and of B'/R vs E, from which E_{max} (exploitation rate which produces maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of relative yield-per-recruit is 1/10th of its value at E=0) and $E_{0.5}$ (value of E under which the stock has been reduced to 50% of its unexploited biomass) were also estimated.

Later using selection ogive Relative yield-per-recruit (Y'/R) is computed from:

$Y'/R = SP_i((Y'/R)_I X G_{i-1})-((Y'/R)_{i+1} X G_i))$ ……………………….(67)

Where,

$(Y'/R)_i$ = relative yield-per-recruit computed from the lower limit of class i

$Y/R = EU^{M/K}(1- \quad (3U/ 1+m) + (3 U^2 /1+2m) \quad - (3U^3 /1+3m)$ (68)

Where,

U and m are defined as equation 63 and 64

P_i = probability of capture between L_i and L_{i+1},

$G_i = P r_j$………………………………………………….…………...(69)

Where

$r_j = (1-c_i)^{Si}/(1-c_{i-1})^{Si}$ ………………………………….……………....(70)

$S_i = (M/K) (E/(1-E))P_i$. ……………………………….…………...(71)

Here, B'/R is estimated from

$(B'/R)_i = (1\text{-}E)\cdot A/B$……………………………………………..(72)

Where,

$A = (1- \ (3U/ 1+m\ ) \ + (3\ U^2 /1+2m) \ - \ (3U^3 /1+3m)$ ……….(73)

$B=(1- \ (3U/ 1+m'\ ) \ + (3\ U^2 /1+2m') \ - \ (3U^3 /1+3m')$ ……...(74)

Where

$m' = 1/(M/K) = m/(1\text{-}E)$. ……………………………………... (75)

E_{max}, $E_{0.1}$ and $E_{0.5}$ were estimated by using the first derivative of the function.

9.2.7. Thomson and Bell Yield and Stock prediction model

This model combines features of Beverton and Holt's Y'/R model with those of VPA, which it inverts (Thomson and Bell, 1934; Sparre and Willmann, 1993). Though Cobia is exploited by multi gear in this study the model was used by limiting to trawlers alone.

The sum of the yields ($Y = SY_i$) was computed from:

$Yi = Ci\ X\ W^{-}i$ ………………………………………………….(76)

Where,

$W^{-}i = (\ 1/Li + 1 – Li)\ X\ (\ a/b+1)\ X\ (\ Li + 1^{\ b+1} + Li^{\ b+1})$……..…..(77)

Where,

a and b are the coefficients of the length-weight relationship

L_i = lower limit of the length class,

L_{i+1} = upper limit of the length class,

$C_i = (N_i\text{-}N_{i+1})(F_i/(M+F_i))$……………………………………..(78)

Where,

$N_{i+1} = N_i \cdot EXP(-(M+F_i) \cdot Dt_i)$ ……………………………………..(79)

$Dt_i = (1/K) \cdot \ln((L_\infty - L_i)/(L_\infty - L_{i+1}))$ …………………………………(80)

The biomass was computed from

$Bi = ((Ni - Ni + 1) / (M + F) X \; Dt_i) X \bar{W}i$ ………………………(81)

The value (V_i) is computed by

$V_i = Y_i \cdot v_i$ …………………………………………………………(82)

Where

v_i = the unit value for class i.

9.3. RESULTS

9.3.1. Mortality estimation

Natural mortality coefficient estimated following Cushing formula was 0.354. The age of longest fish was calculated following VBGF equation of the fish and substituted in the formula. Natural mortality obtained as per Pauly's empirical formula was 0.416. Values obtained by both the methods are found to be very close. However, value obtained by Pauly's empirical formula was used for further calculation, as the same is considered as more reliable and are based on interrelationship between VBGF parameters and mean habitat temperature.

Total mortality value obtained following Beverton and Holt model was 0.77 while value computed by catch curve method was 0.76. Length converted catch curve of Cobia made by plotting relative age against ln (N/Dt) is shown in Fig. 67. As shown in the Fig. 67 Fishing mortality (F) was estimated as 0.36 while exploitation ratio (E) as 0.47. Mortality rates estimated by both the methods were almost similar. However, value estimated by catch curve method was used for further analysis as this provided the facility to proceed to the estimation of probability of capture and this method is based on more input parameters than Beverton and Holt model.

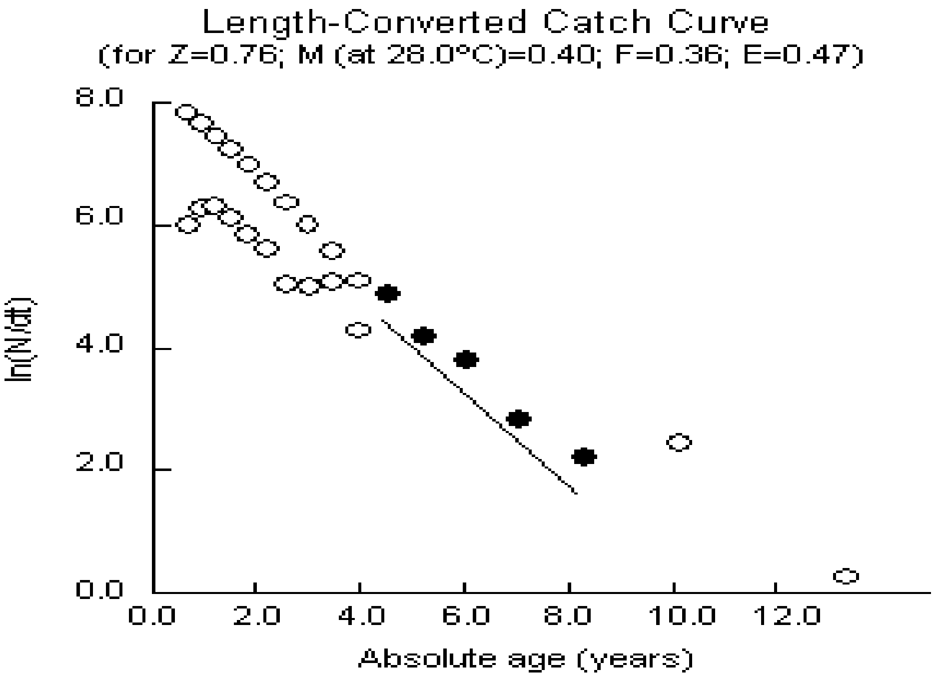

Fig.67. Length converted catch curve of *Rachycentron canadum* inhabiting along north west coast of India

9.3.2. Probability of capture

The relationship between length class and probability of their capture is depicted in Fig. 68. As evident from the graph L_{25}, L_{50} and L_{75} values were estimated as 20.2 cm, 46.4 and 71.65 respectively. These values were further tested with the trawl type selection method and results were found matching with the earlier.

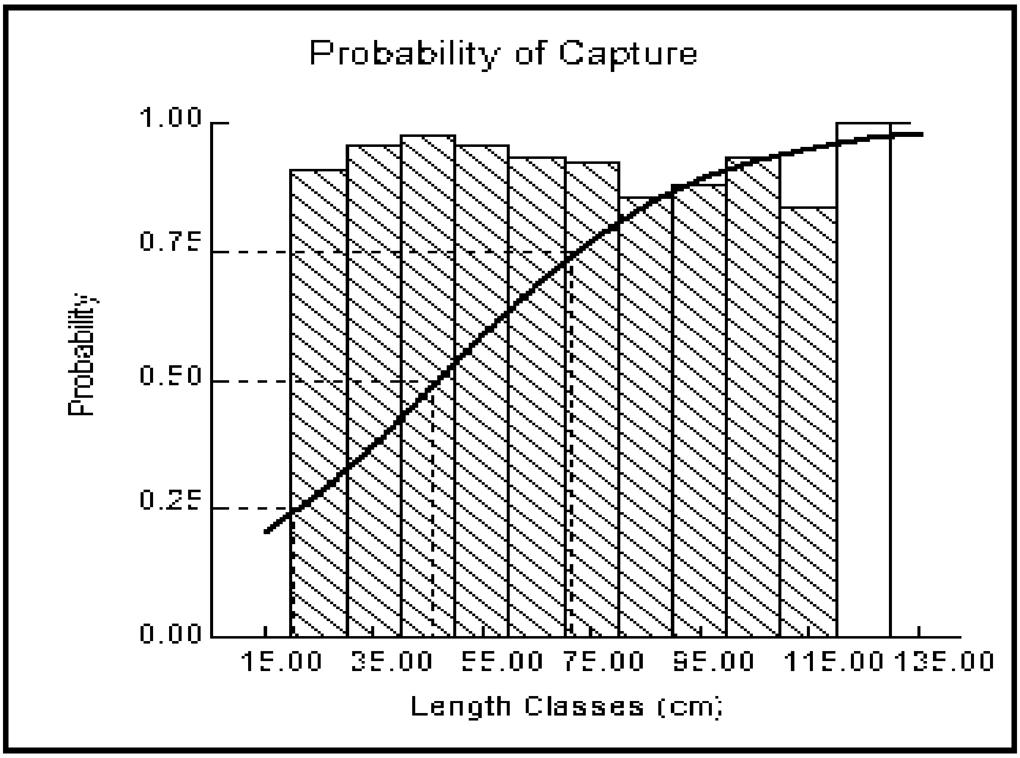

Fig.68. Probability of capture of Rachycentron *canadum* inhabiting along north west coast of India

9.3.3. Sample weight estimation, growth performance indices and life span

Month wise mean weight of fishes and mean weight of each length class of fishes estimated are shown in Table 44 & 45. Mean weight of Cobia ranged between 91.21 gm to 42397.21gm and mean weight of the sample was more during April-July and November. Growth rate was more during initial size groups, which got reduced towards larger sizes.

The growth performance index (ø') estimated following Pauly (1979) was 3.957. Life span of the species estimated based on asymptotic length and growth rate were 12.482 and 12.5 years respectively. Life span estimation based on growth rate will give only an approximate value (King, 1995); hence, value estimated based on asymptotic length is relatively more accurate and therefore used in subsequent analysis.

Table 44. Month wise weight of sample of *Rachycentron canadum* inhabiting along north west coast of India

Month	Sum of frequency	Weight of sample (in gm.)	Mean weight (in gm.)
January	62	53053.17	855.70
February	141	550089.80	3901.35
March	131	498477.60	3805.17
April	134	942573.10	7034.13
May	95	1014009.00	10673.78
June	101	848892.10	8404.87
July	81	581725.10	7181.79
August	54	177331.70	3283.92
September	105	581236.60	5535.59
October	125	782074.20	6256.59
November	98	696163.90	7103.71
December	122	315921.90	2589.52
Mean weight			5637.75

Table 45. Mean weight and growth rate of *Rachycentron canadum* inhabiting along north west coast of India on length group basis

Mid length of size class in cm	Mean weight (in gm.)	Growth rate	Mid length of size class in cm	Mean weight (in gm.)	Growth rate
25	91.21	-	115	9733.26	0.32
35	252.72	1.77	125	12640.68	0.30
45	544.61	1.15	135	16029.38	0.27
55	1007.91	0.85	145	19984.92	0.25
65	1684.44	0.67	155	24553.19	0.23
75	2616.74	0.55	165	26780.33	0.09
85	3847.90	0.47	175	35712.78	0.33
95	5421.57	0.41	185	42397.21	0.19
105	7381.85	0.36			

9.3.4. Recruitment pattern and Virtual Population Analysis (VPA)

Seasonal recruitment pattern of Cobia in percentage is depicted in Fig.69. As seen from the Fig.69, more than 70 percentage of recruitment took place during March to July, with a definite peak during May.

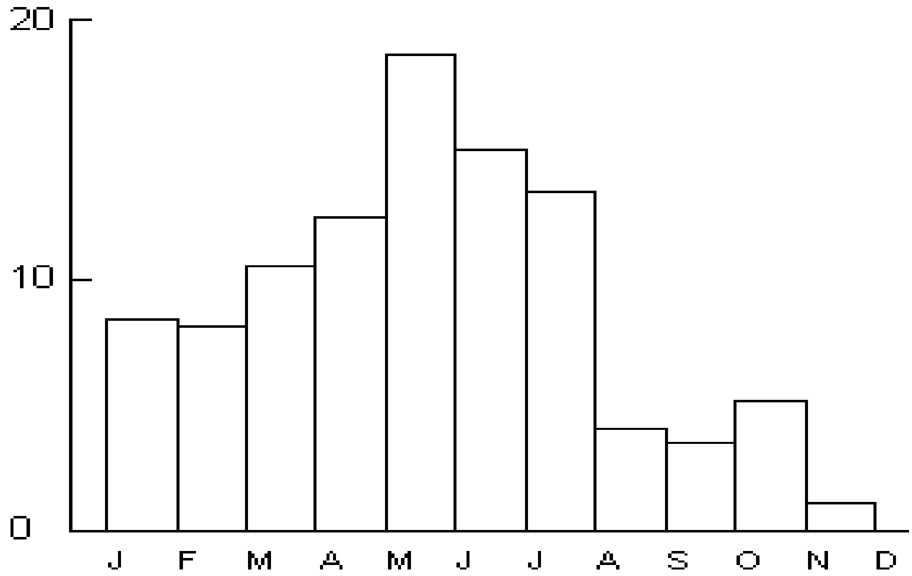

Fig.69. Seasonal recruitment pattern of *Rachycentron canadum* inhabiting along north west coast of India

Result of VPA is shown in Fig.70. The dynamics of the stock influenced by number of survivors and portion of population subjected to natural mortality and fishing mortality are very much reflected in Fig.70. Here, fishing mortality increases towards higher length group as it followed fishing down the size. ie. Larger size group in the population were subsequently removed from the stock by the fishing gears.

Initial terminal fishing mortality was kept as “one” for estimation and Fig. 70 shows that terminal fishing mortality “one” leads to removal of all adults from the population. Tabular form of catch in numbers, population, fishing mortality and study state biomass in different length group are furnished in Table 46. The number of individual in a population reduces towards the higher classes, but biomass values were more in higher length groups. This is mainly due to growth and resultant increase in weight of individuals.

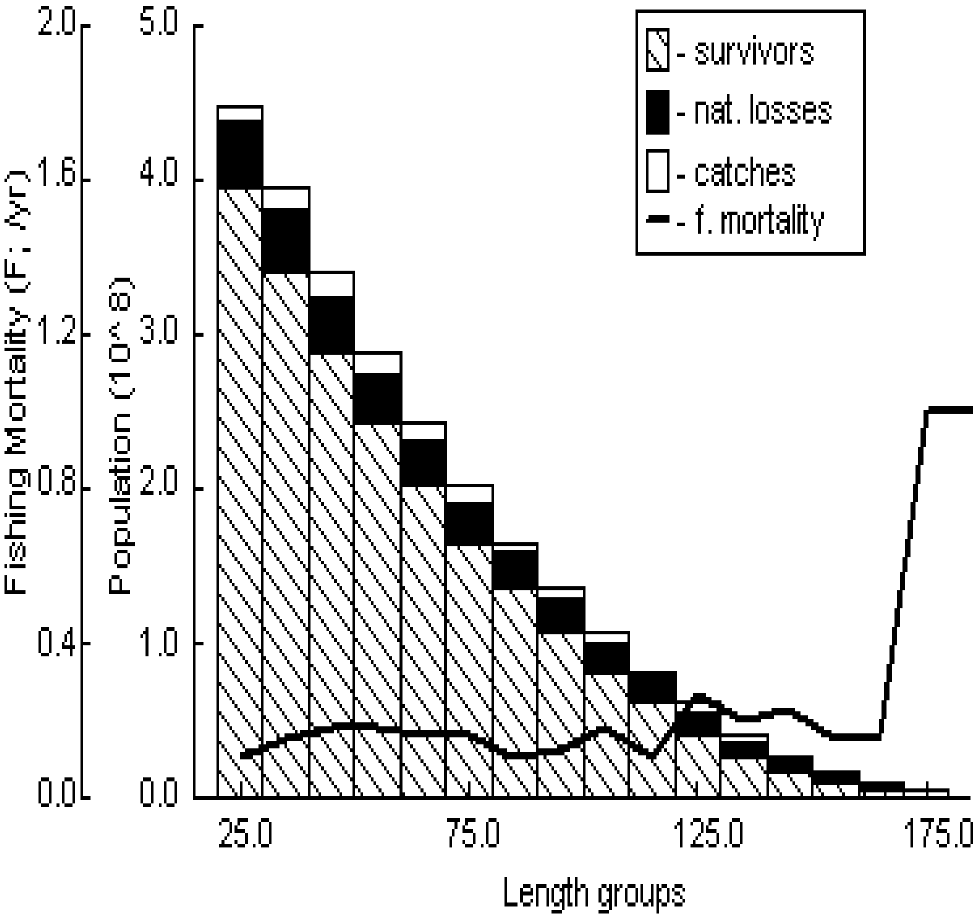

Fig.70. Length structured virtual population analysis of *Rachycentron canadum* inhabiting along north west coast of India

Table 46. Length-structured virtual population analysis of *Rachycentron canadum* inhabiting the north west coast of India

Mid length in cm	Catch in million numbers	Population(N) in million	Fishing mortality(F)	Study state Biomass in thousand tonnes
25	10.50	447.39	0.10	94.52
35	14.30	394.45	0.15	242.97
45	16.20	340.77	0.18	478.09
55	14.10	288.62	0.18	799.44
65	11.50	242.04	0.16	1202.43
75	10.10	201.31	0.16	1672.40
85	6.20	165.04	0.11	2201.87
95	6.50	135.41	0.13	2754.74
105	7.80	108.03	0.18	3264.12
115	4.00	82.12	0.11	3705.72
125	8.20	62.59	0.26	3924.62
135	4.80	41.68	0.20	3832.82
145	4.00	27.09	0.23	3559.37
155	1.90	15.81	0.15	3123.71
165	1.40	8.70	0.16	2540.10
175	2.70	3.81	1.00	3972.88

9.3.5. Relative Yield/Recruitment (Y/R) and Biomass/ Recruitment (B/R) analysis

Results of Relative yield per recruit analysis of *Rachycentron canadum* of north west coast of India - Y/R isopleths diagram with current M/K value is shown as Fig.71. Here, L_c/ L_∞ plotted against exploitation rate. Relative yield and biomass per recruit analysis of *Rachycentron canadum* of north west coast of India with current L_c is shown as Fig.72. The values of Lc/ L_∞ and M/K used for the estimation are 0.237 and 1.7336 respectively. Exploitation rate (E) at different levels as $E_{0.1}$, $E_{0.5}$ and E_{max} estimated by the analysis are 0.402, 0.288 and 0.47 respectively.

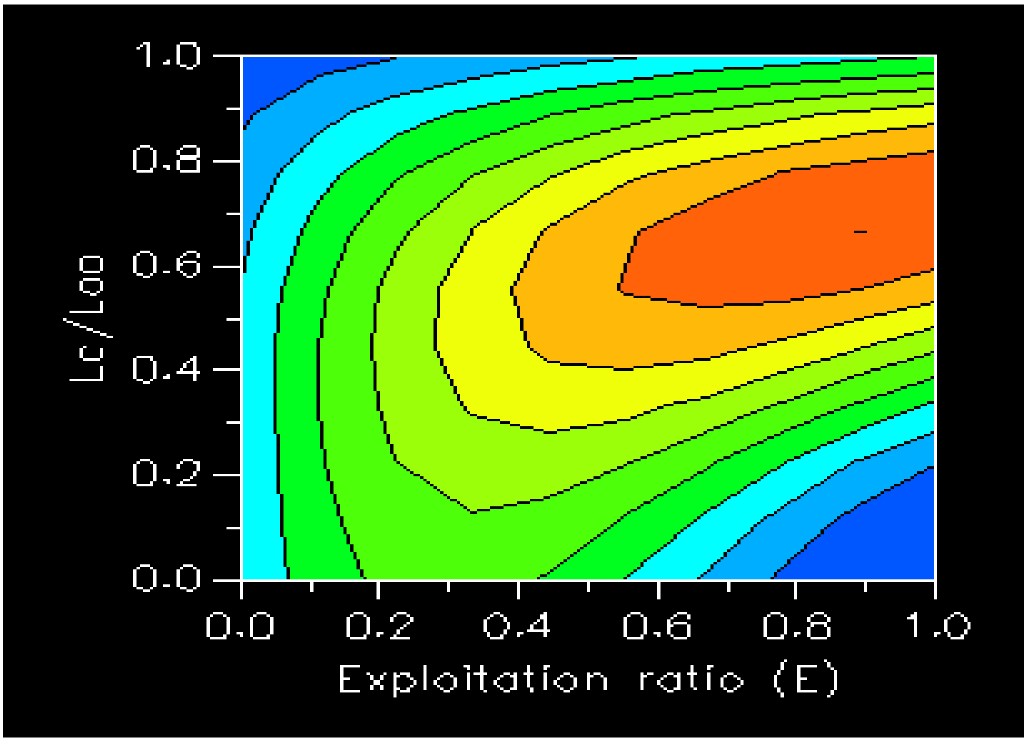

Fig.71. Relative yield per recruit analysis of *Rachycentron canadum* of north west coast of India - Y/R isopleths diagram with current M/K value

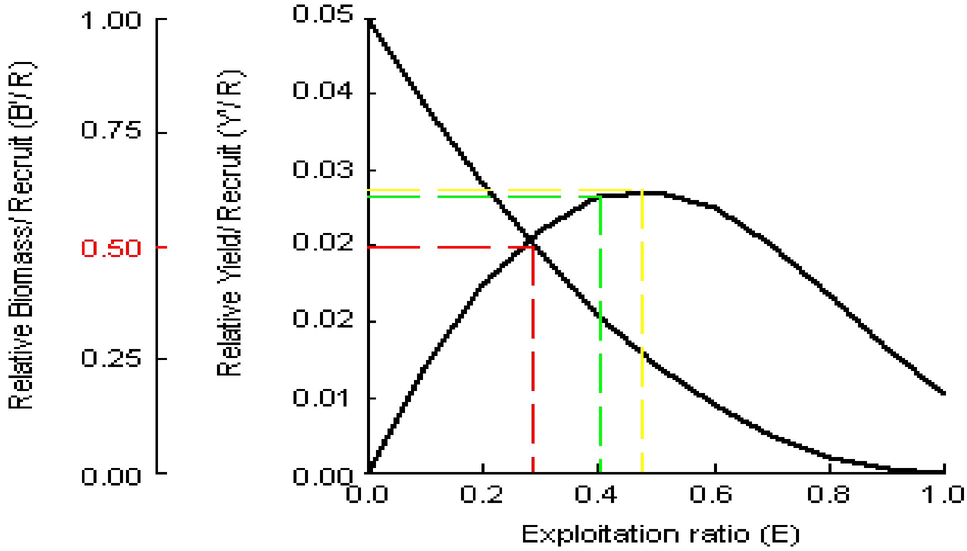

Fig.72. Relative yield and biomass per recruit analysis of *Rachycentron canadum* of north west coast of India with current L_c.

9.3.6. Thomson and Bell Yield and Stock prediction model

Plots of yields, values and biomass estimates for a range of F factors for Cobia cumulative curve and species specific gear specific (trawl net) graphs were illustrated in Fig. 73. Model predicts that, at F equal to 0.4 stock will provide maximum yield but when F equal to 0.3 biomass reach to 50%.

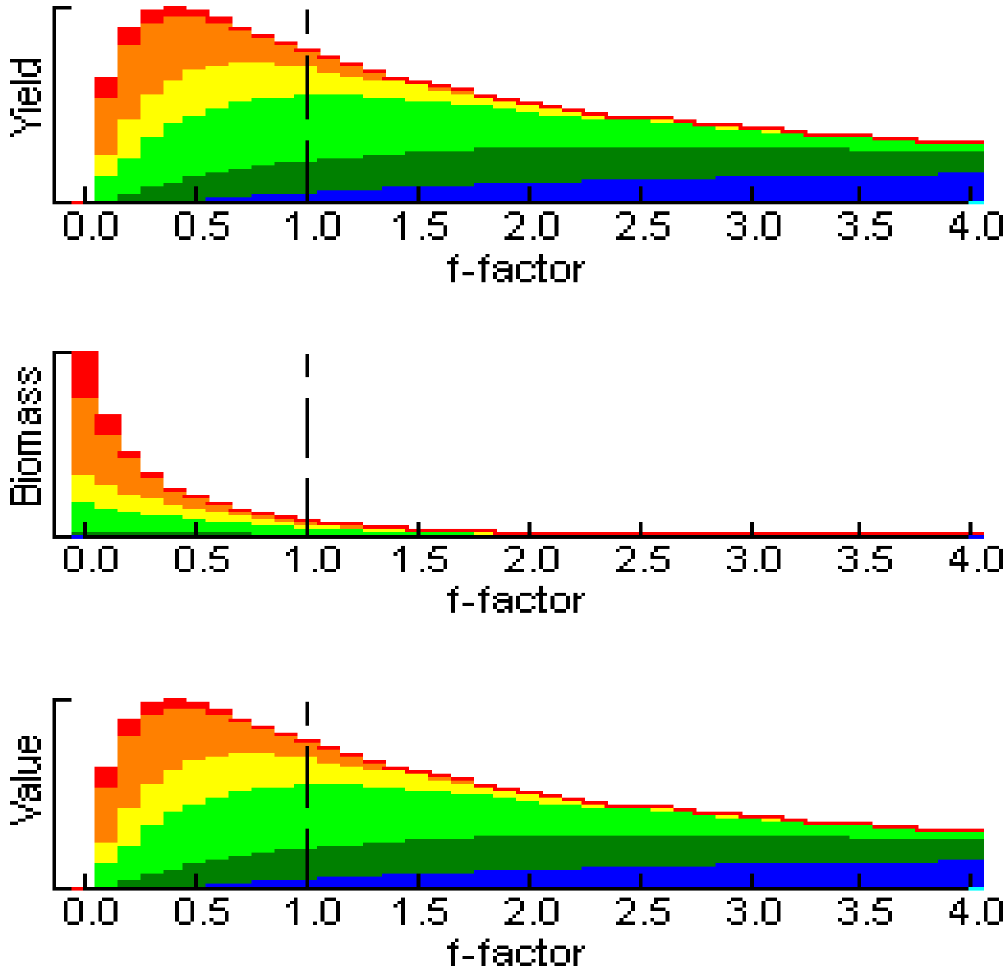

Fig. 73. Thomson and Bell yield prediction of *Rachycentron canadum* of north west coast of India

9.4. DISCUSSION

Natural mortality coefficient estimated following Cushing (1968) and Pauly (1980) were 0.354 and 0.416 respectively. Both the values are less than 0.5. According to King (1995) natural mortality below 0.5 is considered as low; hence, natural mortality of Cobia arrived in the present study can be considered as low. Total mortality value obtained following Beverton and Holt model was 0.77 against 0.76 obtained by catch curve method. Fishing mortality (F) and exploitation ratio (E) estimated were 0.36 and 0.47. Lower rate of natural mortality indicates that more fishing effort is needed to achieve maximum sustainable yield.

Mortality rates of *Rachycentron canadum* reported by various authors from different localities are furnished as Table 47. Natural mortality rate reported by different authors were below 0.5 which ranged from 0.2- 0.41. Mortality rate reported by Richards (1967) and Williams (2001) are comparable with the result of the present study. Somvanshi *et al.* (2000) reported a natural mortality of 0.36 for the Cobia occurring along north west coast of India. In the present study natural mortality estimated is 0.41 from the same area. Somvanshi *et al.* (2000) estimated natural mortality by keeping mean habitat temperature as 25^0 C, which is on a lower side. Present study recorded mean habitat temperature as 28^0 C; hence the same was used for estimation of natural mortality. Total mortality value estimated in the present study is comparable to the results of earlier studies (Franks *et al.*, 1999; Williams, 2001; Fry and Griffiths, 2010).

Table 47. Mortality rates of *Rachycentron canadum* reported by various authors from different localities

Natural mortality (M)	Fishing mortality (F)	Total mortalit y (Z)	Location	Author/s
0.2-0.4	-	-	Chesapeake Bay	Richards (1967)
0.24	-	-	Gulf of Aden	Edword *et al*.(1985)
0.29	-	-	South Africa	Torres (1991)
-	-	0.75	Northeastern Gulf of Mexico	Franks *et al*.(1999)
0.36	-	-	North west coast of India	Somvanshi *et al*.(2000)
0.2-0.4	-	0.72	Gulf of Mexico	Williams (2001)
0.35	-	0.85	North and eastern Australia	Fry and Griffiths(2010)
0.41	0.36	0.76	North west coast of India	Present study

Probability of capture estimated by backward extrapolation of the catch curve (Fig. 68) showed that most of the Cobia juveniles were vulnerable to trawl net. L_{50} value (46. 4cm) and L_{75} value (71.65 cm) estimated by this method were below or at par with the size at maturity(63 cm in the case of male and 70 cm for female).This clearly indicates that exploitation of Cobia stock by trawlers is not at all advisable. In India, there is no targeted fishery for Cobia, but they are mostly caught as bycatch. In a multi species fishery, mesh size regulations aimed at bycatch is not at all feasible. However, ban on fishing of juveniles and voluntary releases of juveniles to sea are possible management measures for the conservation of the stock of Cobia.

Mean weight of the sample recorded during the study is 5637.75 gram. Month wise analysis of mean of sample weight indicated that during April to July and September to November mean weight of sample were above the mean weight of the sample. During January to March and August samples were dominated by juveniles, which indicate that recruitment of smaller fishes to fishery is mainly during the above months. Occurrence of larger specimens during April to July and September to November support the increased spawning activity during these months identified by the present study.

Values of growth performance indices, L_{max} and life span of species reported by different authors from different localities are presented in Table. 48. As evident from the Table 48 L_{max} ranged between 142 cm to 200 cm while present study estimated L_{max} as 185 cm. Maximum length of the fish recorded and L_∞ estimated by the present study were 181 cm and 194.25 cm respectively. Landing records showed that Cobia may reach up to 2 m (Cadenat, 1950 and IGFA, 1991).

Table 48. Growth performance indices (ø'), L_{max} and life span of *Rachycentron canadum* reported by various authors from different localities

L_{max} in cm	ø' (M/F)	Longevity in years (M/F)	Location	Author/s
-	3.61/3.78	10	Chesapeake Bay	Richards (1967)
145	3.8/3.97	10	Western Lousenia	Thompson *et al.*(1991)
200	3.6	-	South Africa	Torres (1991)
142	3.61	14/13	North Carolina	Smith (1995)
165	3.77/3.89	11	Northeastern Gulf of Mexico	Franks *et al*. (1999)
-	-	11	Gulf of Mexico	Williams (2001)
-	-	13	North and eastern Australia	Fry and Griffiths (2010)
185	3.96	12.48	North west coast of India	Present study

Growth performance indices (ø') worked out by different authors from different geographical locations ranged from 3.6 –3.97. These values pertain to various habitats of Cobia and therefore the values cannot be compared. However, ø' value (3.96) estimated by the present study is with in the range of earlier estimates available for Cobia.

Life span of Cobia in terms of years reported from different geographical areas varied from place to place. Longevity values ranged between 10 years and 14 years. Present study estimated the value as 12.48 years. High life span and low mortality rates indicated that Cobia stock in north west coast of India is in good condition.

Fig.69 shows the seasonal recruitment pattern of Cobia in terms of percentage. As illustrated, recruitment pattern of Cobia showed two modes, one during May and other during October. This is indicative of the existence of multi-age group in the stock and their prolonged breading season. Recruitment pattern thus obtained matches with the breeding season assessed by the present study. Both modes in recruitment pattern coincided with south west monsoon and northeast monsoon periods in India, where availability of food organisms in the habitat will be very high.

Results of VPA (Fig.70 &Table. 46) show that fishing mortality increases towards higher length group while natural mortality showed a reverse trend. As larger fishes are less susceptible to predation, natural mortality will reduces when fish grows. Most of the organisms follow this pattern of natural mortality.

Analysis showed that at terminal fishing mortality “one” almost all the fishes above 75 cm length will be vulnerable to fishing.

There was a sudden reduction of catch in numbers from the size group with 75 cm to 85 cm which appears to be very interesting. In general, adult Cobia moves faster, hence chances of escape from the trawl net is more for larger fishes and this may be the reason for reduction of adult fishes in the catches. A completely different picture can be seen if we consider biomass in tonnes, the biomass increases towards larger size group. Fast growth rate observed for this species may be the reason for this increase.

Results of Relative yield per recruit and biomass per recruit and isopleths, in which L_c/ L_∞ plotted against exploitation rate (Fig. 71& Fig.72) illustrates the dynamics of Cobia fishery. The values of Lc/ L_∞ and M/K estimated and used for analysis were 0.237 and 1.7336 respectively. Exploitation rate (E) at different levels like $E_{0.1}$, $E_{0.5}$ and E_{max} were .0.402, 0.288 and 0.47 respectively. As depicted in the Fig. 71 &72, 50% of stock can be removed with an exploitation ratio of 0.288. By increasing the exploitation ratio to $E_{0.1}$ yield from the stock can be increased and maximum yield can be obtained at an exploitation ratio of 0.47. Present exploitation ratio is 0.47, which indicates that stock is exploited optimally or fully and any further increase of fishing effort wills leads to over exploitation and subsequently leads to the collapse of the fishery. Low mortality rate, fast growth rate and high longevity recorded by the present study also manifest the health of stock.

Results of Thompson and Bell yield prediction model (Fig. 73) support the findings of Relative yield per recruit and Biomass per recruit models. Though Cobia is exploited by various fishing gear, prediction made here was exclusively based on trawl gear. As illustrated in the Fig. 73, 50 % of stock can be removed at F factor below 0.3 and maximum yield can be achieved by spending an effort of 0.4. Fishing mortality estimated during the present study is 0.36. This indicates that stock is optimally or fully exploited. Increasing the effort F to one will result in the removal of 90% of the biomass and reduction of yield by 25%.

Any increase of effort beyond optimum level of effort (0.4) mainly affects the biomass of larger sized group; hence, this results in a drastic reduction of biomass. As shown in the Fig.73, increase of effort mainly affects large sized fishes (marked red in colour) than the smaller fishes. Increased life span of the species makes the management of the species more difficult as recovery time needed for the rebuilding the stock may take minimum three to four years.

9.4.1. Conservation and management

Cobia is a pelagic fish whose vertical distribution extent throughout the water column. It is distributed all along the coast of India. There is no targeted Cobia fishery existing anywhere in India and they are mainly exploited as bycatch in the hook and line, troll line, drifts gill net and bottom trawl. Summary of the biological and population parameters of Cobia estimated by the present study are furnished in Table 49. As seen from the Table 49, Cobia matures early at one to two years at 63- 70cm length. Length of probability of capture L_{50} of Cobia by trawl net is less than the size at maturity. This clearly indicates that exploitation of Cobia by existing trawl net is not at all advisable.

In a multi species fishery, mesh size regulation for the targeted and non targeted fishes is extremely difficult. Use of a separate fishing gear for this species may not be economical due to lesser availability of the resource. As a conservation measure complete ban of fishing, keeping and sale of juvenile fishes (Cobia below 63 cm length) will definitely control growth over fishing. Enforcement of ban on keeping and sale of juvenile fish will result in voluntary release of incidentally caught juveniles, as most of the Cobia fishes caught by trawlers are found in live condition immediately after haul.

Peak breeding season, fishing season and recruitment of Cobia coincided with monsoon period. In India uniform ban on trawling exist during these periods. Hence, there is no need for declaration of any closed season for Cobia fishing. Present exploitation rate and maximum allowable exploitation are equal and this suggests that presently stock is either optimally or fully exploited. Higher demand and increased popularity during recent years may lead to targeted exploitation of the resource. The targeted exploitation may lead to increased fishing effort, removal of larger sized fishes, over exploitation and collapse of the fishery. Cobia being long-lived species, recovery of stock will take a minimum three to four years. Hence, at any cost increase of fishing effort should be controlled.

Agencies like Central Marine Fisheries Research Institute (CMFRI), Ministry of Agriculture (MOA) and Marine Product Export Development

Authority (MPEDA) are responsible for data collection from landing centers and publishing of marine fish landing data in India. However, the data banks do not reflect Cobia landings. Cobia is either included with the group other carangids or miscellaneous fishes. This defers fishery managers to assess the fishing trend of Cobia in commercial fishery and recommend fishery management measures for Cobia. Reporting of Cobia landings separately is the need of hour to be implemented immediately.

Present study showed that Cobia can be collected live and utilised for stocking. Popularisation of live collection method and well organized collection center facilities at landing centers and fishing harbors will solve the problem of non availability of fingerlings for stocking. Fishes of size 20 to 30 cm TL can be collected live. Specimens ranging from 30 to 63 cm TL can be released to sea and adult fishes can be stored in ice or in frozen condition. Present study estimated 447.39 million numbers of fishes in the size range of 20 –30 cm. Judicious exploitation of these size group fishes can definitely support Cobia culture till commercial hatchery production succeeds.

Table 49. Primary account on biological and population parameters of *Rachycentron canadum* inhabiting the north west coast of India

Parameters	Value	Remarks/ method
Length at maturity -Male	63 cm	Hodgkiss and Man (1978) method
Length at maturity -Female	70 cm	
Peak Breeding season	July- Aug. and Nov.Jan.	Percentage of mature specimen and Gonadosomatic index
Feecundity	1,231,630–1,800,350	Absolute fecundity
Trophic value	4.386	Christensen and Pauly (1992) method
Age at maturity- Male	1.48 yrs	von Bertalanffy growth equation
Age at maturity -Female	1.71 years	
Growth rate (K)	0.24	ELEFAN method and Ford Walford plot
Asymptotic length (L_∞)	194.25	
Minimum length of sample	22.6 cm	Measurement of sample
Maximum length of sample	183 cm	
Length maximum (L_{max})	185 cm	Foramacion *et al.* (1991) method
Age at zero length (t_0)	-0.615	ELEFAN method and Ford Walford plot
Life span	12.48 years	King (1995) method
Biomass	2209.514 metric tones	Swept area method
Potential yeild	839.6 metric tonnes	Cadimas formula
Natural mortality (M)	0.416	Pauly's empirical formula
Total mortality(Z)	0.76	Catch curve method
Fishing mortality(F)	0.36	
Exploitation ratio	0.47	
Probability of capture L_{25}	20.2 cm	Pauly(1984) method
Probability of capture L_{50}	46.4	
Probability of capture L_{75}	71.65	
Length at capture (L_c)	46.04	
(L_c)/ (L_∞)	0.237	By division
M/K	1.733	By division
$E_{0.1}$	0.402	Relative yield per recruit and biomass per recruit model
$E_{0.5}$	0.288	
E_{max}	0.47	
Exploitation ratio	0.47	Catch curve method

10. LIVE GENE BANKING AND CULTURE PROSPECTS

10.1. INTRODUCTION

Aquaculture research on Cobia started during early 1970's with the collection of wild caught Cobia eggs off the coast of North Carolina (Hassler and Rainville, 1975). The authors described larval development and concluded that Cobia had good aquaculture potential because of its rapid growth and good flesh quality. The first captive spawning of the species was reported from Taiwan Province of China during 1990 and by 1997 the technology to raise large quantities of Cobia fry had been developed (Benetti *et al*., 2008).

Research in the U.S. has focused primarily on tank spawning of wild caught and cultured adult Cobia. Adult Cobia can be anesthetized and moved easily using eugenol (clove oil) at 10 to 20 ppm. By manipulating photoperiod and water temperature spawning can be induced. Researchers in the U.S. have also used hormones to induce adult Cobia caught during their natural spawning season to produce eggs. Both HCG (human chorionic gonadotropin) injected at 275 IU/kg and a slow-release pellet containing salmon GnRHa (gonadotropin-releasing hormone analog) implanted in fish have resulted in spawns (Kaiser and Holt, 2005).

Cobia's phenomenal growth rate, low mortality, flesh quality, good feed conversion rates, hardy nature, wide tolerance of hydrographic parameter and high unit price make them good candidate species for aquaculture. Cobia can be caught from wild and transferred to cages or ponds for culture and also can be used for brood stock development. Salinity tolerance of Cobia is another interesting aspect; their ability to grow at various salinities makes them a potential brackish and mariculture species. In captivity, Cobia of all sizes adapt quickly to confinement, where they feed voraciously and grow rapidly (Kaiser and Holt, 2005).

The majority of Cobia aquaculture production currently comes from China. Other countries involved in production are Taiwan Province of China, United States of America, Taiwan, Bahamas, Brazil, the Dominican Republic, Mexico, Philippines, Puerto Rico, and Vietnam (Benneti *et al.,* 2008). 80.6 percent of total Cobia production comes from China and major share of the rest from Taiwan Province of China. The total value of the global production of this species in 2004 was USD 36.20 million (FAO, 2010).

Cobia culture in India is in experimental stage. Attempts to culture the wild collected Cobia juveniles in confinement, grow out brood stock, induce adults to spawn and develop hatchery produced fry for stocking are taken up by various Govt. research Institutions like Central Marine Fisheries Research Institute (CMFRI), Marine Products Export Development Authority (MPEDA), etc. Some initial success stories also reported from different corners and research front (Gopakumar *et al*., 2010).

One of the major factors that decide the success of fish culture is continuous supply of fingerlings for stocking. Wild collected fingerlings and hatchery-produced seeds can be utilized for above purpose. Significant portion of

Cobia caught by trawlers are juveniles. In India, where multi-species and multi-gear fishery exists, mesh size regulations for a single species is practically difficult. Utilization of these juveniles for culture will be an option for ensuring seed supply to farms. With an aim to utilize juveniles caught by trawlers and to standardise live gene banking techniques, an attempt was made to collect them onboard and stock in tanks for culture. Experiments proved that Cobia juvenile can be collected live and maintained onboard and at shore facility.

Information on culture prospective of Cobia in India is meager. An attempt is made here to assess the facilities available in India and discussed future course of action for the development of Cobia culture in India.

10.2. MATERIALS AND METHODS

M.V. Matsya Varshini, a purse seiner cum trawler carried out fishery resource surveys along the southwest coast of India. Expo model fish trawl was used for the survey of fishery resources. Survey operations of the above vessel each lasted for twenty days during May, 2003, March, 2004, November, 2004, April, 2005 and November, 2005 in which author had participated onboard the vessel as cruise leader. Major objective of the study was to collect live ornamental fishes. As a part of the experiment, juvenile Cobia was also collected with an aim to study their suitability for culture. Fishes caught from the 30- 70 m depth zone during the last 2-3 days of each cruise were utilized for the study.

10.2.1. Live gene banking

Juvenile Cobia caught by trawl net were immediately collected and transferred to a freshwater tank for freshwater bath to destroy the parasites and other pathogenic organisms likely to be present on them. Fishes were kept in the tank for about 30 seconds to a minute, by which time they show signs of inactivity. Freshwater treated fishes were then transferred to the collecting tank. A 250 litre capacity square type white coloured plastic tank was used as the collection tank. Necessary filtration arrangement and aeration were also provided.

Immediately after collection, fishes were found to be in stressed condition. Excessive rate of excretion, increased opercular activity and fast swimming were noticed during the above period. Water exchange of 75% of total water in the collection tank was carried out after one hour of collection to avoid pollution of water due to increased rate of excretion. Further, 50% of water exchange was carried out twice in a day. Care was taken to see that the tank was not exposed to direct sunlight to minimize heating up of the water.

Immediately after reaching the shore, live fishes were transported to shore aquarium in 50 litre plastic buckets. Maximum effort was taken to avoid stress and overcrowding of live fishes. Fishes were stocked in quarantine tank for 21 days after giving a freshwater bath.

10.2.2. Stocking tanks

Four glass tanks of size 5’x2’x2.5’ made of 12 mm toughened glass with silicone sealing were used for stocking the juveniles. Under gravel filter system with substrate of coral sand, fitted with a power head of 2000 litre/hour was used for filtration. Fluorescent tubes fitted on the top cover of the tank were used for providing the lighting. 120 mm mesh sized polyethylene nets were used to cover the top of tank. Pre conditioned sea water (Seawater collected from the open sea was kept in black coloured plastic tanks for more than 21 days for conditioning) was used for filling in the aquarium tanks. 25% water exchange was done at monthly intervals to minimize the nitrate load.

10.2.3. Culture technique

Stocking densities at the rate of 20 cm per 100 litre were slowly increased to the level of 30 cm per 100 liter in each tank. Water quality parameters like temperature, salinity and pH were analysed on a daily basis. Temperature of 30^0C- 32^0C, salinity of 30 ppt. and pH value of 8-8.2 were maintained throughout the period under study. Fishes were fed daily with frozen shrimp pieces, fish pieces and clam meat. Quantity of the feed was decided on trial and error basis. Unutilised food particles were removed from the tank after one hour of each feeding. Percentage of survival of fish worked out by following the formula

PFS= (FC/ FS) X 100……………………………………………(83)

Where,

PFS =Percentage of fishes survived

FC = Number of fishes collected / stocked

FS = Number of fishes survived

10.3. RESULTS

10.3.1. Live gene banking

Exploratory survey of fishery resources off Kerala coast between 30-70 m depth zone indicated the presence of juvenile Cobia in rich concentration that can support Cobia culture practices. Almost all juveniles caught with in 30-70 m depth were found to be landed in live condition. However, fishes collected from deeper water were found to be less active or not fit for stocking. An inverse relationship between the percentage of healthy fishes and the depth of operation was observed during the present study. A similar relation ship was observed in the case of haul duration, where lesser haul duration resulted in the high percentage of healthy fishes. Survival of fishes collected onboard mainly depended on the following factors:

1. Time taken for collection
2. Handling of live fishes by the crew
3. Depth of collection
4. Haul duration;
5. Water exchange rate
6. Rate of aeration.
7. Stocking density in the collection tank

Quick collection, proper handling of live fishes by the crew, lesser haul duration and shallow water operations resulted in increase of survival rate. Water exchange played an important role in the survival rate as the sudden change of environment from open sea to a captive environment resulted in increased rate of excretion and lead to the probable increase of ammonia content. Water exchange of 75% of water after one hour of collection and 50% of water exchange twice in a day are found to be effective. In the 250-litre collection tank 8-10 nos. of fish with sizes averaging 20-30 cm survived and they were in good health for transfer to quarantine tanks. 8.5% of Cobia caught in number was of 20-30 cm size group and percentage of juveniles caught during the study period was 52.14%. Present study collected only those fishes that come under size group 20-30 cm. In the collection tank Cobia used to move very fast for some time until they acclimatise themselves with the condition. Due to stress and changes in the environment, normally they won't take any food for one or two days. After words, they were fed with shrimp and smaller fishes.

10.3.2. Survival rate

Thirty six juvenile Cobia were collected during the study and stocked in the collection tank, of which thirty-three survived and the survival rate worked out to be 91.7%. No mortality was recorded while transportation to quarantine tank. Fishes were again subjected to fresh water bath before stocking them in to quarantine tank. On the first day fish did not took any food, later started feeding on shrimp and fishes like nemipterids, lizardfish etc. No incidence of parasite infestation or bacterial or fungal disease was observed.

Fishes were stocked for 21 days in quarantine tank, and most of the fishes were in healthy condition. Out of the 33 fishes, 31 fishes survived in the quarantine tank, which works out to be a survival of 93.9 %. They were further stocked in rearing tank for two months to assess the suitability for stocking in cages or other confinements. All the fishes stocked in rearing tank were survived and this registered 100% survival. The final percentage of survival was worked out to be 86.1%.

10.4. DISCUSSION

Results of present study indicate that Cobia can be collected in live condition from trawl catches. All the Cobia juveniles caught were found to be live at the time of capture and 8.5% of the total Cobia caught was in the size group of 20-30 cm. Better survival rates and abundance of juveniles indicated that Cobia can be collected from the wild and can be used for setting up of Cobia farms. With proper training to the fishermen on live collection method and by setting up of collection centers on each landing centers, supply of Cobia fingerlings for stocking can be ensured.

Cobia is a voracious feeder and feed on organisms available in their habitat. Hence, they can be fed with non-conventional and undersized fishes, crustaceans and molluscs. Hardy nature, ease of acclimatization to new environment, tolerance to wide ranges of salinity (Denson *et al.*,2003) voracious feeding habit, high growth rate and low mortality make Cobia as a suitable candidate species for culture (Holt *et al*.,2007). High unit prize and demand in local market helps marketing quite easy.

In order to minimize grow-out time as well as to avoid diseases, Cobia produced in cages should be located in sites that provide warm (26 ºC and above) clean water and adequate flow rates through the cage system to provide high dissolved oxygen levels continuously (Benetti, 2002).

According to FAO (2010) Cobia can be cultured within the limit of present cage technologies in terms of depth 25- 100 m and would result in good growth in terms of temperature 26 – 32^0C. India possess 0.219 million sq.km of sea area (0.184 million sq.km along west coast and 0.035 million sq.km along east coast) between 30-100m depth contour (FSI, 2010). Exploratory survey data of FSI fleets indicate that sea surface temperature in Indian waters is above 26 ºC.

In India, large quantities of non-conventional and undersized fishes are thrown overboard, these uneconomical and undersized fishes, crustaceans and molluscs can be used as feed for Cobia. Several studies reported occurrence of non-conventional fishery resources in our coastal and deeper waters (MOA, 2000; Sajeevan and Nair, 2006; Sajeevan *et al.*, 2009). FSI (2008) reported occurrence of deep-sea crab *Charybdys smithii* in bulk quantity along the west coast of India. Crabs were found to be dominant among the gut contents of Cobia and are considered as preferred food items. Both the above resources form major share of trawl discards. These bulk discards can be utilized for feeding Cobia.

Suitable seawater temperature, unpolluted water, sufficient area for setting up of cages, availability of seeds and occurrence of cheap and best food materials are some of the favorable conditions exist in India for setting up of Cobia farms.

Ensure good aquaculture practices to prevent out break of diseases, study on the effect of Cobia cages on the surrounding environment, setting up of hatchery to ensure continuous supply of fingerlings for stocking, improved marketing facilities and export avenues are other priorities to be considered for the development of Cobia farming industry in India

11. SUMMARY

Cobia, *Rachycentron canadum* is a fast growing pelagic fish belonging to the monotypic family Rachycentridae. They show worldwide distribution in tropical and sub tropical waters. Cobia is exploited commercially in various countries like Taiwan, Pakistan, India, United State of America, Australia, Gulf of Mexico and the Caribbean. Recreational fishery of Cobia exists in different parts of the world. In India Cobia is caught as bycatch of trawlers, gillnet and hook and line fishery.

Various studies carried out worldwide by utilizing commercial and recreational data provided information on Cobia. In India, information on Cobia is meager. Considering their importance to the fishery and aquaculture, present study has been carried out by utilizing exploratory data of the Fishery Survey of India(FSI) fleet and commercial landings along Mumbai.

Establishing the taxonomy and systematics of the species, re-describe the species with the help of most vital characters, provide information on food and feeding habits of Cobia, study life history traits of Cobia, estimate age, growth and mortality rates of the fish, bring out the exploitation pattern and to suggest conservation and management measures are the main objectives of this study.

This study also focuses on to bring out the distribution pattern and also to assess the biomass and estimate sustainable yield of Cobia inhabiting in Indian EEZ. In addition to above, present study standardised live collection methods and also reviewed culture prospects.

Samples collected from the FSI vessel *M.V. Matsya Nireekshani* and local landing centers were identified by using standard references and confirmed that Cobia species occurring in Indian waters is *Rachycentron canadum* (Linnaeus, 1766). Morphometric measurements taken from point to point were expressed in percentage to total length and measurements in the head region as percentage of head length. In addition to this, aspect ratio of caudal fin was also worked out to understand the movement and feeding preferences of the fish.

Distinguishing characters, taxonomical account, synonymy and common/ vernacular names of the species were studied and presented. Taxonomical status of the species and history of nomenclature were also reviewed to understand the systematic position of the species. Specimens were subjected to osteological studies. Skull, appendicular and axial skeletons of the specimen were disarticulated, examined and depicted as line sketches.

Depressed cranium with out any supra occipital crest, three sided parietal bone, small and rhomboid ethmoid and square shaped frontal are major features of Cobia cranium. Presence of notch on the posterior margin of the opercle, straight dorsal margin of the opercle, dorsally oriented anterior spur on the sub opercle extending midway to point of articulation between opercle and hyomandibular and small inter opercle visible below pre opercle are major characters of opercular bones.

Presence of palatine teeth, short and wide hyomandibular, presence of endopterygoid, posterior projecting process of ectopterygoid and overlapping of metapterygoid with the posterior process of ectopterygoid are the major characters of anterior facial bones.

Presence of anterior groove on maxilla for ascending process of the pre maxilla, small canine teeth on the pre maxilla, slightly shorter ventral process of the dentary, several rows of slightly recurved canines of equal size on the dentary, deep notch on the dorsal margin of lachrymal bone and absence of supra maxilla are the features of the maxillary bones of Cobia.

First and second branchiostegal rays inserts into a notch on the ventral margin of the ceratohyal, long and rectangular shaped interhyal almost half the depth of ceratohyal and urohyal with longer peg for articulation are the major features of hyoid bones of Cobia.

Rectangular shaped supracleithrum and longer and broader post temporal median process of pectoral bones with long pelvic girdle are significant characters of Cobia. Caudal skeleton have thin rod-like epurals over the ural centrum. Presence of small neural spine present on preural centrum two and three is other distinguishing character of Cobia.

Comparison of osteological characters of Cobia with the members of Coryphaenidae and Echeneidae was made. Results of osteological study and morphological studies indicate its close resemblance to Remora and support the view that Cobia was evolved from Dolphin fishes and remoras followed it. Study also confirmed that Cobia does not have any relative or similar species and is a monotypic species belonging to the family Rachycentridae. Re description of the species was done based on the characters identified.

331 specimens collected from the catches of *M.V. Matsya Nireekshani* and landing centers of Mumbai were subjected to gut content analysis. Stomachs were visually classified according to the fullness of stomach. Occurrence, Gravimetric and Volumetric methods were followed for quantifying the gut contents.

Results of index of preponderance method indicated that fishes followed by crabs are the most preferred food items of Cobia inhabiting the north west coast of India. Sex wise, month wise and length group wise variations in the diet of Cobia were also elucidated. Dominance of crabs among the gut contents of female and dominance of crustaceans in the guts of smaller fishes were observed by the present study. Results of the study indicated that Cobia is an opportunistic feeders and availability of the food items in the habitat is the key factor which decides what Cobia eat.

In this study, feeding intensity was also assessed following methods like Gastrosomatic index, Mean index of feeding intensity and Index of fullness. Sex wise, month wise and length group wise fluctuations in the feeding intensity also were studied. Cobia actively fed during post monsoon period. In general, adult fed actively than the juveniles. Trophic level value estimated (4.36) indicates that Cobia occupy top level position in the food chain.

Life history traits of Cobia occurring along north west coast of India was attempted. Maturity stage, sex ratio, size at first maturity, spawning season, spawning frequency, fecundity and feeding variation during spawning were studied. Present study classified the maturity stages of Cobia in to five stages. Slight predominance of male over female and dominance of female in higher-class groups were observed.

Size at maturity of male and female was estimated at 63 cm and 70 cm respectively. Month wise percentage of mature specimens and gonadosomatic index values showed that Cobia breeds throughout the year with peak spawning activity during July- August and November- January.

Ova diameter studies indicated that Cobia follows a protracted breeding season with the individual spawning more than once in a season. Absolute fecundity estimated during the study ranged from 1.21 to 1.80 million (125 cm-147 cm TL fish). Mature stock of ova in the mature gonads was more than 69%. Study on feeding intensity of fishes during their maturity stages indicated that Cobia takes less food when they attain fully mature stage.

Established the length weight relationship of Cobia by using 285 specimens collected from *M.V. Matsya Nireekshani* and the landing canters of Mumbai. Both male and female followed isometric growth pattern. The equation derived in respect of length-weight relationship is as follows.

Male: $W = 0.004381 \times L^{3.078}$ (r2 = 0.9803)

Female: $W = 0.003958 \times L^{3.1075}$ ($r^2 = 0.9635$)

Pooled: $W = 0.0042 \times L^{3.0895}$ ($r^2 = 0.9725$)

Regression equations were subjected to t test and ANOCOVA for understanding the significance and relation. Both male and female regression equations were not significant and showed that both sexes follow similar relationships.

Fulton's condition factor, Relative condition factor and Modified condition factor for male, female and pooled data were carried out to understand the well being of fish. Month wise analysis showed that the fishes were in good condition through out the period except a few months. Length group wise analysis also indicated that Cobia in different life history stages occurring along north west coast of India were in good condition.

Age and growth of Cobia occurring along north west coast of India was estimated by using length frequency data of 1261 specimens. Both exploratory and commercial data were used for analysis. K value and L_∞ estimated following three methods of direct fit of length frequency like ELEFAN, Shepherd's method and Powell and Wetherall method. Results obtained were complementary to each other.

Length frequency data were subjected to decomposition following model progression analysis. Length at age data thus derived was utilized for estimation of K value and L_∞ following Gulland and Holt plot method and Ford Walford method. L_∞ and K obtained following Ford Walford method were 194.25 and 0.24 respectively, which is same as that of estimated following ELEFAN method. Hence, this value was used for further analysis.

t_0 estimated following von Bertalanffy plot was –0.1567. Negative value indicated that Cobia juveniles grow faster. Parameters estimated by Ford Walford plot (L_∞ and K) and von Bertalanffy plot (t_0) were fitted to the VBGF equation. The VBGF equation thus derived was $Lt = 194.25\ (1\text{-}e^{-0.24(t—0.1567})$. Age and growth parameters thus obtained were substituted to the VBGF and calculated age at maturity of male and female as 1.5 and 1.75 years respectively. Length of fish at different age was estimated by both linking of mean and by fitting VBGF equation and results were found complimentary.

Present study made an attempt to understand the distribution in time and space of Cobia inhabiting both east and west coasts of India. Exploratory resource survey data collected by the trawlers belonging to the FSI for the period from January 1985 to December 2007was the source. Latitude wise, depth wise and month wise catch per unit effort recorded during the resource survey were assessed.

Better catch rates were obtained from the northern latitude of both east and west coast of India. Cobia was caught throughout the year and better catch rates were observed during monsoon period. Bathymetric analysis showed that they were abundant in the 0-50 m depth zone than deeper waters.

Present study estimated biomass of Cobia occurring in Indian waters following swept area method as 2209.514 metric tones. 77% of biomass was from west coast and 33% was from east coast. Following Cadima formula, maximum sustainable yield was computed at 839.6 metric tonnes.

Information on mortality rate is essential for understanding the dynamics of any fish stock. In the present study mortality rates of Cobia was estimated, dynamics of recruitment and exploitation scenario existing in India was assessed with an aim to propose management measures and thereby ensure sustainable exploitation.

The instantaneous rate of natural mortality (M) estimated following Pauly's empirical formula and Cushing formula were 0.416 and 0.354 respectively. Natural mortality (M) estimated following Pauly's empirical formula was used for further calculation.

The instantaneous rate of total mortality (Z) estimated following Beverton and Holt model was 0.77, while value estimated by catch curve method was 0.76. Mortality rate estimated by both methods was almost similar; however instantaneous rate of total mortality (Z) estimated following catch curve method was used for further analysis, as this provides the facility to proceed to the estimation of probability of capture.

By backward extrapolation of the catch curve and comparison of the numbers actually caught with those that "ought" to have been caught L_{25}, L_{50} and L_{75} values were estimated as 20.2 cm, 46.4 and 71.65 respectively. Mean weights of each length class and month wise mean weight of fishes were estimated following Beyer method. Growth rate of the fish in different length groups were also estimated from the mean weight of different length groups.

The growth performance index (ø') estimated following Pauly method was 3.957. Life span of the species estimated based on asymptotic length and growth rate were 12.482 and 12.5 years respectively. Study on recruitment pattern indicated that 70% of recruitment took place during March to July; this matches with the peak-breeding season of Cobia inhabiting northwest coast of India.

Results of virtual population analysis showed the dynamics of the stock. Results indicated the number of survivors and portion of population subjected to natural and fishing mortalities. The number of individual in the population shown reducing trend towards the higher classes while quantum of biomass was more in higher length groups. Relative yield per recruit and biomass per recruit, estimated Lc/ L_{∞} and M/K values as 0.237 and 1.7336 respectively. Exploitation rates (E) at different levels as $E_{0.1}$, $E_{0.5}$ and E_{max} were 0.402, 0.288 and 0.47 respectively.

Thomson and Bell Yield and Stock prediction model predicted that, at F equal to 0.4 stock provided maximum yield but when F equal to 0.3 biomass exploitation was only 50%. Fishing mortality estimated during the present study was 0.36. This indicated that stock is either optimally or fully exploited. Based on the population parameters estimated, present study proposed conservation measures for management of Cobia stock inhabiting along north west coast of India.

With an aim to utilise juveniles caught by trawlers and to standardise live gene banking techniques, an attempt has been made to collect Cobia onboard and stock in tanks for culture. Experiment was conducted onboard *M.V. Matsya*

Varshini during her resource survey operation. Juveniles of size range 20-30 cm were collected immediately after each haul during the last couple of days of cruise. Fishes subjected to quarantine, after fresh water treatment were stocked in tanks and maintained with proper care.

Study revealed that quick collection, proper handling of live fishes by the crew, lesser haul duration and shallow water operations resulted in increase of survival rate. Water exchange to overcome the increased ammonia content due to excessive rate of excretion played an important role to keep the fish in healthy condition.

At shore, fishes were stocked in glass tanks of size 5’x2’x2.5’ made of 12 mm toughened glass with silicone sealing. They were stocked in quarantine tank for twenty-one days and maintained in stocking tanks for two months in order to assess the survival rate. Fishes were fed with frozen fishes, shrimp and clam meat. Survival rate of 86.1% of total fishes collected showed the suitability of live collection technique.

Present study assessed the facilities available for setting up of Cobia farms in India and reviewed culture prospective of Cobia in Indian waters. Popularization of live collection methods, setting up of collection centers at landing centers, utilization of non-conventional fishery resources as feed, use of coastal waters of India for setting up of Cobia cages, etc. are proposed for the successful farming of Cobia in Indian coast.

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* Not referred in original.

Plate 1.A. Cobia Rachycentron canadum(Linnaes,1766)

Plate 1.B. First gill arch of Cobia

Plate 1.C. Gut contents of Cobia

Plate 1.D. Mature ovary of Cobia

Plate 1.E. Mature testis of Cobia