GEAR SELECTIVITY STUDIES ON CERTAIN COMMERCIALLY IMPORTANT CARANGID FISHES OF KANYAKUMARI COAST, TAMILNADU

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

Ph. D. (Fisheries Resource Management)

by

A. BALASUBRAMANIAN, M. F. Sc. (Fishing Technology and Fisheries Engineering)
(FRM 136)

CENTRAL INSTITUTE OF FISHERIES EDUCATION
(Deemed University)

Indian Council of Agricultural Research
Versova, Mumbai 400 061

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Dedicated to
my guide

Dr. B. Meenakumari

2666845, 2666846, 2666847, 2666848
2666763, 2666764, 2666765, 2666766
2668577, 2668578, 2668579, 2668580

भाकृ अनुप
ICAR

Telegram : Matsyaoudyogiki/fishtech.Cochin
Telefax : 0091-484-2668212
E.mail : enk_ciftaris@sancharnet.in
root@cift.ker.nic.in

केन्द्रीय मात्स्यंकी प्रौद्योगिकी संस्थान
CENTRAL INSTITUTE OF FISHERIES TECHNOLOGY
भारतीय कृषि अनुसंधान परिषद
(Indian Council of Agricultural Research)
विल्लिंगडन आईलेंड, मत्स्यपुरी पी. ओ., कोच्चि - 682 029
Willingdon Island, Matsyapuri P.O., Cochin - 682 029

Date: **15.09.2004**

CERTIFICATE

Certified that the thesis entitled "**GEAR SELECTIVITY STUDIES ON CERTAIN COMMERCIALLY IMPORTANT CARANGID FISHES OF KANYAKUMARI COAST, TAMILNADU**" is a record of independent bona fide research work carried out by Mr. **A. Balasubramanian** during the period of study from September 2002 to July 2004 under our supervision and guidance for the degree of Doctor of Philosophy (Fisheries Resource Management) and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title.

Examined
18.06.05

Major Advisor/Chairman

(B. Meenakumari)
HOD (Fishing Technology) and
Principal Scientist,
Fishing Technology Division
Central Institute of Fisheries Technology,
Cochin-29

Advisory Committee

S K Chakraborty
(S. K. Chakraborty)
Principal Scientist
Fisheries Resource
Management Division,
Central Institute of Fisheries
Education, Mumbai-61

(M. R. Boopendranath)
Principal Scientist,
Fishing Technology Division,
Central Institute of Fisheries
Technology, Cochin-29

(K. Venkateswaran)
Scientist (S.G.),
Aquatic Environment and
Microbiology Division,
Central Institute of Fisheries
Education, Mumbai-61

(P. Pravin)
Scientist (S. G.),
Fishing Technology Division,
Central Institute of Fisheries
Technology, Cochin-29

DECLARATION

I hereby declare that the thesis entitled "**GEAR SELECTIVITY STUDIES ON CERTAIN COMMERCIALLY IMPORTANT CARANGID FISHES OF KANYAKUMARI COAST, TAMILNADU**" is an authentic record of the work done by me and that no part thereof has been presented for the award of any degree, diploma, associateship, fellowship or any other similar title.

A. Balasubramanian.

September, 2004
Mumbai

(**A. Balasubramanian**)
Ph. D. Student
Central Institute of
Fisheries Education

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a. balasubramanian

सारांश

बालसुब्रह्मण्यम ए., २००४ कन्याकुमारी तट, तमिल नाडु के कुछ वाणिज्यिक महत्व के कैरेनगीड मत्स्यों पर गिअर चयनात्मकता अध्ययन।

१३.५, १४, १४.५ और १५ से.मी. के विभिन्न मेश आकार के साथ बहुतंतु अपवाही क्लोम जाल और अपवाही हस्त लाइन के साथ विभिन्न हुक आकार जैसे सं. ५, ६, ७ और ८ (मस्टड-नॉर्वीजयन) के उपयोग से मत्स्यन परीक्षण सितंबर २००२ से अप्रैल २००४ तक तमिल नाडु के कन्याकुमारी तट के मत्स्यन तल में संचालित किया गया। प्रस्तुत अध्ययन में, कैरेनगोएडीस फेरडऊ, सी. फुल्वगटेटस, कैरेनेक्स हीबेरी, सी. इग्नोबिलीस, सी. पैपुइन्सीस, सी. सेक्सफास्सीएटीस, सी. टिले, स्कोम्बेरोएडास कोमेरसोनीएनस, एस. आयसन और एस. टाला जैसे दस जातियों से संबंधित कुल १७,५६८ कैरेनगीड मत्स्यों को अपवाही क्लोम जाल से शिकार किया गया और सी. फुल्वगटेटस, सी. हीबेरी, सी. इग्नोबिलीस और एस.कोमेरसोनीएनस नामक चार जातियों से संबंधित १७९३ मत्स्यों को अपवाही हस्त लाइन से शिकार किया गया। विभिन्न जातियों के आकार प्रायिकता वितरण अध्ययन सूचित किया कि हस्त लाइन में, सी. फेरडऊ, सी. सेक्सफास्सीएटीस और एसद्व टाला छोड़कर बाकी के सभी को क्लोम जाल से शिकार किया गया और एस. कोमेरसोनीएनस का शिकार दोनों गिअरों से किया गया। उपर्युक्त जातियों के लिए दोनों गिअर के शिकार में आकार समूह का अति व्याप्ति पायी गयी। ऐसे ही, क्लोम जाल एवं हस्त लाइन दोनों से विभिन्न जातियों के इकट्ठे शिकार के लम्बाई समूह के बीच विशेष भिन्नता (घ्इ०.०१) प्राप्त की गई। एस.ई.एल.ई.सी.टी. पद्धति के प्रयोग से कई मॉडल जैसे सामान्य मान, सामान्य स्थान, लॉग-सामान्य, गामा और द्वि-सामान्य को मत्स्य आंकडों के लिए सज्जित किया गया। सज्जित मॉडलों में से, क्लोम जाल से सी. फुल्वगटेटस (सामान्य मान मॉडल), सी. टिला (लटा-सामान्य) जातियों को छोड़कर दोनों गिअरों से शिकार किए लगभग सभी के लिए द्वि-सामान्य मॉडल और दोनों गिअरों से स्कोम्बेरोएडीस कोमेरसोनीएनस उत्तम पाया गया। मेश एवं हुक के बीच शिकार की मात्रा में कोई विशेष भिन्नता नहीं देखी गई हालाँकि जातियों के बीच भिन्नता देखी गई। सभी जातियों के लम्बा-घेरे का संबंध उच्च सकारात्मक सह संबंध (द्धऊ.९) दिखाई पड़ा। विभिन्न मुख्य भाग अनुपात के लिए सम्पीडित एवं लचीलापन तत्व भिन्न होते है और मोटी रस्सी लम्बे मत्स्यों को शिकार करते है। यह तत्व शिकार दर को बढ़ाता है और कई जातियों में निकटवर्ती मेश आकार के बीच आकार वितरण को अतिव्यापित करने की ओर अग्रसर होता है। पहली परिपक्वता पर लम्बाई के आधार पर, यह अध्ययन सुझाव देता है कि कन्याकुमारी तट तमिल नाडु, भारत में कैरेनगीड मात्स्यकी के वाणिज्यिक शोषण के लिए 15.3 से.मी. का मेश आकार और 4 नं के हुक आकार अनुकूलतम मेश और हुक आकार है।

Abstract

Balasubramanian, A., 2004. Gear selectivity studies on certain commercially important carangid fishes of Kanyakumari coast, Tamil nadu.

Fishing experiments using multifilament drift gillnets with different mesh sizes such as 13.5, 14, 14.5 and 15 cm and drift hand lines with different round bent hook sizes viz., No. 5, 6, 7 and 8 (Mustad-Norway) were conducted in the fishing grounds off Kanyakumari coast of Tamil nadu from September 2002 to April 2004. In the present study, a total of 17,568 carangid fishes belonging to ten species viz., *Carangoides ferdau, C. fulvoguttatus, Caranx heberi, C. ignobilis, C. papuensis, C. sexfasciatus, C. tille, Scomberoides commersonnianus, S. lysan* and *S. tala* caught from drift gillnets and 1793 fishes belonging to four species viz., *C. fulvoguttatus, C. heberi, C. ignobilis* and *S. commersonnianus* caught from drift hand lines. Size frequency distribution of different species studied showed significant ($p<0.05$) variation among different mesh sizes in gillnets and hook sizes in hand lines, in all the species except, *C. ferdau, C. sexfasciatus* and *S. tala* caught from gillnets and *S. commersonnianus* caught from both the gears. Overlapping of size groups were found in the catch of both the gears for the above species. Significant difference ($P<0.01$) was observed between lengths groups of pooled catch of different species obtained from both gillnets and hand lines. A variety of models such as normal scale, normal location, log-normal, gamma and bi-modal were fitted to the fishing data using SELECT methodology. Of the models fitted, bi-normal model was found best fit for almost all the species caught from both the gears except for the species, *C. fulvoguttatus* (normal scale model), *C. tille* (log-normal) from gillnets and *Scomberoides commersonnianus* (log-normal) from both the gears. No significant difference ($P>0.05$) in quantity of catch among different meshes and hooks was observed though difference could be observed among species. Length-girth relationship of all the species showed high positive correlation ($r>0.9$). Compressibility and elasticity factor varied according to different body proportions and thicker twine caught large fishes. This factor increased the catch rate and led to overlapping of size distribution between adjacent mesh sizes in many species. Based on, length at first maturity, this study suggests that mesh size of 15.3 cm and hook size of No. 4 are optimal and could be recommended for the commercial exploitation of carangid fishery along the Kanyakumari coast of Tamil nadu, India, on sustainable basis.

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Introduction

1.INTRODUCTION

India has a vast coastline of 8,129 with Exclusive Economic Zone (EEZ) of 2.02 million square kilometer. The present estimated fishery potential is 3,921 million tons, of which, pelagic stock constitutes 1.742 million tons, demersal stock accounts for 1.933 million tons and other oceanic pelagic constitutes 0.246 million tons (Anon.2000). India ranks sixth position in fish production in the world and it's share is 4.2%. According to a report by Zoological Survey of India (ZSI), of the 2,456 species of fishes in Indian waters, 1800 species are from marine waters. The marine fish production of India was 2.64 million tons during 2002 (Anon, 2003). In group-wise contribution, the pelagic group formed 53.5%, while the demersal fish accounted for 20.5% and crustaceans and molluscs constituted 25.9%.

Indian EEZ is divided into five regions viz., Northeast, Northwest, Southeast, Southwest and union territories. Of them, South east coast alone constituted 25.8% of national marine production during the year 1999 and ranked third position among the five regions. This region includes the EEZ of Andhra pradesh, Tamil nadu and Pondichery. Tamil nadu is one of the important maritime states with high fishery potential in south east coast of India. It has a coast length of 1,076 km with good pelagic fishery potential as evidenced from the contribution to the extent of 22% to the national pelagic fish production which is ranked second.

Carangids are pelagic fishes belonging to the family Carangidae, widely distributed along both east and west coast of India. Carangids are school forming fishes except *Alectis spp*. Though they are marine inhabitants, their young ones occur in brackish water environment. Carangid resource is constituted mainly by horse mackerels, round scads, queen fishes, trevallies, jack and pompanos and are represented by 140 species under 25 genera. They are distributed abundantly in shallow waters upto 60 meters depth, supporting a very good fishery throughout the year in both the coasts, particularly along the coast of Andhra, Tamil nadu, Kerala and Karnataka coasts. Carangids which support the fishery in Indian waters are *Alectis indicus*, *A. ciliaris, Alpes kalla, A. djedaba, Atropus atropus, Atule* *mate, Carangoides armatus C. chrysophrys, C. ferdau, C.gymnostethus, C. malabaricus, C.oblongus, Caranx ignobilis, C. melampygus, C. carangus, C. sansun, C. sem, C. sexfaciatus, Elegatis bipinnulata, Gnathanodon specious, Selar crumenopthalmus, Selaroides leptolepis, Seriolina nigrofaciata, Trachinotus baillonii, T. blochii, Uraspis uraspis,. Trachycentron canadus* and *T. trachurus*. However few species like *M. cordyla, D.russelli, Alectis spp. Alepes djedaba, A.kalla, Atropus atropus, Carangoides malabaricus, C. chrysophrys, Atule mate, Selar crumnopthalmus Selaroides leptolepis, Caranx carangus, C. ignobilis, C. malampygus and C. sexfasciatus* .

The estimated potential of carangid resource in Indian EEZ is 0.447 million tons (Anon, 2000). Carangid catch of India has been fluctuating in the past decades. The annual landings varied from 6,122 tones in 1950 to 1,26,466 tones in 2002. The fishery showed a steady but slow progress till 1980 followed by slight increment upto 1985. Afterwards, a sudden increase in production upto 1995 followed by slight reduction in the consequent years could be noticed. There was a peak production of carangid (1,96,871tonnes) during the year 1995. Carangids constituted nearly 4.79% of the annual marine fish landing in the year 2002. The states of Tamil nadu, Kerala and Karnataka which together contribute more than 70% of the annual carangids catch and are landed both in mechanized and non-mechanized vessels. The west coast of India is the major contributor to the all India annual carangid catch. In India, carangids are exploited by various size classes of mechanized, motorized and non-motorized vessels, which includes catamarans, dug out canoes, plank built canoes other types of canoes with or without inboard or outboard engines and large trawlers.

Gears, such as trawl nets, gill nets, hook and lines and seines are used along the coast of India for harvesting the carangids resource. Trawls and seines are considered as most effective gears for catching small and medium sized carangid fishes. However, drift gill nets and hook and line are most popular gears for capturing larger carangid fishes. Trawl net is the most predominant gear in Tamil nadu and Kerala for fishing carangids whereas in Karnataka purse seine is used and gears like gill net and ring seine are also used in Tamil nadu and Kerala.

Carangids are grouped into four major heads, namely horse mackerels, scads, queen fishes and other carangids. Of them, Scads contributed 38,626 tons, followed by horse mackerels (21,230 tons), other carangids (60.348 tons) and queen fishes/leather jackets (6262 tons) in the year 2002 (Anon, 2003).

Gillnet fishery of India is small-scale localized operation in the commercial sense since less investment with traditional technology is involved in the capture process. However, recent development on motorization of country crafts increased the fish production especially tuna (Gopakumar and Sharma, 1989). Large mesh gillnet is considered as efficient in capturing large pelagic resources of Tamil nadu coast. However, there is no special emphasis on standardizing the operation and net design in relation to specific mesh size to the different kind of fishery resources (Luther *et al.*, 1997). The small and large mesh gillnets are complementary to each other in the exploitation of pelagic resources, if the juvenile fishery is regulated properly. There is no evidence of adverse effect on migrating or spawning stocks of marine fishes (Luther *et al.*, 1997). Gill nets are grouped into two categories based on mesh size;

i) Large meshed gillnet with mesh size of greater than 45 mm

ii) Small meshed gillnet with mesh size of lesser than 45 mm

The overall length of the net ranges between 500 m to 2500 m and depth between 3 m to 15 m through the existing common length and depth are 10,000 m and 10 m respectively. In the case of small mesh gillnet, the length and depth with common mesh size of 14mm, ranges from 100-300 m and 2-7 m respectively. Pomfrets are captured by large meshed drift gill net, having mesh size of 140-160 mm mesh size. In certain region carangid catch contribute in considerable quantity in these gears. Thus, the gillnet with large mesh size is considered as effective gear to exploit pelagic resources (Luther *et al.*, 1997).

In India, about 57,000 hook and line units are in operation and the long line is the second dominant fishing gear, next to drift gill net in marine fishing (Menon *et. al.*, 1993). Long line gear is very effective in Indian coastal waters to capture marine cat fishes, elasmobranches, tunas, seer fishes, carangids and perches especially from uneven non trawlable fishing grounds with coral or rocky outcrops. Tamil Nadu ranks first in long line fishing (39%) followed by Orissa (27%) and Andhrapradesh (19%) (Anon, 1986). Line fishing, in general is used world wide for the capture of fishes like tuna, mackerel, squids, grouper, snapper, lethrinids, sharks, rays, skates etc.,

The marine fish catch of India had shown a steady growth in the second half of the eighties however stagnation was noticed in the nineties (Pillai, 1995). Exploitation was found to be the only pressure on the stock and the other factors are due to marine and land based economic activities, affecting the resources in both oceanic and continental waters (Slad, 1991).

In India marine fishing industry is becoming over capitalized and most of the stocks are heavily exploited. The present fishing effort all along the coast is confined to 70m depth zone with concentration at 10-50m depth ranges. Ninety percent of landings are from 100m depth zone. The need of the hour is responsibility towards resource conservation at optimal level, which requires knowledge on productivity and stock size, exploitation level etc. The information on these aspects is required to formulate management measures to ensure sustained fishery of schooling fishes.

Management of fishery is very expensive since it requires much information like species available, size, quantity of discards, craft and gears etc. It further depends on continuous monitoring system, which charges us more. Conservation based regulations should have to account economic performances, social values, equity, administrative and political acceptability. Indian fishery cannot be regulated through single window since it is a multi-species fishery with open access using diversified crafts and gear being operated throughout the year in entire coast though some are destructive in nature.

Present modes of regulation concentrates on maintenance of either biological or economical efficiency by setting tools like fishing effort, mesh size restriction, selective fishing, closed season and area fishable length group, catch quota, total allowable catch (TAC) and assessment of property rights. The effect of regulation could immediately appear in the stock size despite reduction in catch level for certain periods after the implementation of regulation.

Knowledge of size specific selectivity of commercial fishing gear is important for the proper management of commercial fishery. While getting information on growth, age at first maturity, spawning, fecundity and mortality, it will be easy to maximize the yield and conserving the resources by protecting the catching of juvenile fish. It will be helpful to prepare production model, which determines the strategy for optimizing the yield from the fishery. Adoption of selective fishing will be highly useful for better fishery management in the following ways (Millar and Freyer, 1999)

i) Estimation of incidental mortality i.e., mortality from discards and escapes
ii) Yield per recruit analysis
iii) Age and length based population model
iv) Estimation of population length, frequencies, length at age etc.

In Indian coast, variety of fishing gears is operated for capturing carangids. Of them, trawl net and gill net are predominant gears. Generally, trawl gear is considered as non-selective while gill net is selective. Trawl net is widely used by mechanized sector. But gill nets are mainly used by non-mechanized and motorized. Gill nets are widely used in small scale fisheries since they require small investment and are effective in catching widely scattered fish. The study on selectivity of gill net can provide a scientific base for regulating the fishery.

Tamil nadu has nine maritime districts, of which, Kanyakumari district is located in between south east and south west coast of India and one of the important districts, known for good fishery potential. Total marine fish production of the state for the year 1998-99 is 3,77,483 tons. Of which, Kanyakumari District contributed 38,316 (10.15% of total Tamil nadu production). This district ranks fifth position in fish production in the state (Anon, 1999). Tamil nadu has a coastal length of 1000 km. Kanyakumari coast extends up to about 30 km eastward and westward each and it has a Wedge Bank. This bank constitutes fishes of both Arabian and Bay of Bengal Sea

In this coast many types of fishing gears area employed. Of them, gill net is the most predominant gear. In the year 1998-99, catch obtained from gill net from the Kanyakumari district is 10,046tons though the catch from line fishing is 19,279tons (Anon, 1999). Varieties of fishes are caught in this coast throughout the year. Many fin and shellfishes support the fishery of Kanyakumari district. Among them, carangids support a prosperous fishery year round. The carangid species that contribute significantly to the commercial fish catch are *Carangoides ferdau, C. fulvoguttatus,, Caranx heberi, C. ignobilis, C. papuensis, C. sexfasciatus, C. tille, S.commersonnianus, S. lysan, S. tala, , S. tol* .

The objectives of the present investigation are as follows:

1) To prepare the checklist of carangid fishes that form commercially important fishery in the coast of Kanyakumari , Tamil nadu .
2) To optimize the mesh size for big meshed gill nets, for the commercially exploitation of certain commercially important species of carangids.
3) To optimize the hook size for certain commercially important carangid fishes
4) To study the interaction between the gears employed for capturing the carangid fishes.
5) To fit various models for the selectivity data of gillnets and hand lines

Review of literature

2. REVIEW OF LITERATURE

Species and size of fish caught by a gear is purely determined by the selective characteristics of the gear. Selectivity is defined as a measure of the probability of capturing a particular fish species of known size (Chopin and Arimoto, 1996). All kind of fishing is selective to certain extent. In some cases, it is negligible while in most cases it is appreciable and subsequently affects the population structure. Selectivity is governed by gear itself based on design, material, size, time and method of operation and to some extent interaction between gear and fish. Selection further depends on abundance of species, their length composition of aggregation and biological state like maturity, fat content and state of nutrition etc. Selectivity may greatly vary based on above-mentioned characters and types of gear. Gill nets have a direct relation between minimum, mean and maximum sizes of fish caught unlike trawls. A fish is normally being caught if perimeter of the mesh corresponds to fish body diameter. However, it may vary depending on state of condition of fish like maturity of the gonads and degree of filling of intestine with food etc. So, size of fish caught is subject to variation (Kipling, 1957).

Size of the catch widely varies with selective action of trawls, gill nets, hook and others, since the catch size increases, more small fishes being caught (Nikolski,1988). Selective fishing will help to replenish the minimum stock of spawners of particular population. Size selectivity of fishing gear shows great economic consequences for a fishery and viability of the stock. The short-term effects of mesh size regulations are felt in the immediate catch and revenues of the fishery. But the long-term effects finally find the population dynamics of stock and economy of the fishery. Mesh regulation drives the size selection exerted by the gear and the net productivity of the fish stock escaping harvest. So, determination of the relative selective of one mesh type to that of another is important in predicting the consequences of changes in mesh regulation (Skalski and Perez-Comas, 1993). Improvement of fishing gear selectivity relies on the assumption that fish escaping from gears are not damaged minimally stressed and able to make a complete recovery after escape.

2.1 SELECTIVITY

Fishing gear selectivity is considered as an important factor to regulate any fishery (Sparre and Venema, 1992). Knowledge of gear selectivity can be used to model the fishery responses to change in mesh size or fish population. It conserves juvenile fish, increases the yield and manages the size structure of stock (Hamley, 1975; Wileman *et al* 1996; Hall, 1999; Broadhurst, 2000). It is believed that selectivity of fishing gear has a direct influence on exploited stock (Hamley and Regier, 1973; Hamley, 1975).

Selectivity is defined as a process that causes probability of capture to be size dependent (Hamley, 1975). There are two kind of selectivity, one is absolute and another one is relative selectivity. Absolute selectivity is the proportion of fish captured and retained from those in the population. In the case of relative type, it gives values proportional to the more efficient caught length class (Regier and Robson 1966; Hamley, 1975).

Gear selectivity is determined based on the probability that a fish of given species and size is caught upon encountering a particular gear with specified construction features. Relative probability of capture of a given fish is quantified by estimating the selection curves. Millar and Fryer (1999) classified the selection curves as population selection curve, available selection curve and contact selection curve.

Contact selection curve is applied to assess the effect of mesh changes on production in fisheries management study (Bennett, 1984; Kuikka *et al.*, 1996) since, it quantifies the length distribution between catch and population of fish contact the gear while the population selection curve is used to study exploitation pattern and partial recruitment (Doubleday, 1976). This model is based on Yield per Recruitment, age and length (Myers and Cadigan, 1995) and is used in gill net selection study since it enables the estimation of population length frequency after correcting the observed catch length frequency (Spangler and Collins, 1992).

Selection should be a function of fish girth in meshed gear or gape in the case of hook though length is considered as easiest measure compared to the girth and gape measures. Hence, selection is considered as a function of length (Millar and Fryer, 1999). Main aim of determining the relative selectivity of one mesh with another is to predict the consequence of

2.1.1 Selectivity of Gillnet

Robson, 1966; Hamley, 1975). Understanding the selection properties of gillnet and trammel net leads to rational utilization of stocks in the following ways (Acosta and Appeldoorn, 1995) by correcting size composition of the commercial catch which is based on gear design, standardizing Catch Per Unit Effort (CPUE) for gears of different designs and by determining an optimum mesh size. Estimation of gillnet selectivity are most important for both target and non-target species since both the fishes will influence the fishery directly (Pet *et al.*, 1995). Accurate estimation of gillnet selectivity for each species is required to predict the results of mesh size regulation (Reddin, 1986; Reis and Pawson, 1992).

General factors affecting selectivity of gillnet are mesh size, shape of fish, elasticity and stretching of net, hanging ratio, strength and flexibility of twine, characteristics of net visibility of twine, habitat, fish behaviour and swimming speed (Clark, 1960; Hamley, 1975; Marais, 1985; Borgstrom, 1989; Acosta, 1994; Acosta and Appeldoorn, 1995; Reis and Pawson, 1999; Gray, 2002), condition of fish (Jensen, 1986; Van Densen, 1987) and sex (Boy and Crivelli, 1988). Precise estimation of selectivity is also necessary for interpretation and analyses of gillnet catch statistics in population studies (Winters and Wheeler, 1990; Spangler and Collins, 1992).

Selectivity of gillnets receives wide attention in estimation of population parameters and a correction is required for estimation of gillnet selectivity since gillnets are considered to be highly selective. Hence, gillnet selection receives importance (Ishida, 1964; Cucian and Regier, 1966; Hamley and Regier, 1973; Hamley, 1975; 1980; Rudstam *et al.*, 1984; Borgstorm, 1989; and Gray, 2002). Selectivity is defined by various researchers. Lucas *et al.*, (1960) defined as "Selection can mean any process that causes the probability of capture to vary with the characteristics of the fish; selectivity is a quantitative expression of selections and traditionally means selection by size". Selectivity has been defined as "Gillnet selectivity as the proportion of captured and retained from either a) those in the population b) those that encounter the nets." Since selectivity is usually described as relative efficiency per size class rather than absolute value (a) and (b) are equivalent if the probability of encounter does not vary with fish size (Hamley, 1975; Boy and Crivelli, 1988; Machiels *et al.*, 1994).

According to Lagler (1968), "the size selectivity of gear may be defined by a curve giving for each size of fish the proportion of the total populations of that size which is caught and retained by a unit operation of the gear".

Madsen *et al.*, (1999) observed that neither the selectivity nor abundance could be estimated absolutely but only relative to that of chosen length group. It is traditionally measured relative to that of modal length class, the fish length that has mass retention probability and each mesh size had equal efficiency in catching modal length of fish. Various methods of estimation of gillnet selectivity have been developed and are classified into five different groups (Hamley, 1975). Of them, direct and indirect methods are greatly used for gillnet selectivity estimation. In direct method, selectivity parameters are estimated based on the proportions of the fish caught from different size classes of a population of known length frequency distribution. In the case of Indirect method the selectivity parameters are estimated based on the catches from nets with slightly different mesh sizes (Sparre and Venema, 1992).

If the fishing population structure is known, direct estimation method is good to adopt, otherwise, indirect method of estimation from various mesh sizes and girth measurement could be best of choice (Erzini and Castro, 1998). Absolute selectivity curves are provided by direct method when sampling a tagged population with a known length distribution. But the relative selectivity curves are obtained by indirect methods when sampling fish population with an unknown length composition (Salvanes, 1991). Scientific study on gillnet selectivity was actually started by Baranov (1914) though its importance was realized in earlier days. Baranov (1948) stated that mesh size of gillnet is proportional to the modal length of fish caught in it and gillnet retains fish of length not more than 20 % of the optimum length (Grant 1981; De silva and Sirisena, 1987; Nakatani *et al.*, 1991). Selectivity of gillnets by direct and indirect method has been studied by various researchers Holt (1957), McCombie and Fry (1960) Regier and Robson (1966), Hamley and Regier (1973) Jensen (1977; 1984; and 1986), Qvenild and Skurdal (1981) and Linlokken (1984).

Holt (1957) developed a method for estimating gillnet selectivity curve from comparisons of catches from different mesh sizes. The selection curve is obtained from two meshes and this method had similar shape and mean selection length was proportional to the mesh size. This method is still used by various researchers due to its simplicity and normal selection curve for all meshes with constant efficiency. Olsen (1959) followed the same method for estimating the gillnet selectivity parameters for herring. Once the selectivity is estimated the catches of fish in the experimental gillnet can be adjusted for the effect of mesh selectivity thereby giving an estimate of the corrected size composition of the population from which the sample was drawn (Olsen, 1959; McCombie and Fry, 1960; Gulland and harding 1961).

McCombie and Fry (1960) used ratio of maximum girth to mesh perimeter ratio, Gulland and Harding (1961) used mesh size/best mesh size ratio and Kitahara (1968) used the ratio of fish length to mesh size to produce master selectivity curve. All these methods are graphical type and do not assume the shape of selectivity curve. If the selectivity curve of a fish is known, constant efficiency of gillnet over a range of fish lengths could be obtained by combining mesh sizes (Gulland and Harding, 1961). Regier and Robson (1966) indirectly estimated selectivity for lake Whitefish. Cucin and Regier (1966) and Sechin (1969) directly estimated the gillnet selectivity for known populations. Baranov (1969) defined selection factor for gillnet is as the distribution modal length divided by mesh bar length. It is reported that selectivity curves become higher and selection range larger as mesh size increased (Hamley, 1972; Rudstam *et al.*, 1984; Wulff, 1986; Jensen, 1986; Erzini and Saila, 1988; Ehrhardt and Die, 1988; and Santos *et al.*, 1995 and 1998).

Hamley and Regier (1973) used direct estimate method for finding gillnet selectivity for the fish Walleye and they reported that generally obtaining knowledge of population length distribution was seldom. They explained differences between direct and indirect estimates. The differences were attributed to assumptions used in the indirect method especially that selectivity curve for different meshes are similar in shape and amplitude for each size of fish. Hamley (1975) elaborately described in his review on gillnet selectivity about numerous factors affecting the selectivity and selection works undertaken by various researchers. He, further explained that main aim of direct method of estimation of gillnet is to have comparison study between size distribution of gillnet catch and the population being fished.

Hamley (1975) reported that various approaches and methods have been employed to study selectivity of commercial static gears like gillnet and hooks. Jensen (1982) described that normal distribution could be applied to estimate age specific selectivity which were used to adjust the observed catch data for gear selections before applying the data to estimate population parameters. He combined selectivity curve with mortality equation to give catch curve adjusted for gillnet selection.

Jensen (1984 and 1986) determined selectivity of gillnet used for capturing *Salmo trutta* and Arctic char and turbot respectively. Similarly, Linlokken (1984) estimated the selectivity curve for *Perca fluviatilis*. Wakwabi (1985) estimated selection factor for *Tilapia mossambica* in Kenya water. Jensen (1986) reported that it could be possible to catch over a range of fish length through combinations of mesh sizes if the selectivity curve of a particular species is known. Selectivity curves for different species of salmonids did not vary much.

Boy and Crivelli (1988) determined gillnet selectivity using data on length distribution of fish for each age class length distribution for each mesh. Ehrhardt and Die (1998) estimated selectivity curves using cumulative probability distribution of retention girth at length for drift and encircling gillnets to capture Spanish mackerel off Southern Florida. Direct method of estimation of gillnet selectivity is expensive since it involves tagging of large number of fish or simultaneous sampling of fish population with gear of known selectivity (Borgstrom, 1989; Winters and Wheeler, 1990). Armstrong *et al* (1990) described various selectivity parameters such as selection factor, selection range, selection ogive and L_{50}. Hendersan and Wong (1991) and

Helser *et al* (1991) estimated gillnet selectivity curves. Helser *et al* (1991) defined selectivity is a process of capture which varies systematically as a function of size class of fish and mesh size and used skew normal probability density function to describe the selectivity mathematically. They developed non-linear iterative approach. Overlapping of selection curves of two nets and its magnitude of overlapping are used to determine selectivity (Nakatani *et al.*, 1991; Sparre and Venema, 1992).

Buijse *et al* (1992) felt that gillnet selectivity appeared to have had most pronounced size selective impact on population structure of perch. The mean length observed in the catch was higher than mean length observed in the stock. They concluded that gillnet exploited selectively larger population in even age groups. Shape of selectivity curve is important to decide mode of capture of fish. If the curve is skewed to left side, it indicates method of capture is gilling and in the case of reverse, the mode of capture is entangling (Losanes *et al.*, 1992b). Karunasinghe and Wijeyaratne (1991) investigated optimum selection length, selection factor and possibility of capture for *Amblygaster sirm* caught in gillnets having mesh sizes from 2.3 to 3.8 m. They found that selectivity curves had almost uniform height, which did not change with increasing mesh sizes. Different mesh sizes had equal efficiency for capturing *Amblygaster sirm* of the respective selection length. However, selection factor increased gradually with increasing mesh size and then decreased towards mesh.

Reis and Pawson (1992) explained that gillnet selectivity with different mesh sizes utilized various relationships such as ratio between fish length (L) and mesh size (P) and girth (G) and mesh perimeter (P) and these methods do not require composition of fish population size. Amarasinghe and De silva (1994) studied selectivity patterns of multi-mesh gillnet in Srilankan reservoir for *Oreochromis mossambicus*. Mattson (1994) estimated gillnet selectivity by direct method and selectivity curves were fitted by plotting selectivity against fish length/mesh perimeter ratio. Pierce *et al* (1994) compared direct and indirect estimates of gillnet selectivity for Northern Pike and found that indirect method performed better than direct method. The difference in relative efficiency between these methods was 15 to 24 % for the whole gang of meshes. The difference was attributed to inherent problems existed in both methods.

Acosta and Appeldoorn (1995) reported that selection factor did not increase with increasing mesh size for the nets not having same hanging ratio. But it was not so in the case of varying hanging ratio. Jensen (1995a) attempted to estimate gillnet selectivity for brown trout by direct method. Indirect estimation of gear selectivity depends on assumption that relative efficiency for the modal length of the fish, the length caught most efficiently is equal for all mesh sizes (Jensen, 1995b). Matsuoka *et al* (1995) conducted series of experiments to obtain catch ratios, probability distribution against fish length according to normal distribution of girths with its mean standard deviation. Millar (1995) in his study suggested to fit selection curves simultaneously for all sizes of gears deployed e.g., gillnet and hooks.

Pet *et al.* (1995) estimated gillnet selectivity for multi-species like two tilapia, five cyprinids, two catfishes, one goby and a half beak in a Srilankan reservoir. Petrakis and Stergiou (1995 and 1996) reported that indirect method of estimation of gillnet was ideal than direct method since the gear i.e., beach seine with cod end mesh of 8 mm did not represent the catch of all the fish species existed in the study area and estimated optimum selection length, selection factor and probability of capture for *Mullus surmuletus* and *Diplodus annularis* in the year 1995 and for *M. barbatus, Pagellus erythrinus, P. acarne* and *Spicara flexuosa* in the year 1996. They were caught in the gillnets of four mesh sizes ranging from 12 to 23 mm in Greek waters. They used Holt method for estimating the parameters. Santos *et al.* (1995) determined gillnet selectivity for multi-species fishery of Portugal using Sechin's model based on girth measurements.

Selectivity was observed by Erzini *et al.* (1996a) as species characteristics and difference in selection was also noticed species to species. Jensen and Hesthagen (1996) determined the selectivity of multi-mesh gillnets and series of single net for brown trout and height of curve increased exponentially with mesh sizes of multi-mesh net. Petrakis and Stergiou (1996) found that the modal length of fishes caught in gillnet was higher than that of trawls. Takagi (1996) found that selectivity curve was almost flat i.e., there was equal catchability for salmon in the range of 28-68 cm fork length caught from mesh ranged from 48 to 157 mm.

Selectivity curves for neon flying squid (*Ommastrephes bartrami*) in the North Pacific were well fitted to length frequency distribution by Lee *et al.* (1997) and they reported that large mesh size caught greater size range of squid. Pusty and Borowski (1997) analysed the proportion of fishable length group (35 cm) for the Polish bream *Abramis brama* in gill nets. Santos *et al.* (1998) reported that sea breams of Algarve coast of Portugal were captured at appropriate length by gillnets using legal mesh size. In gill net study, the selectivity is estimated indirectly by analyzing the catches obtained by various mesh sizes fished simultaneously in the same probability (Madsen *et al.*, 1999). Fish catch depends on three process; abundance of population, relative fishing intensity and contact-selection (Millar, 1999). Sulaeman *et al.* (2000) calculated relative catch ratios such as, maximum selectivity lengths, selection length range and slopes of curves and fitted selectivity curve in Kawamura and Matsuoka's method in gillnet selectivity for *Cyprinus carpio* and *Oncorhynchus mykiss*. Fabi *et al* (2002) considered that size classes with a 5 % probability of capture being caught were the limit of selection range. They estimated parameters of selection curves in two ways; i) by using nominal mesh values and ii) by identifying best mesh by best fitting to catch data for each mesh size. Selectivity differs between seasons though there is no significant difference in modal length of selectivity curve. Selection factor is higher for passive gears than active gears (Poulson, 2003).

2.1.1.1 Factors Determine the Selectivity

Various factors have been involved in deciding the selectivity of fishing gears and shape of the selectivity curve.

2.1.1. 1.1 Mesh Characteristics

Gillnet selectivity is greatly affected by mesh opening because of twine thickness and its elasticity (Hamley, 1969). Mesh size is a predominant characteristic affecting the size of fish captured in nets, mesh size regulations are often used to reduce the catch of fish in certain size ranges such as fish below a minimum legal capture size (Kraft and Johnson, 1992). Change in mesh size and net design causes modification in selectivity properties of fishing gear (Giedz, 1966; Hamley, 1975 and Machiels *et al.*, 1994). Baranov (1914 and 1948) gave a principle of geometrical similarity which is being followed till to date for gillnet selectivity. The principle is "*since all meshes are geometrically similar and all fish of the same species (within a reasonable size range) are also geometrically similar, the selectivity curves for different mesh sizes must be similar*".

Based on the above principle, selelctivity curve are plotted against fish girth/mesh perimeter (McCombie and Fry, 1960) or fish length/mesh perimeter (Kitahara, 1968). Selectivity factor is defined as ratio of mesh size to optimal length (Hamley). In contrast to Baranov's principle Ricker (1958) reported that large meshes were more efficient and their selectivity curves were taller and it was endorsed by various researchers (Regier, 1969; Regier and Robson, 1960 and Hamley, 1972). Mesh size of a gillnet is highly selective in relation to fish length and selectivity varies with species of fish (McCombie and Fry, 1960 and Gulland and Harding, 1961). Combinations of various mesh sizes and mesh panels in a single gillnet called multi-mesh gillnet were tested by several researchers (Regier and Robson, 1966; Jensen, 1986).

Regier and Robson (1966) found that different mesh sizes did not have different efficiency for respective selection lengths for catching *Amblygaster sirm*. In direct method, efficiency of gillnet has been found increased with increasing mesh sizes (Hamley and Regier, 1973; Hamley, 1980; Borgstrom, 1989; Jensen, 1995b). Larger mesh sizes are more efficient than small meshes in catching walleye by gillnet (Hamley and Regier, 1973 and Rudstem *et al.*, 1984). Selectivity of different mesh sizes was studied by indirect method by operating multi-meshed nets (Hamley, 1975 and Holst and Poulsen, 1995). Relative depth of penetration by a fish into a mesh can be described by the distance from snout to net mark, again expressed as percentage of fish length (Hamley, 1975). Large mesh sizes are less laborious to remove the catches and avoid catch of undersized fish (Walsen *et al.*, 1979 and Poulsen, 2003).

Efficiency of gillnets or mean size of fish to be captured are increasing with mesh sizes (Hamley, 1980; Marais, 1985; Petrakis and Stergiou, 1996 and Santos *et al.*, 1998). Various attempts have been made to estimate multi-mesh gillnets (Hammer and Filipsson, 1985; Jensen, 1986; and Jensen and Hasthagen, 1996) Huse and Ferno (1990) tested three different hooks viz., standard hook, wide gap and rush hooks and they found that last two hooks gave good results in capturing haddock and cod in Norwegian waters. Caramelo (1988) found that increasing of mesh size increased yield per recruitment (Y/R). Jensen (1990) found that there was no increase in efficiency with increasing mesh size. Winters and Wheeler (1980) found that fishing power varied with mesh size while estimating gillnet selection curves of Atlantic herring (*Clupea harengus harengus*)

Salvanes (1991) reported that gillnet selectivity curve for walleye was over estimated to the left for smallest mesh size and underestimated as the right for the larger mesh. Boy and Crivelli (1988) tried several mesh sizes of gillnet to have random sampling of all size groups in reservoir and lake. Murdiyanto and Suberti (1993) studied the effect of different mesh sizes of bottom set gillnet, ranged from 4-5 inches for capturing *Pampus argenteus*. Shimzu *et al* (1993) studied the effect of various size hooks in capturing juveniles of masu salmon and reported that larger hooks performed better than small hooks. Blady *et al.* (1994) reported that changes in gear design were aimed at causing mesh sizes of net, which influenced directly size structure of the fish retained. Accosta and Appeldoorn (1995) reported that increase in mesh size would allow the fish to approach maturation before recruiting the fishery and optimum length increased with increasing mesh sizes. Jensen (1995) studied the pooled efficiency of multi mesh and found that relative efficiency was wider range than those of gillnet series used in various countries.

Gillnet efficiency differs with mesh size which depend on ecological and ethological differences between the fish of different size and on changing the net characteristics (Jensen and Hesthagen, 1996). Height of selectivity curve increases exponentially with mesh sizes and most distinctly for multi-mesh nets. Multi-mesh reduces relative cost per unit effort; less laborious and achieves the required sample size in reasonable working days (Kulkilahti and Rask, 1996). Psuty and Borrowski (1997) opined that larger meshes had good selection properties. However, they suggested there the above observation should be confirmed by various methods. Yokota *et al* (2001) reported that most of fish were caught by wedging at any mesh size and twine thickness. Fishermen choose one mesh size of gillnet is always in relation to modal marketable fish length which yields good profit (2003).

2.1.1.1.2 Size Distribution

Selectivity can be estimated from size frequency distributions of the catch of the population contained equal number of fish in each size class, otherwise size catch curve will not be similar to the selectivity curve (Hart, 1932; Heckling, 1939; Kennedy, 1950; Peterson, 1954; Reis, 1957; Olver, 1966; Olsen, 1969; Hansen, 1972b and Hamley, 1975). It has been found that there is significant difference in length frequency distribution, age structure, sex and selectivity between gears, mesh and hook sizes (Rollefsen, 1953; Elliot and Beamesderfer, 1990; Nedreaas, *et al.*, 1993). Size and shapes of target fishes are important to study various fishing gears and their selectivity. (Templemen, 1963; Hodder and May, 1965; Regier and Robson, 1966 and Swartz and Van Engel, 1968). Regier and Robson (1966) and Hamley (1975) studied differences in size structure of catches from different stocks by net selection studies. Bertrand (1988) reported that selectivity varied between area to area due to abundance of very different range of fish size.

Siegel and Castellan (1988) and Stergiou and Erzini (2002) studied size frequency distribution for each gear tested by poling the catch using Kolmogorov-smirnov test and found significant difference between species. Borgstrom and Plahte (1992) found that size selective was indirectly proportional to fish size and mesh size. Long line catches larger fish as compared to other gears especially trawls (Hovgard and Riget, 1992; Jorgensen, 1995; Engas *et al.*, 1996 and Huse *et al.*, 2000).

2.1.1.1.3 Morphology or Shape of Fish

Morphology and mesh size are considered as most important parameters, which influence the gear selectivity (Clark, 1960 and Hamley, 1975). Selection factor normally relates with body proportion (Strzyzewski, 1964) and it has been affected to a level of 5-10 % of other factors combined (Andreev, 1962). Some irregularity i.e., skewness in selectivity curve was also observed due to body shape of fish by McCombie and Berst (1968). Thompson and Simanak (1972) opined that general morphology of the sharks was considered important while fabricating the mesh panel. Body appendage and shape of fish play an important role in determining the mode of capture in gillnet (Marais, 1985). Jensen (1986) reported that poor selection was observed in the fish Burbot due to its body shape and behaviour and opined that fatness would affect the selection /effective length interval.

The probability of capture is as a function of morphometric characters of the body between head and maximum girth of fish and it includes body compressibility at the retention point, elasticity of netting material and variability of fish size (Ehrhardt and Die, 1988). Probability of being gilled is related to the girth and general shape of fish (De Silva and Sirisena, 1987). Reis and Pawson (1993 and 1999) studied the influence of size and morphology of various species like *Micropogonias furnieri, Menticirrhus americannus*, *Mugil platanus* and *Breevoortia rectinata* on retentionability of gillnet and girth measurement on its selectivity. They reported that site of enmeshing might vary between species in their position and proximity to one another. Variation would be due to sex and shape of fish body. They represented body shape of each species from relationship between girth and distance from snout.

Machiels *et al.* (1994) reported that the increased catching efficiency in bream gillnet might be due to morphology of the fish which matched better with shape of mesh size. Pierce *et al* (1994) reported that they chose L/P ratio for gillnet selectivity instead of girth based one since

Northern pike has cylindrical form of body shape. Matsuoka *et al* (1995) assessed size selectivity on the basis of variation of fish body shapes, which were compared to the catch ratios. Pet *et al* (1995) studied various range of morphologically different species with respect to gillnet selectivity and this variation within species should be paramount account while estimating gillnet selection. They reported that each species of fish retained in the net depended on its morphology. For examble elongated fish (*Glossogobius giuris* and *Hyporaramphus* gaimardi*)* were caught at maximum girth. Fish of deeper body shapes, bony structures or fat abdomen (*Orochromis mossambicus, O. niloticus, Mystus gulio, M. vittatus and Rasbora daniconius*) prevented the mesh from slipping further over the body. Fish with medium tapered body shapes and/or large scales (*Amblypharyngodon melethnus, Barbus cholo, B. dorsalis and B. sarana*) were caught in between maximum and gill girth.

Petrakis and Stergiou (1995) found that estimation of optimal length of *Diplodus annularis* was lower than *Mullus surmuleus*. It must be due to higher body depth of further species. Relationship between mesh size and shape of fish normally influences the yield and catch composition (Sparre and Venema, 1992). Hovgard (1996) reported that gilling was about three times as efficient as catching at maxillae. Petrakis and Stergiou (1996) found that variation in estimated optimal length of *Pagellus eryghrinus* and *P.acarne* and *Spicara flexuosa*. It was due to fact that the former two species had greater body depth than latter two species. Saly (2001) found out selection factor, selection ranges of fishes studied increased with mesh size and it was attributed to change in body proportion due to attainment of change in sexual maturity. Different body shapes of fishes make gillnet selectivity model more complex, thus selection model applied to one population may not be applicable to another (Kurkilahti *et al.*, 2002) population. Selectivity of gears varied between seasons due to morphological fitness of fish changes over the year (Poulsen, 2003).

2.1.1.1.4 Size of Fish

Size of fish includes various factors like length, weight and girth and their interrelations. They also have major role in determining selectivity and used as a measure for estimation of selectivity and its parameters. However, there is a controversy about using the parameters such as length, girth and their ratio for estimating the selectivity (Hamley and Regier, 1973).

2.1.1.1.4.1 Length

Gillnet catches for fish, which differ in length by more than 20 % of the optimum length with a net. Relation is dependent only on the relative size of fish to a mesh or mentioned as function of the transformed length (function of fish length /mesh size) (Baranov, 1948). Selectivity curves have been drawn based on length and mesh perimeter ratio (Kitahara, 1968). Rudstam *et al.* (1984) reported that fish length and swimming capacity had an effect on encounter probability for gillnets. Jensen (1986) considered modal length was one of the important components in selection studies to find selection range of captured fish and length was also affected by condition factor. De Silva and Sirisena (1987) determined optimum length of capture for different mesh size and worked out relationship between them for *Oreochromis mossambicus*. Optimum size of first capture is estimated by Y/R analysis (Amarsinghe and De silva, 1992) and selection can be found through relationship between optimal lengths and mesh size of gillnets. Millar (1992) opined that selectivity is most often expressed on function of length though girth and mouth gap seemed appropriate measure for selection in gillnet and hook fishing respectively. Length composition of catch varies with gear to gear and mesh sizes (Lowry *et al.*, 1994).

Pierce *et al.* (1994) found conversion factor to translate Total length to Fork length and worked out L/P ratio to find out retention method. The predominant mode of capture found was wedging and increase the ratio led to tangling after 4.25. Zaucha *et al.* (1995) studied relation between length of cod end and gillnet mesh size. Pet *at al* (1996) reported that fishing mortality was the function of length based on a combination of gillnets selectivity curves for various mesh sizes. Petrakis and Stergiou (1996) reported that modal length of species *Pagellus erythrinus, P. acarne, Mullus barbatus,* and *Spicara flexuosa* caught gradually increased with increasing mesh size. Relation of length and mesh size is an important factor, which determines selectivity (Parbayanto *et al.*, 2000). Fish length is mostly used for estimation of gillnet selectivity than girth measurement since, measuring girth is difficult, time consuming and expensive. Another reason for using length measurement is that the girth based model is ultimately adjusted to the fish length. Relationship between mesh size and fish length can be estimated from linear regression method (Kurkilahti *et al.*, 2002).

2.1.1.1.4.2 Girth

Selectivity can be predicted from the inferences obtained from the measurement of gill girth, and maximum girth. Selection range can also be inferred from fish, which has maximum girth, and fish, which has smaller girth than mesh perimeter (Baranov, 1948). Girth approaches maximum girth asymptotically as a function of the distance from tip of snout to the point of maximum girth (Ricker, 1958). Selectivity study using girths measurement is independent from size distribution data for gillnet catches and mode of capture should be wedging and gilling. Selectivity curves have been drawn based on girth-mesh perimeter ratio and maximum girth provides best estimates of fish size, which are captured in a mesh size (McCombie and Fry, 1960). Therefore, G/P ratio was estimated by various researchers to various species. They were 1.26 for white fish (McCombie and Fry, 1960), 1.08 for sockeye salmon (Holt, 1963).

Selectivity is determined primarily by girth (McCombie and Berst, 1969). Theoretical selective curves are drawn based on the assumption (Sechin, 1969; Kawamura, 1972) i) that all fish are fully selected whose maximum girth is greater but head girth is smaller than the mesh perimeter and ii) that girths among any one length class of fish are distributed normally with a common variance for all length classes. Ratio between retained girth and maximum girth is related to mesh perimeter to get retention probabilities. If the retained girth is closer to the point of maximum girth, it indicates less retention of fish. The ratio increases with length (Lander, 1969). In gill net selectivity, body girth of the fish is important feature than its length (McCombie and Berst, 1969; Sechin, 1969; Kawamura, 1972 and Winter and Wheeler, 1990). McCombie and Berst (1969) opined that girth structure in the population might bias estimates based on catch frequency distribution. Girth may differ among fish of same species and length due to various factors like sex, age of maturity, amount of food, seasons and habitat (McCombie and Berst, 1969; Hamley, 1975; Van Densen, 1987; Pet *et al.*, 1995).

Relationship between girth and mesh perimeter is important for estimating gillnet selectivity than fish length/mesh size (McCombie and Berst, 1969; Hendersan and Wong, 1991 and Reis and Pawson, 1999). Girth inference method can be applied to the situation where the catch data of the fish population is absent and it is simple method though complex methods have been used (Sechin, 1969 and Kawamura, 1972). Standard deviation of gilled and maximum girth increases with girth of the fish (Kawamura, 1972). Shape of selectivity curve depends on the variation of girth along the fish body hardness, texture of the body and other projections in the body (Hamley, 1975).

Wakwabi (1985) estimated girth factor for *Tilapia mossambica* in Kenya water. Ehrhardt and Die (1988) used girth measurement to generate probability of capture using Sechin (1969) model. Henderson and Wong (1991) used G/P ratio to fit selectivity data of walleye for eleven different meshed gillnet. Mathai *et al.* (1991) used gilled girth/perimeter ratio to show length frequency distributions of mackerels for different mesh sizes from Indian water to determine gillnet selectivity. Gillnet selectivity was estimated by Borgstrom and Plahte (1992) for stunted brown trout (*Salmo trutta*) using maximum girth as parameter for fish size. Kraft and Johnson (1992) used girth measurement i.e., G/P ratio for fitting selectivity data of gillnet for yellow perch. They reported that for monofilament gillnet nominal perimeters and effective perimeters were equal unlike fyke net, since small size of knots and twine. So, they used nominal perimeters for G/P calculation.

Reis and Pawson (1992) found that head girth was equal to 75 % of maximum girth and its standard deviations by length was the same as that of maximum girth. They further observed that efficiency of monofilament gillnet increases when the ratio of G/P exceeds one. It reached maximum of 1.17 and afterwards started declining until it reached negligible above a ratio of 1.32. Santos *et al* (1995) emphasized that gillnet selectivity might be estimated by examining size distribution of gillnet catches or inferred from maximum and head girth readings. Vulnerability of cyprinids is directly related to girth and mesh size (Alamm *et al.*, 1996). Sangster *et al.* (1996) reported that girth of fish of given length differed from experiment to experiment and was attributed to seasonal condition. Selectivity depended on girth measurement and it could be improved by eliminating seasonal girth effect.

Hovgard *et al.* (1999) reported that girth information of the catches were also important since enmeshing of fish depended on fit between fish size and mesh perimeter. They stated that girth information could be used to interpret the catch process. Reis and Pawson (1999) stated that gillnet is a girth specific gear rather than species specific since several species have similar maximum girth in the available length range to be caught by a particular mesh size. They further opined that the girth measurement would not be precise if the samples were obtained from the commercial catches due to poor record of site of girth at capture.

Knowledge of maximum girth might determine the probability of wedging followed by constructing selectivity curve. Relationship between maximum girth to mesh perimeter determines mode of capture of fish i.e., enmeshed or not. Then the ratio of G/P develops master selectivity curve (Purbayanto *et al.*, 2000). Fish of many species have different girth size for the same length (Kurkilahti *et al.*, 2002). It is a common phenomenon in natural environment. It leads to different probabilities of capture with particular mesh size though they have same length, which will make gillnet selectivity modeling more complex.

2.1.1.1.4.3 Length-Girth Relationship

Selection range in terms of length and modal length can be estimated through relationship between length to maximum girth and gill girth (Konda, 1962 and 1966 and Burd, 1963). Girth is a function of length (Kawamura, 1972) and girths are not necessarily proportional to length (Hamley, 1975). Fish girth-length relationship is important since fish girth is essential criteria in estimating optimum mesh size (Hamley, 1975). De Silva and Sirisena (1987) reported that length-girth relationship for minor cyprinids and *Oreochromis mossambicus* had linear relation and found significant difference.

Ehrhardt and Die (1988) reported that maximum girth increased faster with length than did head girth. So, cumulative distribution function moved further apart as mesh size increased which resulted in increase in selection range and high retention probability. They worked out linear relation between head girth and maximum girth with length separately. High correlations were found in girth-length relationship. It revealed similar allometric growth between sexes of Spanish mackerels. Mathai *et al.* (1991) fitted linear regression between gilled girth and total length in order to convert gilled girth to length and vice versa. Buijse *et al.* (1992) worked out length-girth relationship for perch (*Perca fluviatilis*) and pikeperch (*Stizestedion lucioperca*).

Kraft and Johnson (1982) estimated length-girth relationship for yellow perch in Green Bay, USA, to determine gillnet selectivity and there was no significant difference in the relationship. A linear relationship existed between length versus gill girth and maximum girth according to the study of Reis and Pawson (1992) and Poulsen (2003). However, Reis and Pawson (1992) found no significant difference in the length-girth relationship between catches obtained from angling and gillnet. Relationship between girth, maximum girth and total length were worked out by Pierce *et al.* (1994) for Northern pike of Lake of Isles. Pet *et al.* (1995) modeled length–girth relationship using power function. They found significant relationship between girth and length.

Santos *et al.* (1995 and 1998) worked out linear regression between girth-length for the species of *Pagellus acarne and P. erythrinnus* in the year 1995 and *Diplodus annularis* and *D. bellotti* in the year 1998. They found that maximum girth increased with length than did head girth. It resulted increase in selection range with mesh size. However, the maximum girth in the latter two species increased with length faster than former two.

But it is reverse in the case of head girth. Reis and Pawson (1999) found that there was a similarity in girth-length relationship, fish size and mesh size though length and girth frequency distributions of all species caught by particular mesh size due to species specificity.

However, they observed that significant difference between total length and retained girth and no difference between ratio of Total length (TL) to mean TL and retained girth to mean girth by mesh sizes and species. They reported that variation in length distribution among catch would be always greater than girth distribution due to fish of several lengths might have the same girth. Length-girth relationship was worked out for Japanese whiting, *Sillago japonica* by Parbayanto *et al.* (2000) and for *Mullus barbatus, Lithogathus mormyrus* and *Diplodus annularis* by Fabi *et al.* (2002).

2.1.1.1.5 Length at First Maturity

Various factors like state of maturity of gonads, sex, fullness of stomach etc., influence the girth of fish and decide location of entanglement of fish in a specific mesh (Nikolskii, 1988). Fishery regulation recommends that fish should be caught once they have been recruited to reproduction. Optimizing suitable mesh size in gillnet size at first maturity is considered as one important factor in optimizing a suitable mesh in gillnets selectivity study (Alagaraja *et al.*, 1986). Selectivity factors vary between immature and ripe fish (Strzyzewski, 1964). Size of fish at sexual maturity is considered as standard for catchable size (Ling *et al.*, 1982). Sreekrishna *et al.* (1972) optimized the mesh size based on length at first maturity for *Scomberomorus guttatus*. Information on growth, maturity optimum age, size at recruitment of fish stocks are important to fix the optimum mesh size for each species to maintain fishery in steady state (Kalawar *et al.*, 1985 and Saly, 2001). Dayaratne (1988) observed that change in the body proportion due to sexual maturity is attributed to increase in selection factor with increasing mesh size. Ehrhardt and Die (1988) found that size of maximum girth was increased significantly compared with head girth due to development of gonadal tissues for summer spawning. Salvanes (1991) reported that girth of cod increased during ripening and it influenced selectivity curve.

Buijse *et al.* (1992) calculated size at maturity for perch and pikeperch to assess the spawning stock biomass. Luther *et al.* (1994) reported that sardine *Sardinella gibbosa* exhibited increase in the circumference of girth after it attained gonadal maturity. Petrakis and Stergiou (1995) optimized mesh size for four species based on length at first maturity. Santos *et al.* (1995 and 1998) estimated parameters of maturity ogives for *Diplodus annularis* and *D. bellottii* using General Linear Model (GLM).

Legal length of fish to be captured is normally set at a level when the fish is allowed to spawn at least once i.e., length at first maturity (Psuty and Borowski, 1997). Huse *et al.* (1999) assumed that gonads and pre spawning season affected condition and wedge shape of fish, which in turn reduced the value of selection factor. They further opined that selection of gillnet to be accurate in terms of mean length and sex ratio of the catches. Parbayanto *et al.* (2000) considered information on the maximum length of fish at maturity with the objective of the minimum mesh size to Japanese whiting, which had spawned at least once to avoid negative impact on resources. Fabi *et al.* (2002) worked out length at first maturity for the species of *Lithognathus mormyrus, Diplodus annularis* and *Mullus barbatus*.

2.1.1.1.6 Fishing Power

Fishing power includes various factors like catchability of gears, mesh or hook size, twine size, effort and compressibility and elasticity or stretchability of netting twine etc., These factors have been used for estimation of selectivity of fishing gears. Fishing power is often confounded with other selectivity parameters (Millar and Holst, 1997). Millar and Fryer (1999) fitted selectivity models assuming fishing power was proportional to mesh size.

2.1.1.1.6.1 Catchability

Baranov (1914) described three ways of capturing in gillnet are gilling, wedging and tangling and other recognized methods are trammeling and wrapping or twisting or encircling (Losanes *et al.*, 1992a). Understanding of degree of vulnerability of different species and size group to various fishing gears is important to develop optimal harvesting strategies and rational use of resources (Clark, 1960). In gillnet, mode of capture or place of attachment of fish i.e., gilling, wedging and tangling etc., affects the calculation of selective parameters (Olsen, 1959; and Hamley, 1975). Hamley (1975) described that the catch of fish of a given length in a gillnet is the product of retention probability, abundance of that length group, the effort and efficiency of net.

Catchability or efficiency is defined as the proportion of the total population of certain size classes, which is caught and retained by a unit operation of the gear (Machiels *et al.*, 1994). The probability of capture is divided into three components (Pope *et al.*, 1975 and Rudstam *et al.*, 1984) i) Probability that the fish encounter the net ii) Probability that ability to avoid the net and iii) Probability that retains the fish with the net. These components are affected by various factors such as characteristics of net, size of fish, behaviour of fish, habitat, net placement and swimming speed of fish (Regier and Robson, 1966). Among these, the first two factors heavily affect the catchability and size selection. Majority of catch obtained is comprised of 2 or 3 size ranges including catch mode and selection range (Grant, 1981).

In longline fishery, the catchability of the hook is represented in terms of catch rates, omitting the other factors due to lack of knowledge (Huse and Ferno, 1990). Effect of population density on gillnet catchability for four allometric population of brown trout by Borgstrom (1992) and found that catchability was inversely related to number of fish present. Apart from that catchability co-efficient function and Catch Per Unit Effort (CPUE) were also described by power function. Gillnet catches usually by wedging while trammel nets by entangling (Losanes *et al.*, 1992b). Catchability of fish does not change when the fish size increases (Kurkilahti and Rask, 1996).

2.1.1.1.6.2 Catch Per Unit Effort (CPUE)

Catch per unit effort is otherwise called effort which is measured in terms of number of meshes or hooks, number of nets used per day, number of crafts involved per day and number of fishing trips per day etc. CPUE is affected inter-specific competition for hooks (Rothschild, 1967). CPUE can be used for estimation of selectivity of fishing gears (Hamley, 1972). Schweigert *et al.* (1981) reported that CPUE was greater for the larger mesh size for roe herring. Yang and Gong (1988) compared Korean long line and deep long line and found difference in CPUE of tuna and billfishes between gears. Effort in long line fishery is measured in terms of number of hook set; corresponding catch rates are expressed as the number of fish caught per hundred or thousand hook. In which each hook act as an independent unit.

Dayaratne and Karunasinghe (1994) measured fishing effort in terms of number of fishing trips by each type of boat for particular month. Woll *et al.* (1998) estimated CPUE of gillnets of 300 and 360 mm mesh sizes. Rojo *et al.* (2001) used length frequency for calculating fishing power and estimated relative fishing power between nets by regressing CPUE among nets. Value of slope obtained from the regression indicated index of relative fishing power of one gear with respect to other. They found no difference between fishing powers of gillnets tested though CPUE varied between nets seasonally.

2.1.1.1.6.3 Twine Thickness

Fishing power increases with decrease in ratio of twine diameter to bar length and it is used as an index of flexibility and stretchability (Hovgard, 1996b). Fishing power between nets with different mesh sizes are important to estimate gillnet selectivity. Fishing power of gillnets have a relationship of mesh size to twine diameter ratio and differences in catch rates are also observed between nets of adjacent mesh sizes (Hovgard, 1996b, and 1999). Turunen (1996) found that effect of catchability of gillnets had significant effect between six mesh sizes ranging from 30-35 mm for pike perch but size composition was same for the twine thickness of 0.15 mm and 0.2 mm. Mesh of smaller ratio of twine diameter to mesh opening (bar length) is associated with high flexibility. Mesh shape is maintained by the sretchability and flelxibility of the netting twine (Yokota *et al.*, 2001). Hensen

(1972a) and Nashimoto (1979) reported that gillnet with thin twine captured larger fish due to its high stretchability.

2.1.1.1.6.4 Compressibility of Fish Body and Elasticity of Netting Twine

Normally retention of fish in gill net occurs in the consequence of girth, mesh, compressibility of fish body and elasticity or stretchability of netting twine. Compressibility varies with strength of fish, softness of body, material, and thickness of netting twine (Baranov, 1948 and Konda, 1966). Elasticity and Flexibility affects the selectivity. Elasticity or stretching of mesh is a common phenomenon. It is reported that 5 to 10 % of stretching of mesh results in overlapping of catch and selectivity curves (Baranov, 1948 and Potter, 1983). Compressibility factor denoted as 'K' or perimeter/gilled girth is estimated from individual measurements on mesh perimeter and girth at retained position in the fish (Kawamura, 1972; Clarke and King, 1986; Ehrhardt and Die, 1988; Reis and Pawson, 1992 and Pet *et al.*, 1995).

Compressibility ratio (K) is reported as lower at maximum girth than gill girth (Ehrhardt and Die, 1988; Winter and Wheeler, 1990 and Pet *et al.*, 1995). Compressibiity factor (K) and selection factor depends on elasticity of the net material (Pet *et al.*, 1995). Santos *et al.* (1995) suggested that incorporation of body compressibility and elasticity at retention girth and mesh stretching would give more realistic result in gillnet selectivity study as proposed by Regier and Robson (1960). Fabi *et al.* (2002) stated that quantification of body compressibility at the retention point and elasticity of netting material was difficult, towards selection process.

2.1.1.2 Mathematical Modeling of Selectivity Curve

Approximation of selectivity curves into some mathematical distribution will make comfortable and easy to describe selectivity curves and compare the descriptions with the curves. There is no reason being expected for any particular shape of curve. So any mathematical approximation or fit will have little biological significance (Hamley, 1975). Various opinions about parametric presentation of various theoretical distributions for selectivity curves have been given as normal distribution (Holt, 1963), lognormal distribution (McCombie and Fry, 1960), skewed normal distribution (Regier and Robson, 1966) and gamma distribution (Hendersen and Wong, 1991).

2.1.1. 2.1 Mathematical Models for Gillnet

Shape of behaviour of the estimated selection function is greatly affected by method of estimating gear selectivity and the selectivity model adopted (Amjourn, 1997). Estimation of gillnets selectivity represents an integral part of some fish stock assessment and should be major aspect for any search for alternative harvesting strategies. Generally gillnet selection curves appear in bell shape with uni-mode. In some cases, they are skewed, bimodal and multi-modal since fish are caught by different process like wedging or tangling by teeth, fin, rays or other body projections. These types of capture leads to complex selection curve. Several probability distribution have been applied to explain selection of gillnet. However, the common probability distribution applied is normal distribution (Hamley and Regier, 1973; Hamley, 1975; Losanes *et al.*, 1992a) and graphical methods

Holt (1957) developed a model for mesh selectivity and it is still popular for indirect method of estimation by fitting pre-determined distribution. Olsen (1959) used variation of Holt's method to fit for experimental curve to herring selectivity. McCombie and Fry (1960) fitted selectivity data of whitefish to type 'B' curve of lognormal distribution. Later McCombie and Berst (1969) fitted the same data for skew normal distribution. Gulland and Harding (1961) brought modification to McCombie and Fry (1960) method and expressed that selectivity curve could be constructed by non-parametric method. This method depends on ratio between best mesh and mesh used per length group of fish. This model shows asymmetrical curve. This was again brought for two modifications by Regier and Robson (1966) and expressed gamma distribution for selectivity curve of gillnet. They developed an extended Holt's method also to the case of standard deviation increase with mesh size and he tried this model also and stated girth distribution of fish caught follows normal distribution but length distribution follows generally left skewed model. Holt method was widely used by various researchers extensively in selectivity studies (Garrod, 1961; Burd, 1963; Olsen and

Tjemsland, 1963; Giedz, 1971; Washington, 1972; De Silva and Sirisena. 1987; Leon and Guardiola, 1988; Martins *et al.*, 1990; Winter and Wheeler. 1990; Boje *et al.*, 1997; Acosta and Appeldoorn, 1995; Petrakis and Stergiou, 1996; Psuty and Borowski, 1997; Rojo *et al.*, 2001 and Saly, 2001).

Kitahara (1968 and 1971) brought further modification in both McCombie and Berst (1969) and Ishida's method who scaled the abscissa in fish length /perimeter. Holt (1963) and Sparre and Venema, (1989) believed that selectivity curve,of gillnet belonged to bell shaped family and follows normal distribution. Fish catch obtained from gillnets have been distributed by normal distribution (Gulland, 1969). Sechin model was used by various researchers (Kawamura, 1972; Reis and Pawson, 1992; Santos *et al.*. 1995 and Fabie *et al.*, 2002). Jensen (1973) expressed that selectivity curve could be constructed by non-parametric method.

Fonteles and Alcantara (1977) used two methods for the estimation of selection curves for Spanish mackeral (*Scomberomorus maculatus*). The methods used were McCombie and Fry (1960) using G/P ratio and Holt model by fitting pre-determined normal distribution. They found that selectivity curve were bimodal due to gilling and entangling of fish in the net. Lehmann (1983) estimated the parameter of multivariate normal distribution by maximum likelihood (ML). Residual maximum likelihood (REML) was used for estimation of the mean selectivity curves to avoid underestimation of variances. Trent *et al.* (1983) reported that commercial fisheries data reflected only the abundance of fish during the capture not the selectivity of effect of gears. Wakwabi (1985) followed uni-modal distribution for *Tilapia mossambica* in Kenya water through the entire selectivity was shown shifted with slight change in mesh size. Selectivity curve reaches maximum at length and tapers off on both the sides for the length greater at lesser than this curve is symmetrical and bell shaped if the selection curve is perfect and called as normal curve. Retention rate reaches from 0 to 1 and reduces to 0. The curve consists of two knife edged curve and looks one at the reflection of other (Alagaraja *et al.*, 1986).

Jensen (1986) used graphical method of Gulland and Harding (1961) for his gillnet selection study through direct method. General Linear Model (GLM) can be used to estimate selectivity of each mesh size based on total catch in each length group (Kirkwood and Walker, 1986). Kirkwood and Walker (1986) and Wulff (1986) found small differences in the estimation of selectivity by non-linear regression and maximum likelihood method, and so developed non-linear maximizing likelihood function to estimate parameters of the selectivity curve. They modeled gillnet selectivity with gamma distribution with length at optimal selectivity proportional to mesh size and with constant variance of all mesh size.

Van Densen (1987) estimated selection curve based on Holt (1963) method. But this selection curve was transformed into curve as a function of maximum girth/mesh perimeter ratio, since he believed that it yielded more realistic description. For which McCombie and Berst (1969) method was used for estimating selectivity for yellow perch (*Perca flavescens*). Ehrhardt and Die (1988) used Sechin (1969) model to find out selectivity curve for Spanish mackeral. They reported that curve developed by this model was not normal curve and stated further that Holt (1957) model required catch data from two contiguous mesh sizes to find theoretical standard deviation and the resultant curve was the standard deviation of selectivity curve of tow contiguous meshes. Maximizing function requires lot of time to estimate the selectivity curve parameters. Considering this, Saila and Erzini (1989) developed Monte Carlo optimization technique to reduce the analyzing time and to estimate parameters of skew normal selectivity curves upto eight parameters.

Helser *et al.* (1991) developed a new mathematical model across mesh size and size class of spotted trout *Gynacion nebulosus* for estimation of gillnet selectivity. Henderson and Wong (1991) fitted gillnet selectivity data to gamma function for eleven mesh sizes, which used to capture walleye (*Stizostedion vitreum vitreum*). In which adjustments were made to catches for both retention and encounter probabilities. Karunasinghe and Wijeyaratne (1991) used Holt model (1963) for fitting gillnet selectivity data obtained for *Amblygaster sirm*. In this model selection curves for two gillnets with slightly different mesh sizes could be mathematically described by two overlapping normal probability function with the same standard deviation as suggested by Baranov (1914).

Backiel (1992) used various methods for gillnet selectivity study. They were Gulland and Harding method (1961), Sechin model (1969) and Jensen (1986) model. Borgstrom and Plahte (1992) developed a model for capture probabilities separating the processes of encountering the net and being retained. Swimming speed and retention probabilities were estimated from the developed model. Selectivity curves of gillnet and trammel net was estimated by skew normal function and the parameters of the models were obtained using Monte Carlo simulation method. Fujimori *et al.* (1992) found that skewness of the semi trammel net decreased linearity with increase in mesh size. Hovgard and Riget (1992) used bi-normal selection curve to describe the selectivity of gillnets, which were used to sample population of juveniles of Grenland cod.

Kraft and Johnson (1992) fitted a Pearson type I equation (Hamley and Regier, 1973) to the selectivity data for yellow perch. Selectivity curve of gillnet is described as symmetrical bell shaped curve such as log-normal distribution curve (Losanes *et al.*, 1992b; Millar, 1995; Yokata *et al.*, 2001), skew-normal model (Hansen *et al.*, 1997; Helser *et al.*, 1991) and narrower for entangling net like trammel net. Millar (1992) tried to fit the selectivity data to gamma and lognormal and developed SELECT (Share Each Length Catch Total) for application of polytomous data analysis. It could be applied while three or more different sizes of the same gear were fished simultaneously. He presumed that for schooling fishes the over dispersed Poisson distribution might be more appropriate one and selection curve parameters were estimated using maximum likelihood method. Amarasinghe and De Silva (1994) used Baranov-Holt model to estimate selectivity of gillnet for capturing *Oreochromis mossambicus* and *O. niloticus*. Curves for both species were asymmetrical due to entangling. However, Garrod (1961) reported bell shaped curve for cichilids. Pierce *et al.* (1994) used McCombie and Fry (1960) method and Gamma function (Henderson and Wong, 1991) for the indirect estimates of Northern pike gillnet selectivity.

Holst and Poulsen (1995) applied both parametric and non-parametric models to estimate size distributions of population and found that estimated size distributions, which did not depend on the choice of selectivity model but selectivity data. It is found that maximum retention girth is robust for different shapes of selection models like normal, log-normal, gamma and logistic while it is sensitive to differing fishing efficiencies (Millar, 1995). Pet *et al.* (1995) fit Holt (1957) model and Sechin (1969) model for their selectivity data collected from various fishes like tilapia, cyprinids and other fishes in Srilankan water. They reported that both the models were only suitable to reconstruct population structures of species with low tangling percentage. Further they reported that extended Holt model was more suitable than Sechin model since later resulted narrow selective curve. These two extended models were compared by plotting the estimated selection ranges (i.e., 50% selection) from both methods on mesh size. River and Dumont (1995) described a model derived from Gulland and Harding's iterative method in order to calculate selectivity of a series of gillnets for a brown trout population Nino Lake corsuca.

Santos *et al.* (1995 and 1998) used Sechin model for estimating gillnet selectivity for *Pagellus acarne* and *P. erythrinus* and reported good result. Bi-modal curve is combination of two normal curve while the gillnet curve is normally bell shaped uni-modal curve with two parameters. Uni-modal with or without skewness includes normal, lognormal, inverse Gaussian curve (Hovgard, 1996a; Millar, 1999). Mesh selectivity for lake trout *Salvelinus namaycus* was modeled by Hansen *et al* (1997) as a non-linear response surface which described changes in mean, standard deviation, skewness of fish length cross mesh size. This included five selectivity parameters. Millar and Holst (1997) used log-linear model to adjust selectivity curves on the basis of several functional models. They further explained that maximum likelihood model could be reduced to log-linear model for number of uni-modal curves for expected catches in a mesh size. They were normal scale, normal location (where modal length is proportional to mesh size but spread curve is fixed), gamma and lognormal selection curves. Erzini and Castro developed Non-linear regression model (1998). It is an alternative model developed by Wulff (1986) and Kirkwood and Walker (1986).

Helser *et al.* (1998) worked out selectivity of the experimental gillnets for female and male spotted sea trout and described based on four parameters of normal probability density function. In which Type A and B curves were solved using non-linear regression. The model estimated selectivity parameter different functional form and differences between models. Kurkilahti *et al.* (1998) tried a bi-modal model based on modified normal density distribution fitted over length range of smelt *Osmerus eperlanus.* The model had eight parameters and the height of second peak was allowed to change with fish length. Pooled relative efficiency of the modal increased with fish length. Yokoyama *et al.* (1998) estimated gillnet selection curves for crest head flounder (*Pleurnectes schrenki*) using cumulative probability distributions of the retention girth at length. The catch data for the above estimation obtained were from six different mesh sized gillnets. They used Sechin model and found width selection curve increased with mesh size and corresponded with body length frequencies obtained from each mesh size.

Hovgard *et al.* (1999) used normal, lognormal and gamma distribution models, which produced curves with wider selection range. Huse *et al.* (1999) used GILLNET programme, which comprised of models like normal scale, normal location (constant spread), lognormal, gamma and Bi-modal, to fit gillnet selection curves and reported that both modal length and spread of curve were proportional to mesh size. They further found that lognormal model yielded good fit for gillnet selection data among all the other models tested. Huse *et al.* (2000) and Stergiou and Erzini (2002) used four fit of models similar to that of models implemented in SELECT, namely normal, normal scale, log-normal and gamma and found that gamma distribution model was best fit for the collected gillnet selectivity data. Fujimori and Tokai (2001) estimated gillnet selectivity parameters using SELECT model with ML method.

Yokata *et al.* (2001) fitted lognormal model to fit his gillnet data and its parameters were estimated by SOLVER on MS EXCEL to maximize the log-likelihood function. Fabie *et al.* (2002) used Sechin (1969) method as modified by Reis and Pawson (1992) to estimate net selectivity from girth factors. They reported that optimum catch size varied based on model used. Kurkilatiti *et al.* (2002) used indirect method of Gulland and Harding (1961) mathematical model with relationships between mesh size, fish length, condition factor and shape of selection curve.

2.1.1.3 Gillnet Selectivity Studies in Indian Waters

In Indian waters various gillnet selectivity studies have been conducted to optimize mesh size for commercial exploitation of important marine and fresh waters. Joseph and Sebastian (1964) studied the effect of different mesh sizes in small meshed gillnets of Kerala. Koura and Shahun (1969) studied selection action of gillnets for different species. Sreekrishna *et al.* (1972) made an attempt to evolve a suitable mesh size for the commercially important species *Scomberomorus guttatus.* Similarly Sulochanan *et al.* (1975) attempted to find out optimum mesh size for *Scomberomorus commersoni* in Cochin waters. They used McCombie and Berst (1969) method for theoretical estimates. In which gilled girth to mesh perimeter and maximum girth to mesh perimeter ratio were estimated to find out selectivity of gillnets. However, Baranov's (1948) method was used for observed data to find relation between mesh size and selection length.

Panicker *et al.* (1978) studied selectivity of gillnets for *Hilsa toli* and *Pampus argenteus* at Veraval coast. They studied selectivity in terms of twine thickness; mesh sizes, hanging co-efficient to standardize an optimal gear for exploitation of above species. Sathyanarayanappa *et al.* (1990) standardized optimum mesh size for capturing *Silago sihama* from Mangalore coast. Mathai (1991) conducted mesh selectivity studies on mackerel gillnets of West coast with nylon net of 210/1/2 using mesh sizes from 40 to 60 mm and found 50 mm was optimum size for mackeral. Kartha and Rao (1991) determined optimum mesh size for catla, mirgal and rohu found in Gandhi sagar reservoir.

Neethiselvan *et al.* (2001) studied gillnet selectivity for optimizing mesh size for *Sardinella gibbosa.* Saly (2001) estimated optimum selection length, selection factor and probability of capture for *Sardinella longiceps*, *O. argenteus* and *Penaeus indicus* caught in Poly Amide (PA) mono filament with mesh sizes ranged from 30-50 mm. Jude *et al.* (2002a; 2002b; 2002c) found optimum mesh sizes for various tunas in Tuticorin coast of Tamil nadu. Ravikumar (2003) studied gillnet selectivity for various lesser sardines`in Thoothukudi coast of Tamil nadu.

2.1.2 Hook and Line Selectivity

Effectiveness of hook selection study is influenced by numerous factors (Bjordal, 1989) like hook size and design (Foster, 1973; Bjordal and Lokkeborg, 1996 and Huse and Ferno, 1990), abundance of targeted species and size distribution (Boggs, 1992; Engas *et al.*, 1996) spacing between hooks and numbers per cluster (Hamley and Skud, 1978), setting method (Lokkeborg, 1998), soak duration (Lokkeborg, 1990; Lokkeborg and Bjordal, 1995 and Broadhurst and Hazin, 2001), hooking responses (Johannessan *et al.*, 1993 and Bjordal and Lokkeborg, 1996) and ability to remain on hooks during fishing (Bjordal and Lokkeborg, 1996), inter-specific competition for baits (Skud,1978; Engas and Lokkeborg, 1994), bait and bait size (Moreno *et al.*, 1992; and Bjordal and Lokkeborg, 1996). Various researchers have conducted numerous comparative studies on selectivity of hook and line especially on long line for various species like Cod (McCracken, 1963; Saetersdal, 1963; Hovgard and Riget, 1992; and Huse *et al.*, 2000) and Haddock (McCracken, 1963).

2.1.2.1 Selectivity Based on Hook Size

Competition among fish of different sizes indicated by length frequency distribution obtained from hand-line and angling. It is obvious that larger fish are more successful competitors (Allen, 1963; Bertrand, 1988). McCracken (1963) and Satersdal (1963) found larger hooks caught larger fish than small hooks. However, it was negatively given by Takeuchi and Koike (1969) that decrease in the efficiency of hooks with increase in hook size for spiny goby (*Acanthogobius flavimalus*) in Japanese water. It was found that circle hook was more effective than the traditional 'J' hooks for capturing two species of gadoid and two smaller elasmobranches (Forster, 1973; Huse and Ferno, 1990). However, it was not found true for macurid and large elasmobranches. It is assumed that hook has an optimum catching efficiency for certain fish length, which is increased with hook size (Koike *et al.*, 1968;

Kokike and Kanda, 1978 and Kanda *et al.*, 1978). They used the methodology developed for gillnet to estimate hook selectivity.

It is opined that hook have very broad selection curves (Pope *et al.*, 1975). Ralston (1982) and Bertrand (1988) did not get any effect on selectivity of hook after`modification of the hook size. Johannessan (1983) did not observe any selection for cod and haddock by small hooks, which caught more fishes of all sizes than larger hooks. Peeling (1985) found that the traditional 'J' shaped hook performed better than the circle hook for catching halibut and hake and no difference was observed but in number of fishes of cod and haddock caught by these hooks. Hook fishing is regarded as size selective fishing since it reduces capturing younger year classes (Klein, 1986; Lokkeborg and Bjordal, 1992). Ferno *et al.* (1986) conducted field study on the behaviour of whiting towards baited hooks.

Skeid *et al.* (1986) carried out a comparative long line fishing to test new hook designs. Selectivity parameters are not function of gear size (Wulff, 1986 and Erzini and Castro, 1998). Bertrand (1988) studied selectivity of hooks of No.5, 7, and 8. He found no significant difference between hooks as well as size of caught fish by the three hooks and baits in handline fishing of *Lethrinus mahsene*, Carangidae and Lutjanidae, etc. Similar results were observed by Ralston (1990). However, Cortez-Zarago *et al.* (1989) and Ralston (1990) observed obvious selectivity effect in hand line fishing for yellow fin tuna and snappers respectively.

Hook design is also an important factor, which affects species selectivity of long line (Huse and Ferno, 1990). Knowledge on selection about hook fishing is scarce (Ralston, 1990; Millar, 1992). Polacheck (1991) opined that number of hooks in long line could be used as best measure of stock assessment. Catching process is largely affected by hook and biological aspects of target fish (Lokkeborg and Bjordal, 1992). They concluded in their long line review that greater variation in hook sizes gave higher effect on size selectivity and moderate differences in hook size might give less effect of selectivity. Hovgard and Reiget (1992) found long line was more effective in catching larger fish. Chopin *et al.* (1996) and Otway *et al.* (1996) caught larger snappers in long lines than other gears.

Erzini *et al.* (1996a and b) studied different hook selectivity in an artisanal long line fishery of South Portugal coast. In this study, they found that there was significant difference in size selectivity for certain species. Erzini *et `al.* (1997) observed no differences in the selectivity of different hook size employed for capturing while sea and red sea breams. Santana-Hernandez *et al.* (1997) studied long line selectivity in Mexican water and effect of operation depth in efficiency of gear. Erzini *et al.* (1998) reported that catch rate was higher for largest hook than small hook and catch size distributions were highly overlapped. They found difficulty in fitting the selectivity curve since the methodology used, assumed that the parameters of the chosen selectivity curves were afunction of hook size.

Erzini *et al.* (1999) focused on size selectivity of hooks with various sizes No. 5,7,9,10,11,13 and15 and felt lack of evidence for difference in size selectivity since hook size was a common result for many of the species. Further, they observed that decrease in catch rate with increase in hook size. Selection of a size class by a fishing gear depends on difference in the size frequency distribution of the catch exists in the population of the fished area (Tokai and Ueta, 1999). It was reported that 'J' type and circle hook exhibited similar performance in capturing striped bass and Atlantic blue fin tuna (Caruso, 2000 and Skomal *et al.*, 2002). Huse *et al.* (2000) followed Millar plot (Millar, 1995) to study the long line selectivity based on catch composition in each 5 cm length group for each gear. Shimzu *et al.* (2000) reported that maximum value of selectivity curve might decrease with hook size increased. Erzini *et al.* (2001) conducted hook selectivity study with four hook sizes (No. 10,9,7 and 5) for semi-pelagic fishery in South Portugal water. The study revealed that there was no significant difference observed between hook sizes and high overlap of size frequency distributions. Cooke *et al.* (2003) found that circle hooks had lower capture efficiency than other type hooks for capturing rock bass.

2.1.2.2 Selectivity Based on Bait

McCracken (1954) observed that squid was effective bait for capturing cod and hake but mackerel was more effective in the case of haddock fishing. McCracken (1963) found that smaller hooks baited with small bait caught more small fish than larger hook with larger bait in longline fishing for cod though no such difference was observed for larger cod. Space selective effect of bait was observed in tuna long lining by various Japanese researchers and it has been proved by capturing tuna and marlin with the baits of saury and mackerel respectively (Shimmada and Tsurrudome, 1971; Imas 1972 and Imai and Shirakawa, 1972). Werner (1974) found that linear relation between predator and optimal size of its prey.

Artificial baits also have good effect on species selectivity (Yamaguchi *et al.*, 1983). Bjordal (1983a) studied effect of efficiency of hooks with reduced bait size and found small baits gave much lower catch increase, and no increase for cod fish above 60 cm. In another experiment, the same author found that 25 % increase in catch rate for the fish ling when bait size was reduced to 50 % though no difference was observed for the fish tusk (Bjordal, 1983b) i.e., small baits did not give high catch rate. Johannessen (1983) found larger bait caught larger cod irrespective of hook size. Ferno and Huse 1983 studied behaviour of fish towards baited hook.

Yamaguchi *et al.* (1983) studied combined effect of sliced squid with artificial bait and found promising result. Lokkeborg (1985) dealt with factors influencing the catchability of natural and artifical bait. Prey preferences influence the size selection of fish (Hart, 1986). Lokkeborg (1990) found that artificial bait caught fewer small cod. Visual appearance is also an important factor for size selectivity effect of bait size (Lokkeborg and Bjordal, 1992). They found that combination of inedible body with bait lowered the proportion of undersize haddock than hooks with bait only. They also made an extensive review on hook selectivity.

Lokkeborg and Bjordal (1995) found that there was no size selectivity in the catch obtained from hooks with an inedible body (made of plastic) along with bait. However, they opined that increasing bait size attaching with inedible fish might affect size selectivity. Erzini *et al.* (1997) found relationship between mouth size and size of fish in deciding hook selectivity. Huse and Soldal (2001) attempted to improve size selection in pelagic long line fisheries for haddock with different hooks. They studied the effect of visual stimuli in pelagic long line fisheries, hooks with red and white nylon bristles attached to shank. But there was no significant catch with this lure. However, the hook with inedible plastic body reduced the catch of undersized fish to considerable level. Broadhurst and Hazin (2001) analyzed the impact of vertical and horizontal orientation of bait on the efficiency of hooking.

2.1.2.3. Modeling of Hook and Line

Very little information on modeling of hook selectivity has been shown (Ralston, 1990). Hook selection curve is uni-modal right skewed and may be modeled by lognormal density function (Holt, 1963 and Pope *et al.*, 1975). Hook selection curves are assumed as very broad uni-modal and monotone curves (Myhre, 1969; Pope *et al.*, 1975; and Ralston, 1990). Many researchers tried to fit hook selection to logistic function (Charwin, 1958; McCracken, 1963; Saetersdal, 1963 and Raltson, 1982) or to the normal distribution. Models developed for gillnet can be used for hook selection also (Koike *et al.*, 1968; Koike and Kanda, 1978; Kanda *et al.*, 1978).

Asymmetrical and flattened selection curves were brought by Leclerc and Power (1980) for four hook selection for *Salmo fontinalis, S.salar* and yellow fin tuna respectively. Wulff (1986) developed a new model to estimate hook selectivity parameters by maximization of likelihood function. Shimizu *et al.* (1990) modeled catch statistics obtained from pole and line fishing to analyse characteristics of the increase of numbers with time. A result of the experiments showed was a plot of connected straight lines as asymptotic curve.

It is believed that bell shaped curves can be employed for size selectivity in hooks and gillnet fishing (Hovgard and Riget, 1992; Millar and Walsh, 1992). Using SELECT model, variety of models can be fitted to catches obtained from hook selectivity study. Otway and Craig (1993) found that neither logistic nor normal curve could be employed directly to hook selectivity. However, Halliday and Kenchington (1993) fit hook selection for logistic model for cod but they failed to fit the same for haddock. Hence, Halliday (2002) tried the SELECT method for calculating size selection of long line gear combination. Millar (1995) tried to fit selectivity data collected from two different hook sizes to various models like, normal, gamma, log-normal and logistic and found both normal an gamma selection curve gave precisely same fit.

Erzini *et al.* (1996a, 1997 and 1998) and Sousa *et al.* (1998) tried various models like proportional, linear and polynomial for hook selectivity. Erzini *et al.* (1996a and b) used Ralston plot (1982) to find out ideal selectivity model for hook. This plot is nothing but a ratio of catches of larger to smaller hook sizes against fish length. Based on the plot, they selected skew-normal selectivity and methodology of Helser *et al.* (1991) fitted the model by non-linear least squares using SAS (Statistical Analysis Software). Finding from the experiment were optimal length, standard deviation and co-efficient of skewness was function of hook size. In this study, they compared different models such as simple linear and polynomial for modeling above parameters and found that simple linear method was sufficient for modeling the relationship between optimal length and over all hook size despite, polynomial functional offered better fit for certain species (*Diplodus sargus* and *D. vulgaris*).

Nedreaas *et al.* (1996) stated that selection curve for longline was dome shaped due to the loss of largest specimen. Punt *et al.* (1996) applied a model for expressing relationship between hook size and length distribution of *Hottentot pachymetopm blochii* caught from line fishing. Selectivity function was modeled by gamma distribution and suggested to incorporate hook size into the stock assessment since it influenced the size distribution of catch. Erzini *et al.* (1997) used skew normal selectivity model with linear and polynomial function for hook selection. They reported that there was no approximate form of the selectivity model for hook and line though they proposed both logistic and bell shaped selectivity curve.

Millar and Holst (1997) opined that log-linear model could be applied for hook selectivity study. Erzini *et al.* (1998) proposed some models for hook selectivity study such as normal, skew-normal and logistic type since there is no appropriate model suggested for hook selectivity. They found that logistic model was suitable for small species. Huse *et al.* (1999) found that selection curve for long line catch data was dome shaped though they tested both sigmoid and dome shaped selection curve for long lines. Tokai and Ueta (1999) opined that selectivity data obtained from squid jigging could be fit for sigmoid and logistic function. Parameters for the above function were determined by maximum likelihood method, which has been implemented in SELECT model.

Huse *et al.* (2000) reported that longline selectivity followed uni-modal distributions when compared to that of gillnet. However, while comparing longline catches with trawl net, no model was found fit. Huse and Soldal (2001) used proportions of catch for each length group taken by experimental gear divided by sum of proportions of catch from this greatest gear and control gear to indicate the hook selectivity. It is analogous to SELECT method (Millar, 1991). Shimzu *et al* (2000) modeled hook selection curve using Ishida's method from stochastic models of hooking mechanism by plotting catch from different hook sizes to total length and estimated using multiple linear regression analysis. Selection curve was uni-modal with gentle long right slope and had equal maximum value. Selectivity curve was also estimated as polynomial curve using SOLVER on MS- EXCEL. Selectivity curve obtained from Ishida's method was better fit than stochastic model.

Overlapping catch size frequency distribution has important implications for the modeling of selectivity (Erzini *et al.*, 2001). Stergiou and Erzini (2002) used Millar plot to find out which model would be suitable for hooks, prior to estimation of selectivity parameters. This plot suggested the logistic type selectivity for long line data and they observed logistic or atleast intermediate between normal and logistic would be best fit for long line selectivity though they tried to fit other models implemented in GILLNET (Constat, 1998) software.

2.1.2.4 Studies on Hook Selectivity in Indian Water

Chirocentrus dorab was found as cheapest and most effective bait by Deshpande *et al.* (1970) to capture three species of shark namely, tiger shark, grey shark and hammer headed shark. Kartha *et al.* (1973) found hook No.5 was effective among 4 hooks tested in the drift long lines of

Veraval coast and tested three types of baits to find effectiveness. Rajan (1982) and Joel and Ebeneser, (1993) made a brief account on operation of shark lines at Thoothoor village at Kanyakumari coast, Tamil nadu. Carangids are poorly caught by hook No. 7 with baits of smaller sharks, rays and sardines etc. in Cochin waters (Anon, 1986).

Menon *et al.* (1989) studied about hook and line fishery of North Kerala for catfishes. Rao *et al* (1989) found hooks of 0/1 to 0/4 as suitable for shark fishing by long lining. Hooks No. 7 and 8 have been used for kalava fishing in Cochin waters and hand lines for perch are also used in South-West coast from Colachal to Alleppy (Mathew and Venugopal, 1990). Fishery Survey of India (FSI) conducted experimental long line fishing to explore tuna resources in Indian seas. George *et al.* (1993) found that Indian flat-round bent hooks were as effective as Norwegian round bent hooks of size 0/4 in shark fishing of West coast.

Parnote (1994) reported that efforts were made to locate tuna fishing grounds and propagate tuna long lining through training. Varghese *et al.* (1997) studied the properties and performance of indigenous fishing hooks and imported hooks and found minor changes between them. They further studied interrelationship between numbering systems and different parameters of hooks. Dineshbabu *et al.* (1999) described about hooks and line fishery off Satpathi water in Maharastra. Durai (2003) attempted to study long line selectivity for various lethrinids species of Tuticorin coast of Tamil nadu.

2.1.3 Relative Selection of Various Fishing Gears

Knowledge of relative distribution of fishing mortality and fishing effort between various fishing gears, size selections and their impact on stock are required to manage and assess the artisanal, multi-species and multi-gear fisheries. It can be obtained through comparative study among gears for the relative impact of each gear (Chopin *et al.*, 1996 and Stergiou and Erzini, 2002). Several studies have been undertaken to study the relative selection among various gears like trawl, gillnet long line, seines and traps etc.

Hamley (1975) described that one mode of estimation of selectivity of gillnet was by comparing its catch with catch of non-selective gear like trawl or purse seines. Saetersdol (1963) studied long line and trawl selectivity of cod` caught from Barents Sea based on their size distribution. Bjordal and Laevas (1990) from Bering Sea and Hovgard and Regiet (1992). They reported that long line was more selective than trawl net. McCracken (1963) found that size distribution obtained from trawl and long line was similar and justified as asymptotic selection curve in the comparative selection study of different hook sizes.

Saetersdal (1963), Hovgard and Regiet (1992) and Huse *et al.* (2000) worked out catch ratios between longline and otter trawl for each length group and plotting of these ratios against length, yielded asymptotic selection curve. It has been showed poor selection of small cod by longline when compared to trawl (Bratberg, 1965 and Bjordal, 1988). Kyrtatos (1982) studied difference in catch composition between gears like trawl, gillnets, trammel nets long lines, beach seines and purse seine though he did not analyse the data quantitatively. Koike and Takeuchi (1985) and Salvanes (1991) compared selectivity between trammel net and gillnet. They found that gillnet selection followed normal curve when the trammel net was skewed due to entangling of large individuals. Similarly Koike and Matuda (1988) reported that right skewed selection curve for trammel net while compared with gillnet.

Hovgard and Riget (1990) and Jorgensen (1995) conducted comparative study between trawls and long lines to find out relative selection between these two gears based on CPUE by size class. Selectivity of gillnet and trammel net was compared by Losanes *et al.* (1990) and found shape of selection resembled trammel net with rightly skewed selection curves. Kraft and Johnson (1992) compared the selectivity of fyke net and gillnet and found that selectivity of fyke net was similar to gillnet for fish groups with same girth to perimeter ratio. Size selectivity of longline was done by Hovgard and Riget (1992) and Myhre (1995) by comparing the size distributions of catch by long line and trawl considering that latter gear was non-selective. Selective fishing by long line performed better than other gears tested (Hovgard and Riget 1992; Huse *et al.*, 1996). Study conducted by Aldebert *et al.* (1993) on relative catch of hake fishes from four gears (2 trawls, gillnet and long line) revealed that type of fishing gears (trawl) had greater influence on the others (gillnet and long line). The study included further Virtual Population Analysis (VPA) and Yield per Recruitment (Y/R) to determine interaction between gears.

Nedreaas *et al.* (1993 and 1996) observed differences in length distributions of Greenland Halibut caught from various gears like trawl net, gillnet and long line and the variation was due to gear specific selection properties. Freyre and Maronas (1995) described gillnet selectivity curve for the freshwater fish silver side (*Odonthestes bonariensis bonariensis*) and model for estimation of retain co-efficient. Similarly various comparative studies to estimate catch composition, size ranges and catch rates were conducted between mono filament and multi filament gillnet (Erzini *et al.*, 1996) and gillnet and long line (Stergiou and Erzini, 2002). Mean length of fish captured from long lines is greater than gillnet (Nedreaes *et al.*, 1996; Huse *et al.*, 1987 and Halliday, 2002). Stergiou *et al.* (1996) undertook a comparative study between gillnet and trammel net to study the size distribution among gears. Huse *et al.* (1999 and 2000) studied comparative selection for Halibut (1999) and haddock (2000) between trawl, gillnet and long lines and found significant difference in selectivity among gears. They estimated L_{50} for cod and influence of gears on length distribution of fishes.

Halliday (2002) found in his comparative size selection study by bottom long lines and otter trawl for cod and haddock, larger hooks were less efficient in capturing small cods but more efficient in capturing large ones. However, he could not observe notable selection properties between different hook sizes. Stergiou *et al.* (2002) described that good selectivity of species could be high in static gears like long lines, gillnets and trammel net compared to active gear like trawls and beach seines.

Materials and Methods

3. MATERIALS AND METHODS

3.1 Study Site

For the present study, Kanyakumari and other two fishing villages of this district located in the South East coast of India, namely, Chinnamuttam and Arokyapuram were selected as experimental stations for operating large meshed drift gillnets and drift hand lines (Fig.1).

3.1.1 Features of Gillnet Fishing Grounds

The fishing grounds, where experimental gillnets operated are located in the latitude and longitude of 08° 01.145'N; 077°.49.137'E to 08°. 00.821'N; 077°.45.192'E. The fishing grounds are located 16 nautical mile (n.m.) and 13 n.m off the Kanyakumari coast with a depth of 30 to 60 m. The bottom topography of the ground is rocky and corals were also present which inhabited various carangid species. They are locally called as "Parai Meenu", which are usually found associated with rocks and corals. The fishing grounds were found reachable within 2 to 3.5 h by Fibre Reinforced Plastics (FRP) boat powered by inboard engine of 30 h.p. Carangid species found available throughout the year in these areas, though the peak season is from July to November. Another special feature of this area is that the local fishermen use of large meshed drift gillnet with various mesh sizes. They are operated by special kind of boat, the details of which are given in section 3.2.1.

3.1.2 Features of Drift Hand Line Fishing Ground

Traditional fishing ground was selected as experimental fishing ground for the operation of drift hand line in the present study. Area of the fishing ground is located around the position, having latitude and longitude of 08°.02.425'N; 077°.34.590'E. This ground is located off Kanyakumari at a distance of 2.45 n.m. from the shore and the depth of the ground varied from 15 to 25 m. Time required to reach the ground was 30 minutes. The topography of the ground resembled fishing grounds of gillnets in all aspects.

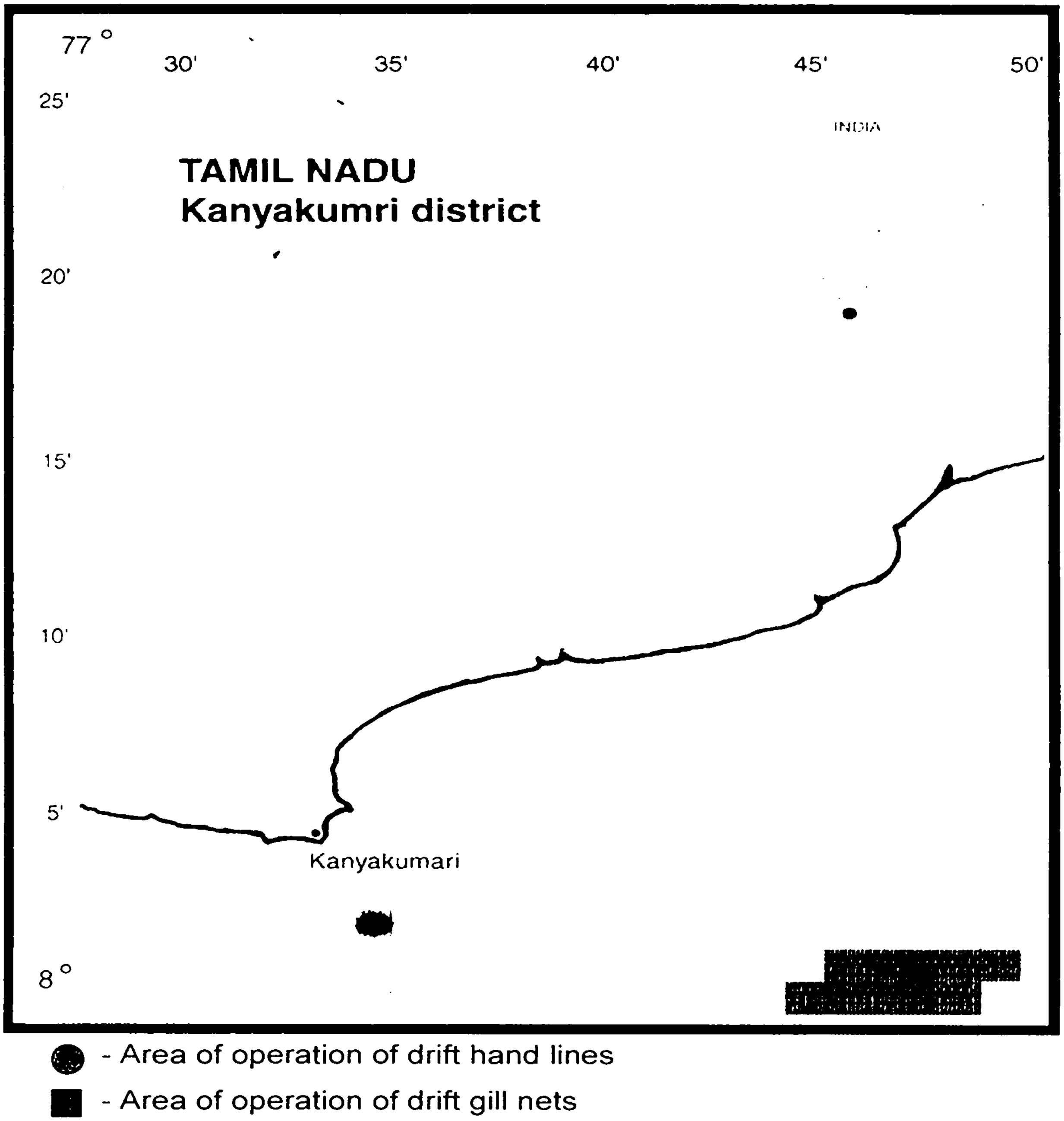


Fig. 1. Map showing areas of operation of experimental gears in Kanyakumari coast of Tamil nadu

3.2 Descriptions of Crafts

Craft used were, Fibre Reinforced Plastic (FRP) boat with Inboard Engine (IBE) for mesh selectivity studies and Catamarans with Outboard Motor (OBM) for hook selectivity studies.

3.2.1 Design of FRP Boat

Craft used for the operation of large meshed drift gillnets was FRP boat, which is commonly called as drift gill-netter and locally called as " Vazhivala boat". These are boats seized by Indian Government from Srilankan militants and sold to fishermen through auction. Boat is originally made in Japan. The Overall length (OAL) and beam of the boat is 8.4 m and 1.1 m respectively. The molded depth of the boat was 1.8 m. The boat was operated with Yanmar 25 N engine made in Japan having 30 h.p This is a two cylinder marine engine with the maximum revolution per minute (rpm) of 220 for optimal function of the fixed pitch propeller. The gearbox capable of reducing the rpm of the propeller shaft by half was used. The diesel consumption was about 4.5 liter per hour

3.2.2 Boat Catamaran

Four boat catamarans were selected for the present study. Of these, two craft were selected from Kanyakumari and rest of the two from Chinnamuttam and Arokyapuram respectively. Craft selected in this study were used to operate drift hand line. The catamarans were fabricated with four to six logs. OAL of the four and six logged catamaran was 8.13 m and 7.67 m respectively. Beam of the four logged craft was1.3 m while it was 0.95 m for six logged craft. Both sail and OBM were used as propulsive devices. The OBM used was indigenously manufactured 'Lampadi' and horsepower of the engine was 7 and 6 for the craft of four and six logged catamarans respectively.

3.3 Description of Experimental Gears

In the present study there were two kinds of gears used to conduct the experimental fishing in Kanyakumari coast. They were large meshed drift gillnets and drift hand lines

3.3.1 Drift Gillnets

Gillnets used in the present study was made up of imported polyamide 6.6 (PA 6.6) which is commonly known as *Nylon*. The large mesh gillnets, comprised of panels of four different mesh size varied from 13.5, 14, 14,5 and 15 cm (Table 1. and Fig. 2 to 6). Mesh size was measured between opposite knots when fully stretched in cm scale (FAO, 1978). The technical details of the nets were similar to that of commercial and conventional gear operated by local fishermen of Kanyakumari coast, are given in Table 1. The common mesh size used in the commercial fishery is 14.0 cm. In the present study, two fishermen who were identified to operate the experimental nets with three different meshes viz., 13.5 cm, 14.5 cm and 15 cm along with the conventional mesh size 14 cm for finding the relative selection of capture of commercially important carangids.

The size of the twine used for the experimental nets were R-tex 737 and R-tex 786 for mesh size of 13.5 cm & 14 cm and 14.5 cm & 15 cm respectively. Each net with 1000 mesh in length and 80 meshes in depth was treated as one unit and were hung to head rope of 75m-length (2 X 6mm dia). After tying the net with the head rope, the floats made up of Poly Vinyl Chloride (PVC) were attached to the head rope with a string. The length of the string was adjusted to keep the net in the depth of water column by making a knot or untying it. A total of 8 floats were attached to the net. The ends of each net were attached with a master float made up of thermocol blocks.

Footrope was not attached to the net, but stones were used as sinker. They were directly attached to the meshes at both ends. Sinkers were seldom used in the net because the net had sufficient weight to keep the net in upright position. A total of 36 units of gillnets with 9 units each in four mesh sizes viz., 13.5 cm, 14 cm, 14.5 cm and 15 cm were used for experimental operation. The hanging ratio followed for these nets ranged from 0.5 to 0.56.

3.3.2 Fabrication of Drift Hand Line

Four different sizes of hooks viz., No. 5, 6, 7 and 8 were used in the experimental hand line gears. Of these hooks, No. 7 is conventionally used by

Table. 1 Technical details of large meshed drift gillnets used in the Kanyakumari coast

S.No.	Characters	Specifications
1	Local Name	VAZHI VALA
2	Mesh sizes	13.5 cm, 14 cm, 14.5 cm and 15 cm
3	Twine type	Polyamide 6.6 – Multi-filament
4	Twine specifications	R tex 737 for mesh 13.5 and 14 cm
		R tex 786 for mesh 14.5 and 15 cm
	Thickness	1.05 for R tex 737 and 1.21 for R tex 786
	Breaking strength	296.93 N for R tex 737 and 328 N for R tex 786
5	Length of net	1000 meshes
6	Depth of net	80 meshes
7	Number of meshes per fleet in length	36000
8	Head rope	
	a) Length	75 m
	b) Type of material	Polypropylene
	c) Diameter	6 mm
9	Number of nets (shots) used	36 (9 X 4 (meshes))
10	Hanging co-efficient	0.5 to 0.56
11	Foot rope	Nil
12	Floats	
	a) Material	Poly vinyl Chloride (PVC)
	b) Size	100 X 20 (diameter X thickness in mm)
	c) Numbers used	08 per unit
	d) Rope used to attach the float	Polypropylene
	e) Size of the rope	3 mm
	f) Length of rope	60 cm
13	Sinkers	
	a) Material	Stone
	b) Weight	250 g
	c) Numbers used	2 per unit
14	Master float	
	a) Material	Thermocole
	b) Size	280 X 280 X 190 mm (L X B X H)
	c) Numbers used	01 per unit
	d) Rope used to attach the float	Polypropylene
	e) Diameter of rope	5 mm

Drift Gillnet
Carangids
Kanyakumari
Tamil Nadu

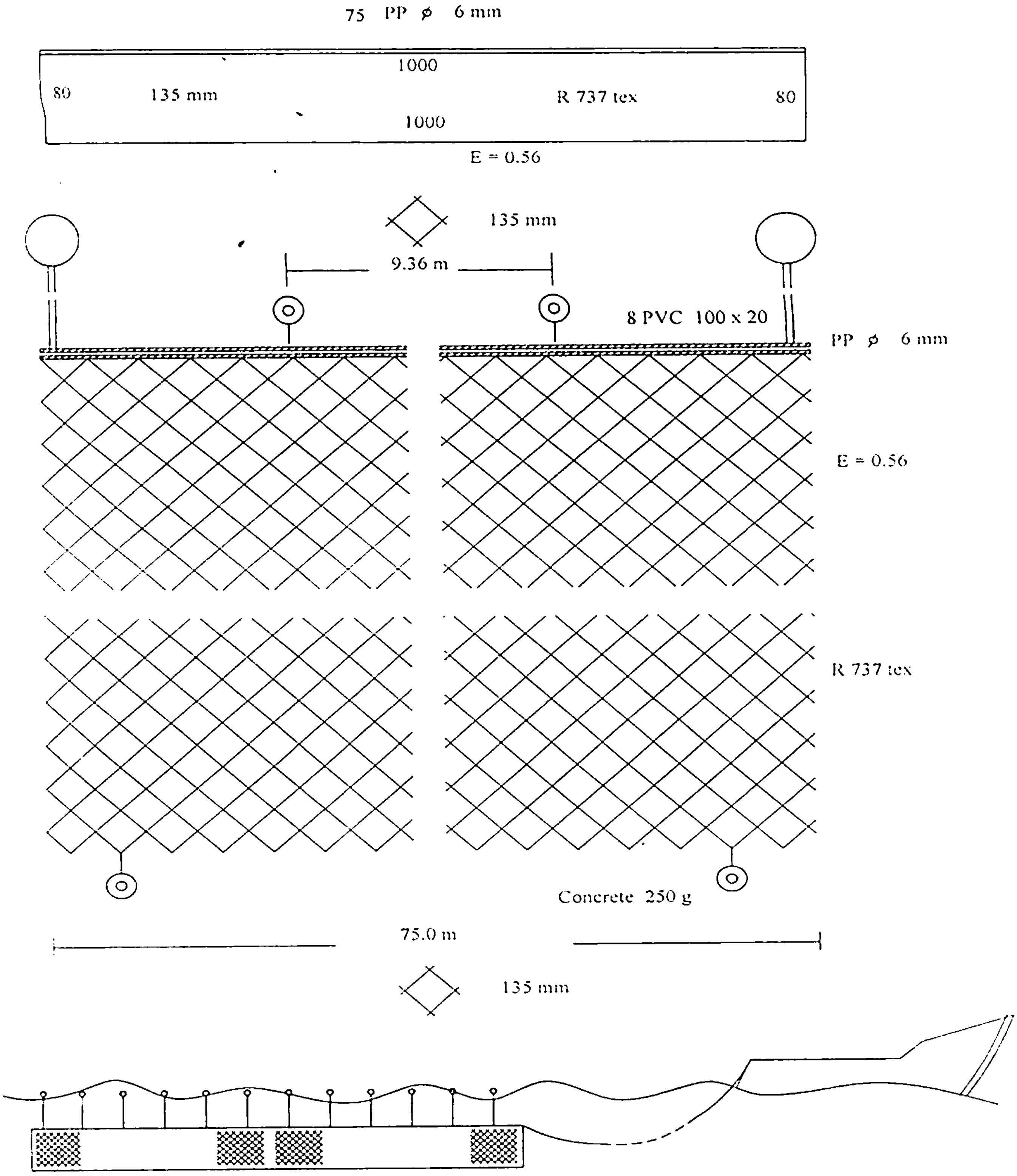


Fig. 2 Design of large meshed drift gillnet (13.5cm)

Drift Gillnet
Carangids
Kanyakumari
Tamil Nadu

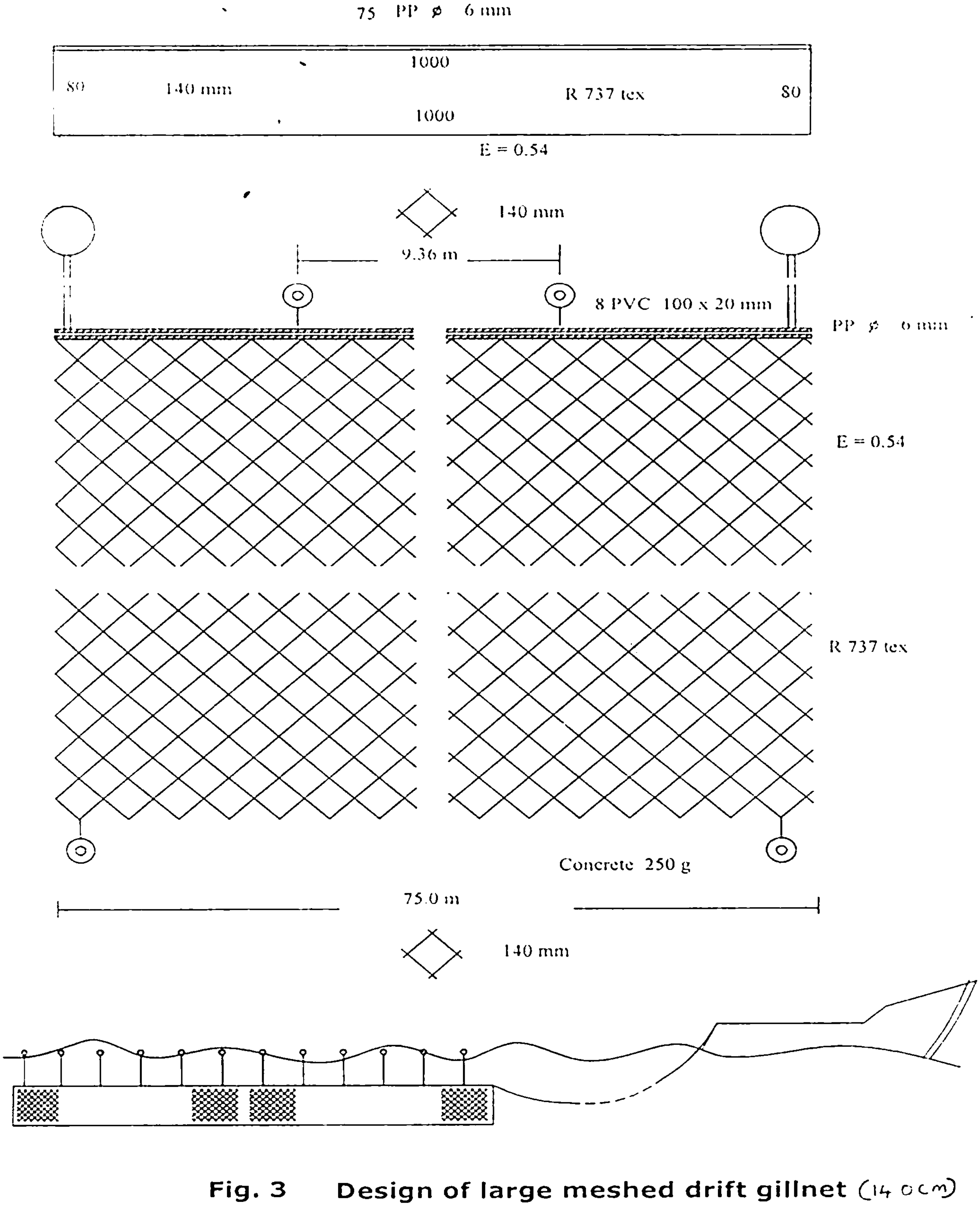


Fig. 3 Design of large meshed drift gillnet (14.0 cm)

Drift Gillnet
Carangids
Kanyakumari
Tamil Nadu

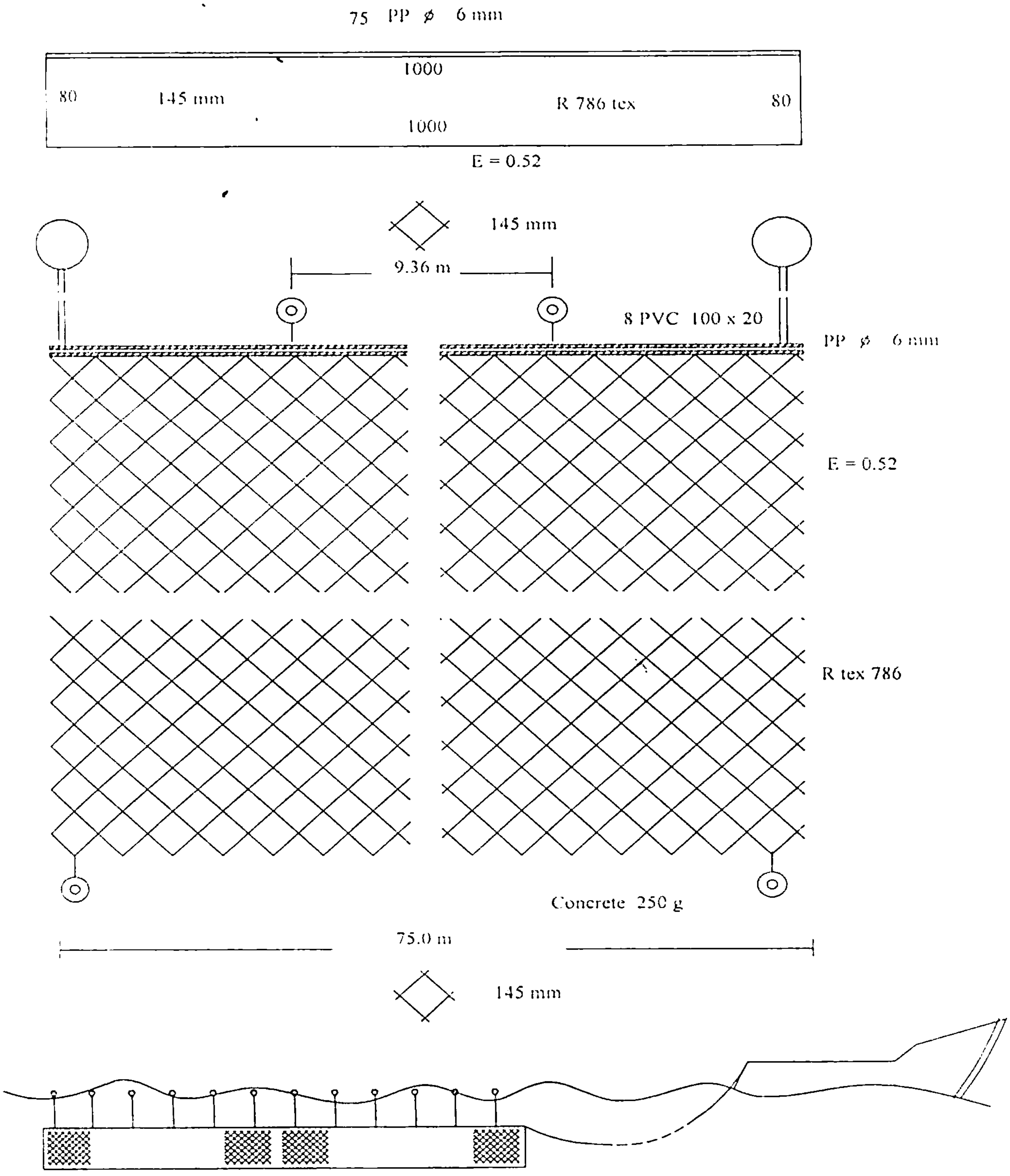


Fig. 4 Design of large meshed drift gillnet (14.5 cm)

Drift Gillnet
Carangids
Kanyakumari
Tamil Nadu

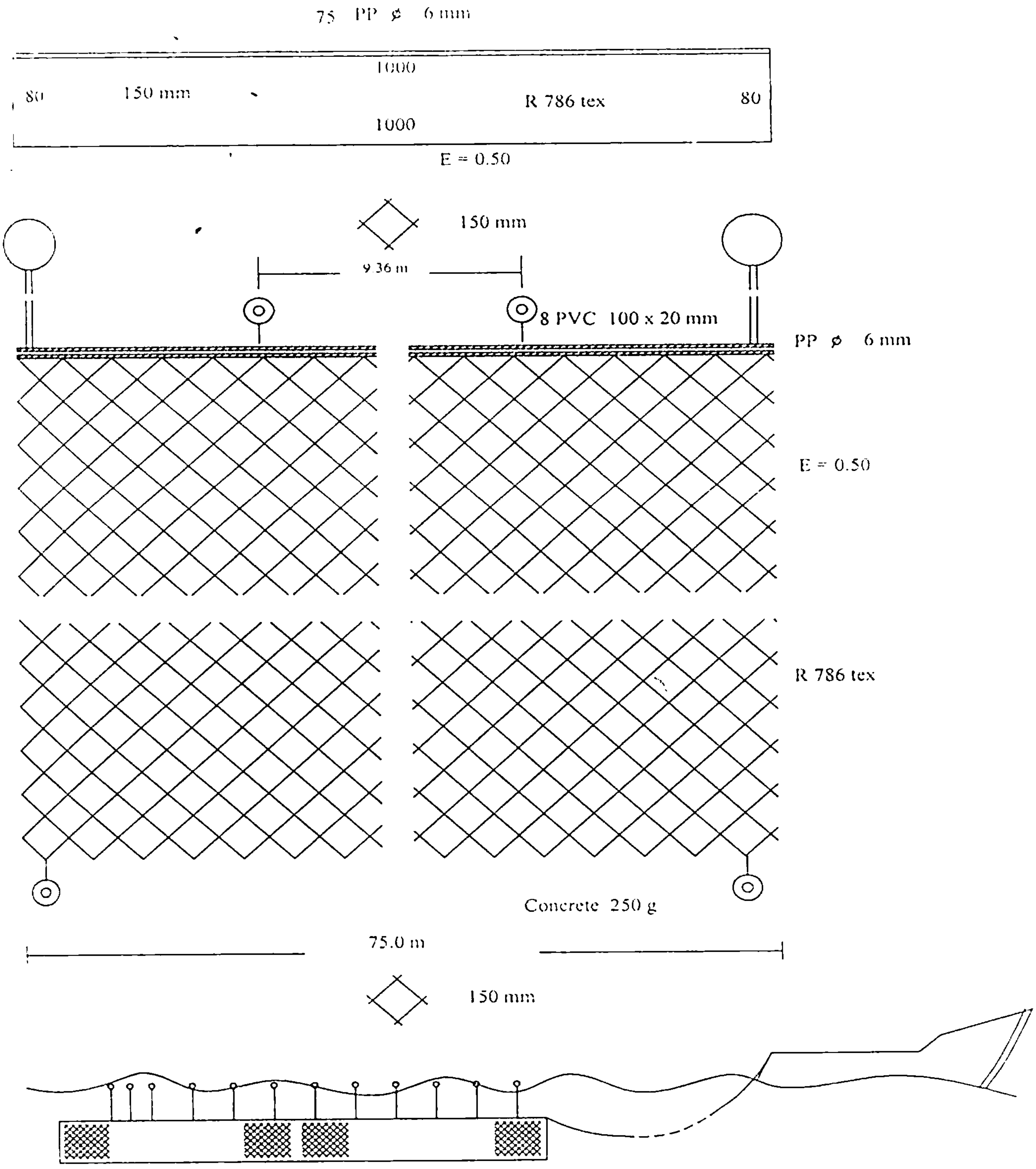


Fig. 5 Design of large meshed drift gillnet (15.0 cm)

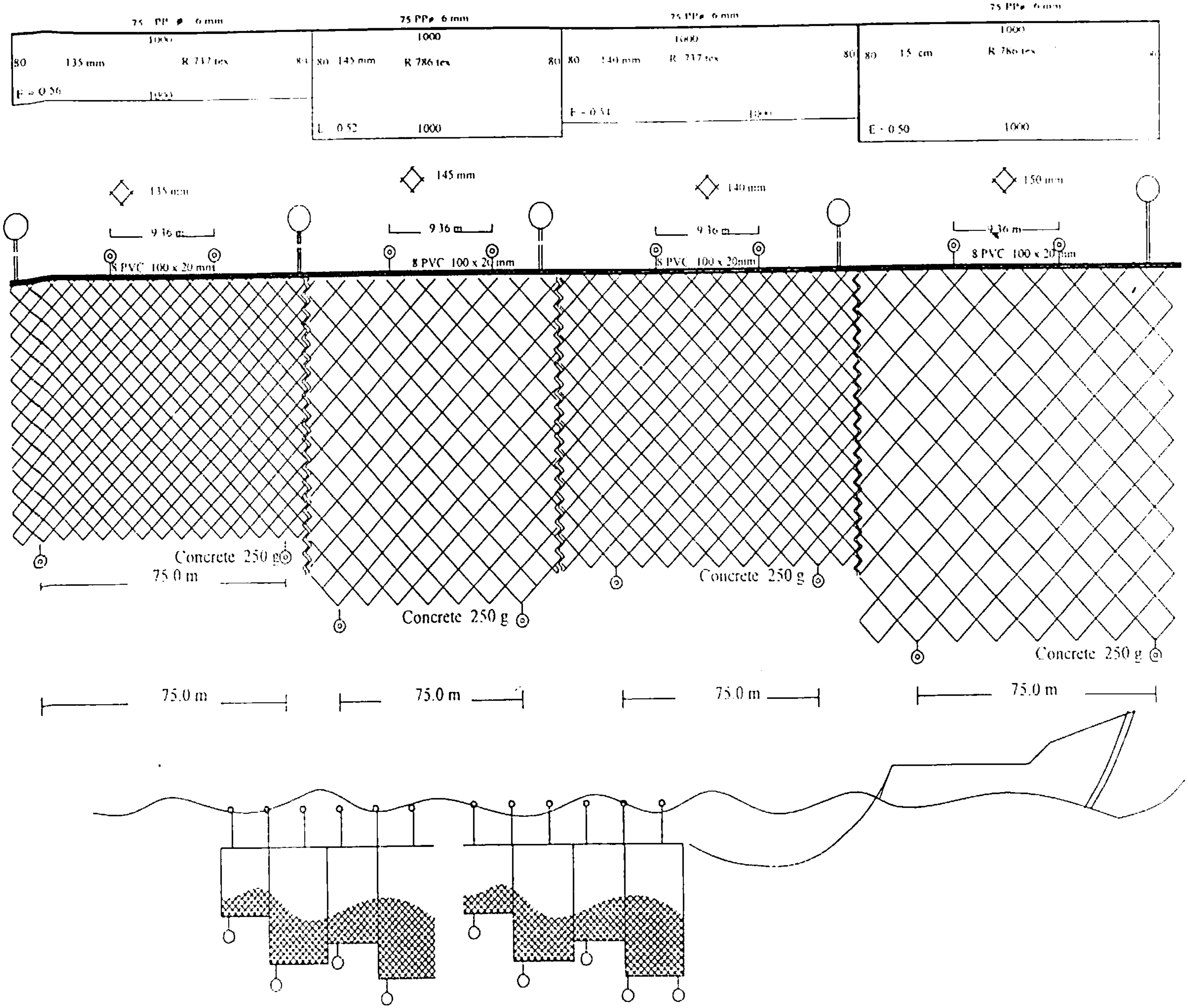


Fig. 6 Design of large multi-mesh drift gillnet

local fishermen. These hooks were Norwegian, Mustad, 'J' shaped flattened tinned round-bent type hooks (2315 oval). The dimensions like, height (shank length), gap (width), maximum width (maximum gap) depth (throat) was measured for 10 pieces to get mean of the dimensions of the hooks with standard deviation (Table 2a and Fig. 7 and 8).

Fabrication of drift hand line was done with help of locally identified fishermen. Totally four lines with different thickness were used to attach hook. Lines were made up of PA 6.6 (Nylon) monofilament. Diameters of the lines used were 2, 1.7 and 0.8 mm. At the end of each hand line, three hook of similar size were tied using 0.5 mm thick wire. The hook size was randomly changed in every fishing operation throughout the study to avoid interaction between hook sizes and bias in sampling different strata with different hooks. The length of the first line was 150 m and sinker was not used to allow it to drift in the surface water. The length of the second line was 125 m and had weight of 100 g from 20 m away from the end of line. Length of third line was 90 m and weights of 300 g and 200 g were attached to this line at a distance of 75 m and 25 m respectively from the end of line. The fourth line was selected with the length of 60 m and weight of 1000 g and 300 g were attached to the line at a distance of 40 m and 15 m respectively. Weights used were mild steel balls or stones. Three sets of hand lines were fabricated and used for the study.

3.4 Experimental Fishing Operations

Fishing operations included gillnetting and hand lining. Entire fishing operations were carried out in the selected experimental fishing stations. Fishing operations were carried out for 20 months from September 2002 to April 2004. The following species were selected as target species for the present study; *Carangoides ferdau* (**pulliadi**), *C. fulvoguttatus* (**kolluva parai**), *Caranx heberi* (**vella parai**), *C. ignobilis* (**vattha parai**), *C. papuensis* (**karu vattha parai**), *C. sexfasciatus* (**chakkani**), *C. tille* (**kumuli**), and three more species commonly called as leather jackets and vernacularly called as **katta**, *Scomberoides commersonnianus S. lysan*, and *S. tala* (Plates 1-10)

Table 2. Technical details of drift hand line

S.No.	Details	Specifications	
1	Local Name	ODU KAIRU	
2	Hook sizes	No.5, 6, 7 and 8 (Mustad, Norway)	
3	Type of Hook	'J' shaped oval flattened tinned round bent see hook (2315)	
4	Lines used		
	a) material	Polyamide (PA 6.6) Monofilament	
	b) Number of lines	4	
	c) Dimensions of lines	Length (m)	Diameter (mm)
		i) 150	2
		ii) 125	1.7
		iii) 90	1.7
		iv) 60	0.8
5	Weights added to lines	Length (m)	*Weight (grams) & distance from end of line
		i) 150	Nil
		ii) 125	20 m, 100g
		iii) 90	25 m -200 g 75 m -300 g
		iv) 60	15 m -300 g 40 m - 1000 g

* distance from the end of hook

Table. 2a Mean dimensions of experimental hooks used in hand lines

S.No	Hook Number	Shank length or Height (H) (mm)	Maximum Width (W) (mm)	Gap (mm)	Hook Depth (mm)	Overall Maximum size(H X W) mm²
1	5	57.83 ± 0.25	22.63 ± 0.56	20.13 ± 0.49	24.83 ± 0.61	1308.69
2	6	51.85 ± 0.20	20.48 ± 0.45	18.08 ± 0.35	21.73 ± 0.44	1061.8
3	7	46.75 ± 0.32	18.80 ± 0.62	16.85 ± 0.62	19.9 ± 0.02	878.90
4	8	41.7 ± 0.24	16.35 ± 0.28	14.60 ± 0.37	17.58 ± 0.32	681.79

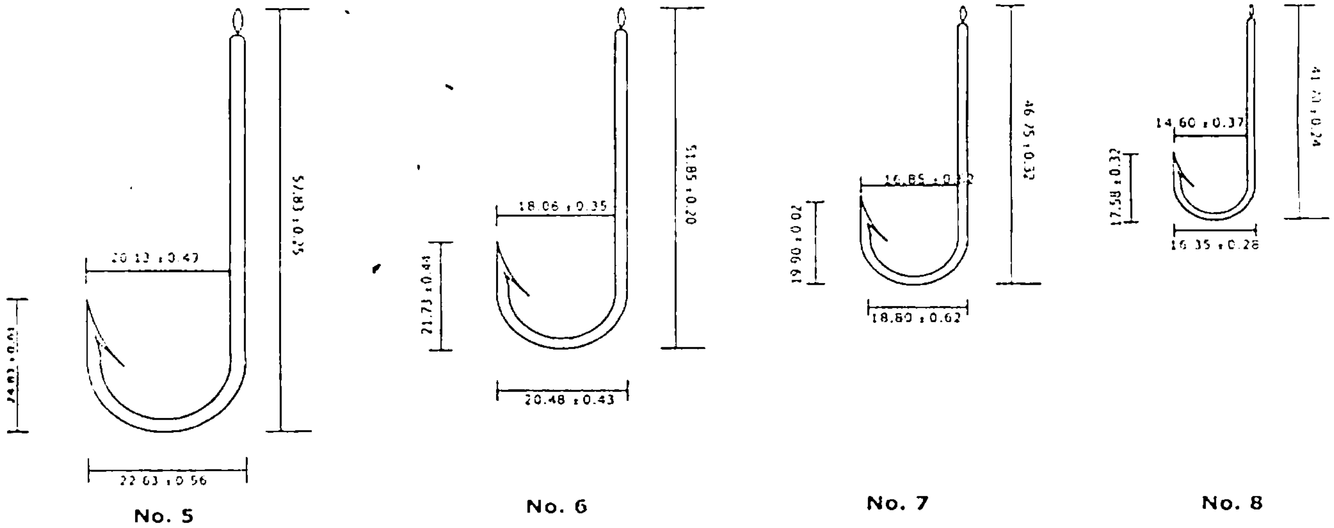


Fig. 7Dimensiones of (mm ±S.D) of hooks used in the experiments

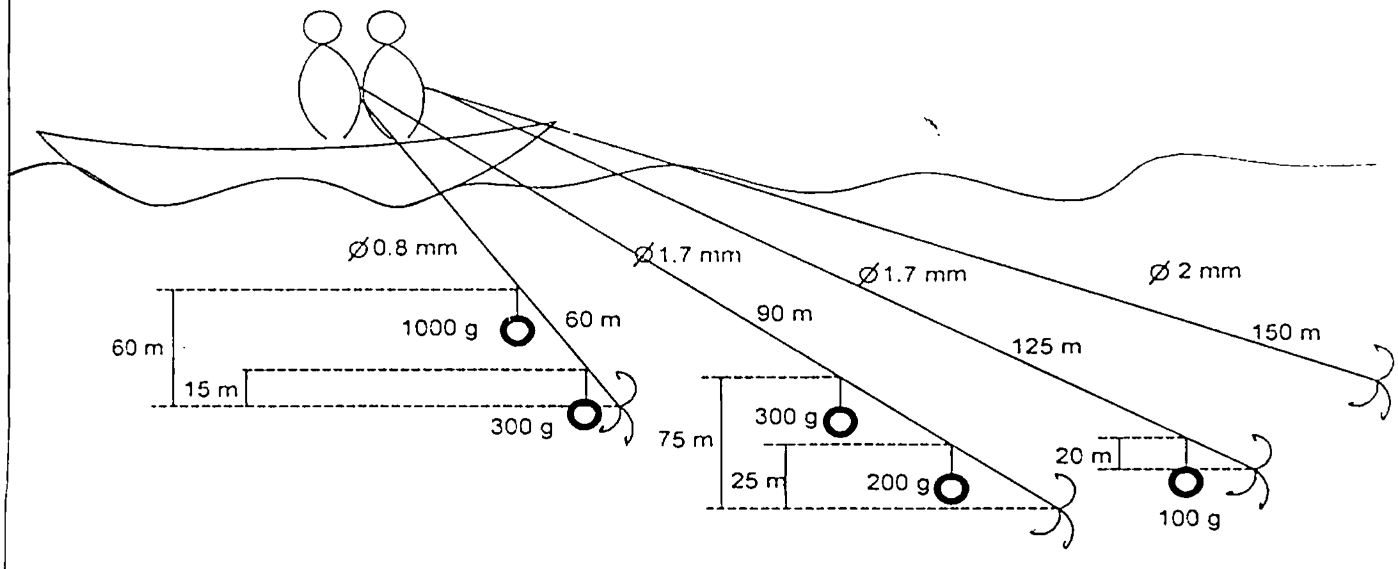


Fig. 8 Operation of drift handlines in Kanyakumari coast

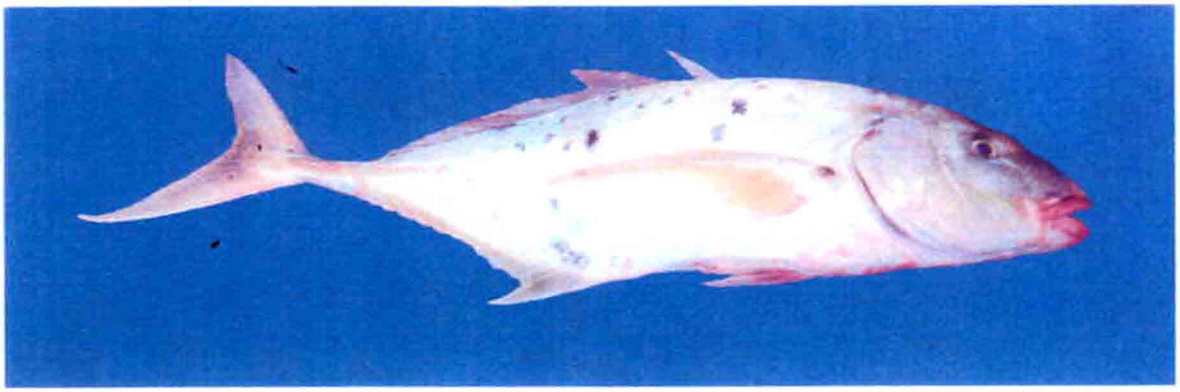


Plate 1. *Carangoides ferdau*

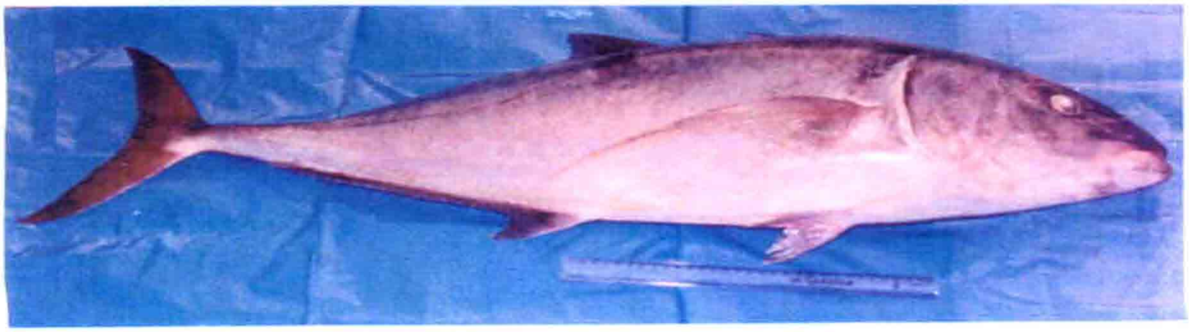


Plate 2. *Carangoides fulvoguttatus*

Plate 3. *Caranx heberi*

Plate 4. *Caranx ignobilis*

Plate 5. *Caranx papuensis*

Plate 6. *Caranx sexfasciatus*

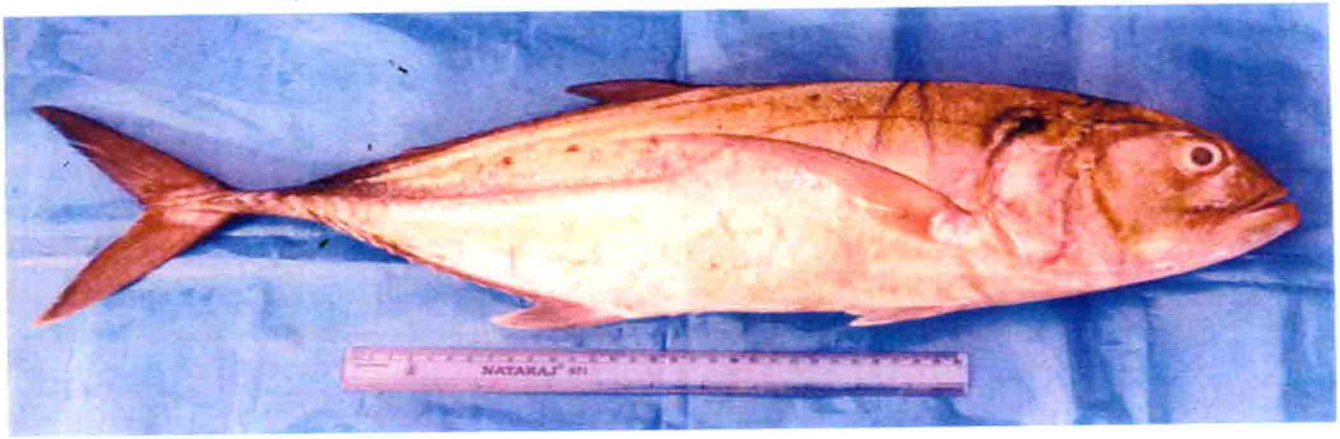


Plate 7. *Caranx tille*

Plate 8. *Scomberoides commersonnianus*

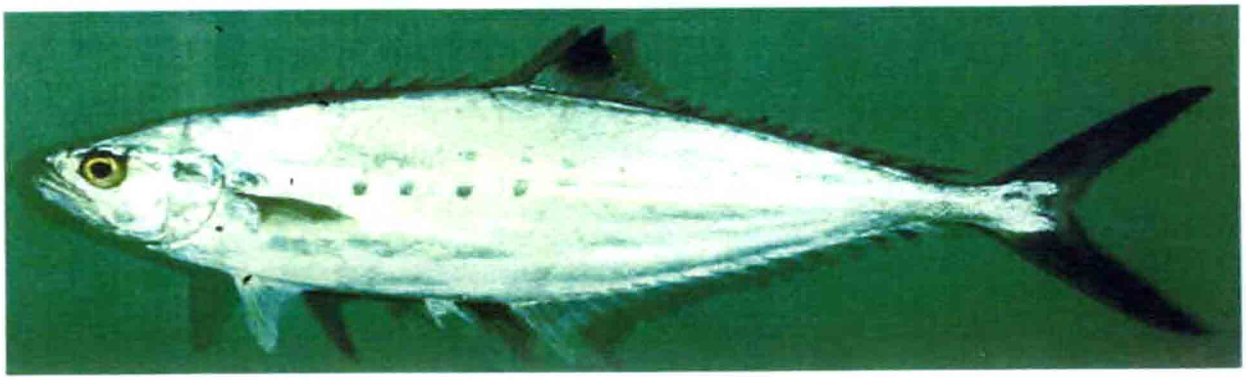


Plate 9. *Scomberoides lysan*

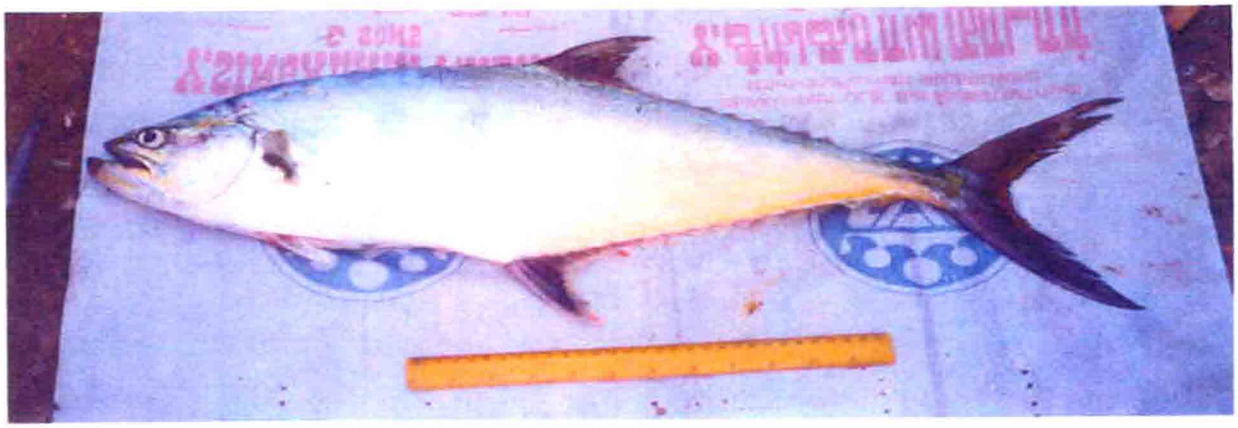


Plate 10. *Scomberoides tala*

3.4.1 Drift Gillnet Operation

The drift gillnet locally known as *vazhi vala* with mesh sizes of 13.5, 14, 14.5 and 15 cm were operated. The net with mesh size 14 cm is operated by commercial fishermen was taken as control net. All the four nets were operated by local fishermen. The fishermen set out for fishing by 16:00 h and it takes 2 h to reach the fishing ground. After reaching the ground, the nets were released into the sea along the wind direction. After releasing, one end of the head rope was tied to the boat. The nets were allowed to drift for 4 to 6 h parallel to the direction of the wind and water current. Nets were hauled after elapsing of soaking hours. The gilled fishes were removed while hauling. Fishermen were asked to keep the sorted catch in separate boxes provided to them in order to avoid mixing of catches from one mesh with other. Sampling was done in alternate days. Randomized arrangement of mesh panels were changed for every operation. Similarly, the fishing trials were carried out throughout the study period from September 2002 to March 2004.

3.4.2 Operation of Drift Hand Line

In this study artisanal gear called ' drift hand line' which is locally known as *odu kairu*, was selected for determining the selectivity effect of different sizes of hooks. Two fishermen from Kanyakumari and one each from Chinnamuttam and Arokyapuram village (Kanyakumari District, Tamil nadu) were selected for operation of experimental fishing gear. OBM was not used while operating hand lines. Crew size of each craft was five. After bringing the hand lines to the fishing ground, they were weighed after attaching the hooks to the lines. Hooks were randomly assigned to the lines for every operation. After tying the weight, each hook was baited. Fish such as, *Sardinella longiceps, Sardinella* spp., *Atule mate,* and *Caranx heberi* were used as baits. Effect of bait on hooking rate was not studied since, different baits were used in single day operation based on availability of the type of bait.

After baiting each hand line was held tied to the leg of individual member of crew of the craft and care was taken to avoid tangling of one line with the other. Lines were allowed to drift along the water current for seven hours from 06:00 h to 13:00 h. As soon as fish bites the hook, the line was hauled-up to remove the catch. The hook was baited and cast into the water again. Fishermen were asked to keep the catch obtained from each hook size in separate boxes provided to them to record the length frequency and effort data of catch by hook size. The total duration of fishing voyage lasted for 11 h from 05:00 h to 16:00 h though the time required to reach the ground was one hour only. During the fishing operation, 12 hooks of four sizes were operated from each craft. In total, 48 hooks were operated per fishing trip from four crafts. Rusted hook were replaced immediately with new ones. For the entire operation, 200 numbers of hooks of each size were used. Fishing trials were conducted almost daily except Sundays and religious holidays. Experimental fishing was conducted for a period of one year from June 2003 to May 2004.

3.5 Data Collection

Carangids were segregated from the catch of gillnets species wise based on mesh size and species-wise in gillnet fishing. Similarly. carangids were separated in hand line fishing based on hook size.

3.5.1 Collection of Data from Gillnet Catch

In this study, scientific name of the catch of all the species including non-targeted carangid and other fishes were noted. Morphometric measurements of each target species were recorded. Measurements included were Total Length (TL) which was taken from tip of the snout to tip of upper lobe of caudal fin or bigger lobe of the caudal fin, Fork Length (FL) which was measured from tip of the snout to fork of the caudal fin, Gill Girth or Head girth (Gg) which was the circumference of the fish at aft-most point of opercular cover or gill cover, Maximum girth (Gmax) which was estimated at the point where circumference was maximum in the fish body and Gilled girth or Retained girth (Gr) was measured at the mark left by the mesh. Gmax varied from fish to fish due to body shape of the fish. In some fishes, Gmax was measured at the origin of first dorsal fin and in some cases; it was just after the opercular region or post opercular or pelvic region.

All lengths and girths were measured using flexible nylon measuring tape. The girth measurements were performed for a sub-sample of total catch in different numbers for the ten species. The girths and lengths measurements were taken to the nearest mm and cm, respectively. Besides, weight (W) of individual fish of all ten species was recorded to the nearest gram by 10 kg weighing top pan balance. Fish, which had the weight of more than 10 kg, was not measured. Length frequency data of all the ten species caught in gillnets of different mesh size was recorded with 2 cm class interval. Proportion of fish caught by gilling, wedging or entangling was recorded based on the impression of twine visible on fish body due to wedging or gilling. If the mark was found at Gmax, it was considered as wedging. In the case of mark observed at Gg, mode of capturing was gilling and no mark was observed on the body, it was considered to the entangling. Samples of each species studied were preserved in 5 % formalin for further taxonomical studies. Maturity stages of each species were also observed by collecting the gonads from the caught fish. Mean FL, TL, Gg, Gmax and mean weight were also obtained from pooling the catch data from all mesh sizes.

3.5.2 Collection of Data from Drift Hand Lines Catch

Catch obtained from different hook sizes of hand lines were brought to the land in separate boxes after segregation of catch species wise according to hook size. Fish captured from the hand lines were only 4 species though some carangids and seer fishes were caught in few numbers. Scientific name of the species caught were recorded. All morphometric measurements, weight of individual fish and length frequency data for the class interval of 4 cm was recorded as done for gillnet catches, for each of the four species. Total number of hooks operated per day was also recorded.

3.6 Data Analysis

3.6.1 Selectivity Model

The selectivity model used for the analysis was **SELECT** (Share Each Length Class Total) developed by Millar (1992) which has been implemented in a selectivity software called **GILLNET** (Generalized Including Log-Linear N. Estimation Technique) developed by Constat (www.constat.dk). The model is built on the assumption that the N_{Lj}, number of fish of length class 'L' encountered in the gear 'j' or expected to contact or caught in the gear is considered as Poisson distributed or the number of fish of length class 'L' is also Poisson distributed (Feller, 1968).

The relative fishing intensity (P_j) which is the probability that a fish of length 'L' contacts the gear 'j', given that it has come into contact with the combined gear and the contact selection curve for given gear size 'j' (r_j (L)) with the mean λ_L. The relative fishing intensity is assumed to be constant and the model for analyzing the data collected from different gears with different dimensions is

$$N_{Lj} \approx \text{Pois}\ (P_j\ \lambda_L\ r_j\ (L))\ \ldots\ldots(1)$$

Symbol λ_L indicates abundance parameter, which is nuisance parameter (Millar, 1992). This parameter is not necessarily to be calculated. However, they are required to determine number of degrees of freedom and are estimated implicitly while estimating the selection curve parameters.

The expected value of catch (VL_j) is included instead of N_{Lj} Hence, we get

$$V_{Lj} = P_j \lambda_{Ll}\ r_j\ (L)\ \ldots\ldots(2)$$

The expected value of catch of length 'L' fish in gillnet 'j' is expressed in log-linear form. Hence, the log-linear form (Millar and Holst, 1997) is

$$\text{Log}(V_{Lj}) = \log(P_j) + \log(\lambda_L) + \log(r_j\ (L))\ldots\ldots(3)$$

$$= \Sigma\,\beta \cdot f_i\ (mj,L)\ \ldots\ldots(4)$$

where f_i (mj,L) is function only 'mj' and 'L'

In this model, selection curves are assumed to be normal shaped. So,

$$r_j\ (L) = \exp\left[- \frac{(L - \mu_j)^2}{2\sigma^2_j} \right]\ \ldots\ldots(5)$$

and the curves observe geometrical similarity (i.e., mean (μ_j) and spread or variance (σ^2_j) is proportional to mesh size (m_j).

$$\mu_j = k_1 . m_j \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$\sigma_j^2 = k_2 \ m_j^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where k_1 and k_2 are parameters to be estimated. When these values and $r_j(L)$ are substituted in the equation (4), we get the following;

$$\mathrm{Log}(V_{Lj}) = \log(P_j) + \log(\lambda_L) - \frac{(L - \mu_j)^2}{2\sigma^2_j}$$

$$= \log(P_j) + \log(\lambda_L) - \frac{(L - k_1 . m_j)^2}{2 \ k_2 . m_j^2}$$

$$= \log(P_j) + \log(\lambda_L) - \frac{k_1^2}{2k^2} + \frac{k_1}{k_2} \cdot \frac{L}{m_j} - \frac{1}{2 \ k_2} \cdot \left(\frac{L}{m_j} \right)^2 \ldots\ldots\ldots\ldots (8)$$

$$= \log(P_j) + \log(\lambda_L) + \beta_o + \beta_1 \cdot X_{Lj} + \beta_2 \cdot X_{Lj}^2 \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where

$$\beta_o = -\frac{k_1^2}{2 \ k_2} \ ; \quad \beta_1 = \frac{k_1}{k_2} \ ; \quad \beta_2 = -\frac{1}{2 \ k_2} \ \text{and} \ X_{Lj} = \frac{L}{m_j}$$

Estimates of k_1 and k_2 can be calculated from the above β_1 and $\beta 2$ relations. In the case of population length distribution is not assumed then log

(λ_L) is fitted as a factor and hence constant βo becomes redundant since it is confounded with log (λ_L) factor. Further, if relative fishing power is assumed as equal or '1' then log (P_j) form which is equal to log (m_j)be excluded and the model becomes

$$\text{Log}\ (V_{Lj}) = \text{factor}\ (L) + \beta_1 \cdot X_{Lj} + \beta_2 \cdot X_{Lj}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

If the fishing intensity is considered as proportional to mesh size then the model equation is given as;

$$\text{Log}\ (V_{Lj}) = \log\ (m_j) + \text{factor}\ (L) + \beta_1 \cdot X_{Lj} + \beta_2 \cdot X_{Lj}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

If any model assumes population length distribution, then the model will yields log-linear form. It can be explained by giving the following example, if the population length distribution is assumed to be normal with mean θ and variance τ^2 then,

$$\lambda_L = N \exp \left(\frac{-\ (L - \theta)^2}{2\tau^2} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

The value of λ_L is substituted in the equation (8), so, we get log-linear model for normal curve with constant spread is

$$\text{Log}\ (V_{Lj}) = \left(\log(N) - \frac{k_1^2}{2k^2} - \frac{\theta^2}{2\tau^2} \right) + \left(\frac{\theta}{\tau^2} \right) L + \left(\frac{1}{2\tau^2} \right) L^2 + \left(\frac{k_1}{k_2} \right) \frac{L}{m_j} + \left(-\frac{1}{2\ k_2} \right) \left(\frac{L}{m_j} \right)^2 \quad \ldots\ldots(13)$$

$$\text{Log}(V_{Lj}) = \beta_0 + \beta_1 L + \beta_2 L^2 + \beta_3 \cdot X_{Lj} + \beta_4 \cdot X_{Lj}^2 \ldots\ldots\ldots\ldots\ldots\ldots(14)$$

Derivations for other selection curves shown in the Table 3 follow the similar method. From this derivation, selection curve parameters are estimated. Above models and derivation belongs to log-linear model.

SELECT Method

The SELECT method basically follow the log-linear model though it has small variation that it eliminates the λ_L parameter from the maximization problem. The principle of this method is the proportions of the total catch for each length class 'L' taken by each gear (mesh or hook) (j_1) to the total catch of all the meshes or hooks combined ($j = 1,2,3\ldots\ldots\ldots j$) of the same length class ($\Sigma\, n_{Lj}$) (Millar, 1992).

Let $n_{L+} = \Sigma\, n_{Lj}$ be the total catch of length class 'L' by all 'j' gears combined and let

$$y_{lj} = \frac{n_{Lj}}{n_{L+}}$$

It is expressed that y_{lj} have multinomial distribution with n_{L+} trials and probabilities, so the expected value (E) of the model is shown as follows;

$$\phi_{Lj} = E(y_{lj}) = \frac{P_j\, \lambda_L\, r_j\,(L)}{\Sigma_j\, P_j\, \lambda_L\, r_j\,(L)}, \quad j = 1,2\ldots\ldots j \quad \ldots\ldots\ldots\ldots\ldots(15)$$

In this method, λ_L is omitted since, the probabilities ϕ do not depend on it and hence the log-likelihood for the proportion of the catch data is

$$\sum_{L} \sum_{j} n_{Lj} \log_e (\phi_{Lj}) \quad \ldots\ldots(16)$$

Selectivity parameters are estimated by maximizing the above log-likelihood function.

3.6.1.1 Modeling of Gillnet Selection

The software **GILLNET** which implements the methodology of SELECT method of Millar (1992) was used to estimate the selectivity parameters. This software contains five different functions (Table 3.) namely,

1) Normal location (where model length is proportional to mesh sizes but with fixed spread of the curve),
2) Normal scale
3) Log-normal
4) Gamma
5) Bi-modal

Of these five, the first four belong to Uni-modal or Uni-normal models with two parameters. All these distribution follow Baranov's principle of geometric similarity (Baranov, 1948) except normal location curve. It leads to fitting of unit curve independent of mesh size for each function. All the models were used to estimate selectivity parameters of gillnet and to get selection curves for the data collected from the ten target species from gillnet. They were, *Carangoides ferdau, C. fulvoguttatus*, *Caranx heberi*, *Caranx ignobilis*, *C. papuensis*, *C. sexfasciatus*, *C. tille*, *Scomberoides commersonnianus*, *S. lysan*, and *S. tala*.

Besides, the residual plots were obtained along with selection curves by plotting mesh size against length class. These plots reveal about some features related with effect of fishing power and catch (McCullagh and Nelder, 1989). The data were fitted twice to the above curves based on assumption of equal fishing power of the gillnets and then again considering the fishing power to be proportional to mesh size (Millar and Holst, 1997). Here model deviances (D) (likelihood ratio goodness of fit statistics) from each fit were calculated for corresponding degrees of freedom. Degrees of freedom (DF)

Table 3. Various Uni-modal and Bi-modal models used in the present selectivity studies

Model and Parameters	Selection curve	Log-linear model $[\beta_1]\{f_1(m_1,l)\}+[\beta_2]\{f_2(m_1,l)\}$
Normal location (k, s) (constant spread)	$\exp\left(-\frac{(l-k.m_j)^2}{2s^2}\right)$	$\left[\frac{k}{s^2}\right].\{l.m_1\}+\left[-\frac{k^2}{2s^2}\right].[m_1^2]$
Normal scale (k₁, k₂)	$\exp\left(-\frac{(l-k_1.m_j)^2}{2k_2^2.m_j^2}\right)$	$\left[\frac{k_1}{k_2^2}\right].\left\{\frac{l}{m_j}\right\}+\left[-\frac{1}{2k_2^2}\right].\left\{\left(\frac{l}{m_1}\right)^2\right\}$
Lognormal (m, s)	$\frac{m_j}{l.m_1}\exp\left[m-\frac{s^2}{2}-\frac{\left(\log(l)-m-\log\left(\frac{m_j}{m_1}\right)\right)^2}{2s^2}\right]$	$\left[\frac{1}{s^2}\right].\left[\log(l).\log\left(\frac{m_j}{m_1}\right)-\frac{1}{2}\log^2\left(\frac{m_j}{m_1}\right)\right]$ $+\left[1-\frac{m}{s^2}\right].\left\{\log\left(\frac{m_j}{m_1}\right)\right\}$
Gamma (k, a)	$\left(\frac{l}{(k-1).a.m_j}\right)^{k-1}\exp\left(k-1-\frac{l}{a.m_j}\right)$	$[k-1]\left\{\log\left(\frac{l}{m_j}\right)\right\}+\left[-\frac{1}{a}\right].\left\{\frac{l}{m_j}\right\}$
Bimodal or Binormal (a_1, b_1, a_2, b_2, ω)	$\exp\left(-\frac{(l-a_1.m_j)^2}{2b_1^2.m_j^2}\right)+\varpi\exp\left(-\frac{(l-a_2m_j)^2}{2b_2^2}\right)$	

was calculated by number of length class multiplied by number of mesh sizes used minus number of length class and number of parameters involved (Millar and Fryer, 1999). Deviance was sum of all the residuals obtained from each length class and mesh sizes, i.e.,

$$D = \sum_{ij} res_{ij}^2$$

where, res_{ij} is residual of i^{th} length class of j^{th} mesh size.

The deviance statistics and residual plots were used to assess fit of the selectivity model. . Evaluation of model statistics and fits were done as given in the section 3.6.1.3 and 3.6.1.4

3.6.1.2 Modeling of Drift Hand Line

Estimation of selection parameters, selectivity curves, deviances statistics and residual plots for the four species caught from hand line fishing were estimated using GILLNET programme as done for gillnet data. The species studied were, *Caranx heberi, Caranx ignobilis, Carangoides fulvoguttatus, Scomberoides. commersonnianus.* Evaluation of model statistics and fits were done as given in the section 3.6.1.3 and 3.6.1.4

3.6.1.3. Validtity of Models

After fitting all the models, goodness of fit was evaluated using model deviance (D) (McCullagh and Nelder, 1989). The model, which had less deviance value, was considered as better fit. Deviance value was also evaluated whether it was smaller than degrees of freedom as a rule of thumb that D should be within the same magnitude of DF i.e., D should be always less than DF. Residual deviance (D) was further evaluated by referring it into the chi-square distribution $D \sim \chi^2(DF)$ since, justification or rejection of a model should never be based on deviance alone (Holst *et al.*, 1994). After referring, the ratio of D to DF (D/DF) or dispersion parameter was calculated for all the models of each species. If the dispersion parameter value was higher than one, the model was considered as over dispersion or high spread or variance (Holst *et al.*, 1994). The model, which had over dispersion, was inferred as lack of fit. Significant difference between models were also studied based on difference between model deviance which, was considered as statistics of chi-square distribution, for the degree of freedom of number of non-zero length class minus number of parameter to be estimated (Wileman *et al.*, 1996). After assessing the fit with above-mentioned statistical tools, the better-fit model for all species, were further inspected from residual plots.

Residual plots were prepared by plotting mesh sizes in y-axis and length class in x-axis. A good fit of plot was regarded as presence of small and randomly distributed plots of residuals. The value of all the residual were observed to find out whether they lied in the range of 2 (Holst *et al.*, 1994). If it was found so, it was inferred that the model yielded good fit in a normal distribution. The better fit model which showed lack of fit were further extended to bi-modal model to get an improved model, i.e., a model which has less deviance and avoids systematic trends in the residual plots.

3.6.1.4 Refitting of Models

The model required further fitting were subjected to bi-modal form (Holst *et al.*, 1994). Deviance, Degrees of freedom and residual plots were also estimated and analysed as did in uni-modal models. In this model, degrees of freedom were lesser by 3 to uni-modal model since this model has 5 parameters unlike 2 in the uni-modal form. Best-fit model for all species were studied similarly. The above validations and refitting were done for both selectivity data obtained from drift gillnets and drift hand lines of all the species caught.

3.7 Length – Girth Relation

Enmeshing of fish in gillnet is dependent on the relationship between its girth and mesh size of the net. It is important to understand the relationship between girth and length to work out conversion from girth to length and vice-versa. The relationships between girth and length were estimated in two ways in relation to total length (TL) and fork length (FL). Totally four kind of relations were worked out in this study. They were;

i) Gill girth and Total length

ii) Maximum girth and Total length

iii) Gill girth and Fork length

iv) Maximum girth and Fork length

The relationships were determined using simple linear-regression method as given below:

$$Gg = a + bTL$$

$$Gmax = a + bTL$$

$$Gg = a + bFL$$

$$Gmax = a + bFL$$

The above relationships were estimated after pooling the catch from various meshes tested for the ten species. Besides, a common relationships between girths and lengths were found after pooling all the catches from both the gears employed irrespective of the mesh and hook sizes tested.

All the above relationships were determined by using MS-Excel data analysis software and the measurements of girth and length were given in cm. Regression of girths and lengths were statistically compared to verifying appropriateness of the aggregation of retaining girth with various positions for the ten target species of carangid. Similarly, relationships between Total length and Fork length were worked out.

3.8 Estimation of Length at First Maturity

Gonads of target species obtained from gillnets and hand lines were collected from the fish caught, fish landing centers and fish market and preserved in the formalin to find out maturity of the fishes in relation to length. Maturity stages were determined by seven-scale point method. Method used by Venkataramanujam and Ramanathan (1994) was used to find the maturity stages, and the stages were classified as immature, maturing virgins, maturing, mature, gravid, ripe and spent. After analyzing, the fish that contained the eggs of stage 4 to 7 were considered as mature. Taking the total length expressed in cm in 'x' axis and percentage of mature specimens in 'y' axis, a graph was drawn. Length at which 50% of the animals found mature was taken as the length at first maturity (Lm50).

3.9 Compressibility and Elasticity Factor (K)

Compressibility-Elasticity factor (K) for all ten target species caught from gillnet were estimated after pooling the catch from all mesh size of each species using the following formula (Ehrhardt and Die, 1988);

$$K = \frac{\textbf{Mesh perimeter of retaining mesh (cm)}}{\textbf{Girth at retention position (cm)}}$$

'K' value for maximum girth and gill girth was calculated for every mesh size tested (Table 29) and mean Kmax, Kgill were calculated after pooling all catch data from all mesh sizes.

3.10 Interaction Between Gears

Interaction between gears used namely gillnets and hand lines were found out by comparing observed catch proportion of the catch in each length group of one with other gear. This comparison led to find out which gear was more selective. The proportion of each length group in the total catch in each length group was calculated for pairs of gear. The proportion ratio is;

$$\frac{\text{Hand line catch for particular length group}}{\text{Hand line catch for particular length group} + \text{Catch from gillnet for the same length group}}$$

3.11 Estimation of Optimum Mesh and Hook Size

Optimization of mesh and hook size for commercial exploitation of carangid fisheries of Kanyakumari coast was done based on the fish which had maximum length at first maturity (Lm50) among the carangids, contributing significantly to fishery. So, that, all the other species constituting to the fishery will have enough opportunity for spawning and sustaining their respective stocks and for attaining improved length at first capture (l_c). Estimation was done based on the relationship given by Baranov (1948),

$$m = kl$$

where, m = mesh bar (cm)
k = selectivity coefficient
l = modal length (cm)

Mesh which caught relatively low percentage of undersized fish (i.e., less quantity of fish below length at first maturity) was considered as better mesh size to work out 'k' value for all the species caught using above equation. Optimum mesh size was calculated, using above relationship, from the obtained 'k' value and length at first maturity for the fish, which attains maximum length (Lmax). Length at first capture (l_c) was calculated for all ten species caught from gillnets were determined using the estimated optimum mesh size and their respective 'k' value. Estimated mesh size was considered as optimum mesh size.

Similarly, optimum hook size was estimated along with 'k' and l_c for all four species caught from drift hand lines using same formula substituting hook gap (inner distance between shank and point) in place of mesh bar 'l'. In hook optimization, the hook, which caught less quantity of fish below Lm50, was considered as better hook to find out estimated optimum size hook.

Results

4. Results

4.1 Check List of Carangid Species of Kanyakumari Coast

The checklist of carangid fishes that contributes the carangid fishery in the Kanyakumari coast of Tamil nadu, India is presented below.

Class : Actinopterygii
Order : Perciformes
Family : Carangidae
Genus : *Alectis*
Species : *Alelctis ciliaris*, Bloch, 1788
Alelctis indicus, Ruppell, 1830
Genus : *Alepes*
Species : *Alepes djedaba*, Forsskal, 1775
Genus : *Atule*
Species : *Atule mate* Cuvier, 1833
Genus : *Carangoides*
Species : ***Carangoides ferdau,*** Forsskal, 1775
C. fulvoguttatus, Forsskal, 1775
C. gymnostethus , Cuvier, 1833
C. malabaricus, Bloch & Schneider,1801
Genus : *Caranx*
Species : ***Caranx heberi***, Bennett, 1830
C. ignobilis, Forsskal, 1775
C. papuenssis, Alleyne &Macleay, 1877
C. para, Cuvier, 1833
C. sexfasciatus, Quoy & Galmard, 1825
C. tille, Cuvier, 1833
Genus : *Elagatis*
Species : *Elagatis bipinnulata*,quoy&Galmard,1824
Genus : *Megalaspis*
Species : *Megalaspis cordyla,* Linnaeus, 1758
Genus : *Parastomateus*
Species : *Parastomateus niger*, Bloch, 1795

Genus : *Scomberoides*
Species : ***Scomberoides***
Commersonnianus, *Lacepede, 1801*
S. lysan, Forsskal, 1775
S. tala, Cuvier, 1832
S. tol, Cuvier, 1832
Genus : *Selar*
Species : *Selar crumenophthalmus,* Bloch, 1793
Genus : *Selaroides*
Species : *Selaroides leptolepis,* Cuvier, 1832
Genus : *Trachinotus*
Species :
Trachinotus baillonii, Lacepede, 1801

Trachinotus blochii, Lacepede, 1801
Trachinotus mookalee, Cuvier, 1832

* : The species mentioned in the bold letters are selected for the study.

4.2 Size Distribution

In the present study a total of 17,568 carangid fishes belonging to ten species were caught from gillnets with four different meshes viz., 13.5 cm, 14 cm, 14.5 cm and 15 cm and 1793 carangid fishes belonging four species were caught from drift hand lines with four different hooks viz., No.5, No.6, No.7 and No.8. The gillnets catch was contributed by Carangoides *ferdau* (5.16%), *Caranqoides fulvoguttatus* (12.7%), *Caranx heberi* (19.7%), *C. ignobilis* (14.7 %), *C. papuensis* (8.38%), *C. sexfasciatus* (6.86%), *C. tille* (8.94%), *Scomberoides commersonnianus* (7.79%), *S. lysan* (9.52%), *S.tala* (6.34 %) while catches of drift handllines accounted by *Carangoides fulvoguttatus* (29.22 %), *Caranx heberi* (31.34%), *C. ignobilis* (18.4 %), *Scomberoides commersonnianus* (21.03) (Table. 4 to 17).

Length frequency distribution of all ten-target species of gillnets and four species of hand lines are shown in Fig.9and 10 respectively (Table 4-17). Size frequency distributions of different species studied showed

Table. 4 Percentage of length frequency data of *Carangoides ferdau* caught from gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14.0	14.5	15.0
1	30.5	0	0	0	0
2	32.5	1.21	0	0	0
3	34.5	1.61	0	0	0
4	36.5	0.4	0	0	0
5	38.5	0	0	0	0
6	40.5	0.4	0	0	0
7	42.5	1.61	0	0.5	0
8	44.5	2.42	0	0	0
9	46.5	5.65	0	0	0
10	48.5	10.9	2.86	0	0
11	50.5	27	6.12	0	0
12	52.5	18.1	10.2	0	0
13	54.5	11.7	11.4	0	0
14	56.5	4.84	31	0.99	0
15	58.5	4.84	15.9	2.48	0
16	60.5	3.23	8.16	4.95	0.47
17	62.5	2.02	4.08	7.92	0.95
18	64.5	2.02	1.22	8.42	1.42
19	66.5	1.21	0.41	9.9	7.58
20	68.5	0.4	1.63	12.4	8.53
21	70.5	0	1.63	24.3	12.8
22	72.5	0	1.22	10.9	27
23	74.5	0	0.41	9.41	14.7
24	76.5	0	1.63	2.48	10.4
25	78.5	0	2.04	1.98	5.69
26	80.5	0	0	1.98	5.69
27	82.5	0	0	0.99	2.84
28	84.5	0.4	0	0	0.47
29	86.5	0	0	0	0.47
30	88.5	0	0	0.5	0.47
31	90.5	0	0	0	0.47

Table. 5 Percentage of length frequency data of *Carangoides fulvoguttatus* caught from drift gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14.0	14.5	15.0
1	20.5	0	0	0	0.2
2	22.5	0.57	0	0	0
3	24.5	0	0.16	0	0
4	26.5	0	0	0	0
5	28.5	0.29	0	0	0
6	30.5	0.29	0	0	0
7	32.5	1.43	0	0.13	0
8	34.5	0.57	0	0	0
9	36.5	1.72	0	0	0
10	38.5	1.72	0.16	0	0
11	40.5	3.44	0.16	0	0
12	42.5	2.29	0.33	0	0
13	44.5	1.43	0.81	0.27	0.39
14	46.5	2.29	2.6	1.33	0.39
15	48.5	2.29	2.28	1.33	0.59
16	50.5	4.58	3.41	2.39	0.98
17	52.5	5.16	5.53	1.86	3.53
18	54.5	8.88	6.83	3.72	1.76
19	56.5	12.9	7.15	3.85	1.76
20	58.5	15.5	6.99	4.91	1.57
21	60.5	9.17	7.15	2.92	0.59
22	62.5	9.17	6.67	3.85	0.98
23	64.5	5.73	9.27	3.19	0.2
24	66.5	3.15	13.8	3.85	1.18
25	68.5	1.43	4.39	2.26	1.57
26	70.5	0.86	3.09	1.99	2.55
27	72.5	0.57	3.09	2.66	2.94
28	74.5	0.57	1.79	3.05	4.31
29	76.5	0.86	2.6	6.51	4.51
30	78.5	1.15	2.11	4.52	5.49
31	80.5	0.57	2.6	11.4	6.86

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	**14.0**	**14.5**	**15.0**
32	82.5	0.29	2.44	14.2	7.65
33	84.5	0.86	1.46	5.31	8.43
34	86.5	0	1.46	5.05	20
35	88.5	0.29	0.33	2.66	10.2
36	90.5	0	0.49	1.73	3.14
37	92.5	0	0.33	1.73	1.57
38	94.5	0	0.33	1.59	2.55
39	96.5	0	0.16	1.2	1.76
40	98.5	0	0	0.27	1.76
41	100.5	0	0	0.13	0.59
42	102.5	0	0	0.13	0

Table. 6 Percengage of length frequency catch data of *Caranx heberi* caught from drift gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14	14.5	15
1	20.5	0.42	0.09	0	0.31
2	22.5	0.42	0	0	0
3	24.5	0.1	0	0	0
4	26.5	0	0	0	0
5	28.5	0.21	0	0	0
6	30.5	0.1	0.09	0	0
7	32.5	0.42	0.26	0	0
8	34.5	2.2	0.26	0	0
9	36.5	4.19	1.4	0	0
10	38.5	4.61	2.1	0.14	0
11	40.5	5.03	2.19	0.28	0.15
12	42.5	5.97	4.02	0.14	0
13	44.5	7.13	6.12	0.56	0
14	46.5	13.4	6.3	1.12	0.31
15	48.5	11.6	7.09	0.7	0.92
16	50.5	9.64	7.52	2.79	1.08
17	52.5	7.23	8.66	4.61	3.38
18	54.5	7.02	12.2	4.89	4.76
19	56.5	6.5	9.36	8.1	7.22
20	58.5	4.72	5.6	8.8	8.45
21	60.5	3.46	5.16	9.78	7.53
22	62.5	1.78	4.55	11.5	4.92
23	64.5	1.47	4.37	15.9	8.14
24	66.5	1.05	2.8	9.78	9.83
25	68.5	0.73	2.89	5.45	18.6
26	70.5	0.1	2.19	3.07	7.22
27	72.5	0	1.05	2.23	5.07
28	74.5	0.1	1.22	1.82	2.61
29	76.5	0	0.52	1.82	2.76
30	78.5	0	0.35	1.12	1.69
31	80.5	0	0.52	1.4	1.69
32	82.5	0.21	0.26	1.82	1.38
33	84.5	0	0.09	0.84	1.23
34	86.5	0	0	0.7	0.31
35	88.5	0	0.09	0.28	0.31
36	90.5	0	0.17	0.28	0
37	92.5	0	0.26	0.14	0.15
38	94.5	0.1	0.17	0	0
39	96.5	0	0.09	0	0

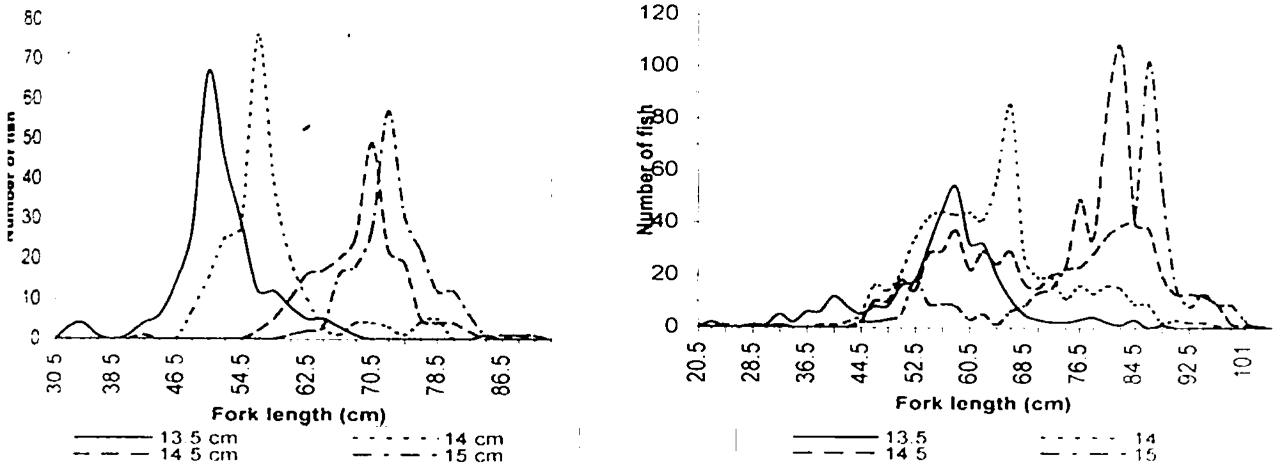
Table. 7 Percentage of length frequency data of *Caranx ignobilis* caught from drift gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14	14.5	15
1	30.5	0.38	0	0	0.44
2	32.5	1.34	0	0	0
3	34.5	0.57	0	0.49	0.33
4	36.5	4.39	0	0.66	0.44
5	38.5	4.96	0.9	0.49	0.33
6	40.5	5.34	1.62	0.99	0.67
7	42.5	5.92	1.26	0.82	0.56
8	44.5	6.3	1.62	0.99	0.56
9	46.5	7.06	0.54	1.15	0.89
10	48.5	7.44	1.44	0.99	0.56
11	50.5	7.82	3.42	0.99	0.67
12	52.5	11.3	3.24	1.15	0.33
13	54.5	8.4	3.6	1.48	0.44
14	56.5	8.02	5.95	1.98	1.11
15	58.5	7.25	6.67	3.29	2.33
16	60.5	6.49	9.55	5.77	2.89
17	62.5	2.86	12.4	6.75	3.33
18	64.5	1.34	13.3	7.91	4.56
19	66.5	1.34	18.4	9.72	5.11
20	68.5	1.34	5.23	11.5	5.78
21	70.5	0.19	3.06	6.92	6.44
22	72.5	0	2.52	6.75	7.44
23	74.5	0	1.44	5.11	7.44
24	76.5	0	1.62	4.94	8.56
25	78.5	0	0.54	3.29	8
26	80.5	0	0.72	2.64	7.56
27	82.5	0	0	1.65	5.67
28	84.5	0	0	1.48	3.78
29	86.5	0	0	2.14	3.11
30	88.5	0	0	2.47	3
31	90.5	0	0	0.82	1.67
32	92.5	0	0.18	1.32	1.22
33	94.5	0	0.36	0.99	0.67
34	96.5	0	0.18	0.66	1
35	98.5	0	0.18	0.66	0.78
36	100.5	0	0	0.49	1.11
37	102.5	0	0	0	0.44
38	104.5	0	0	0.33	0.56
39	106.5	0	0	0.16	0.22

Fig. 9 Length frequency of various carangid fishes cauaght from gillnets with different mesh sizes

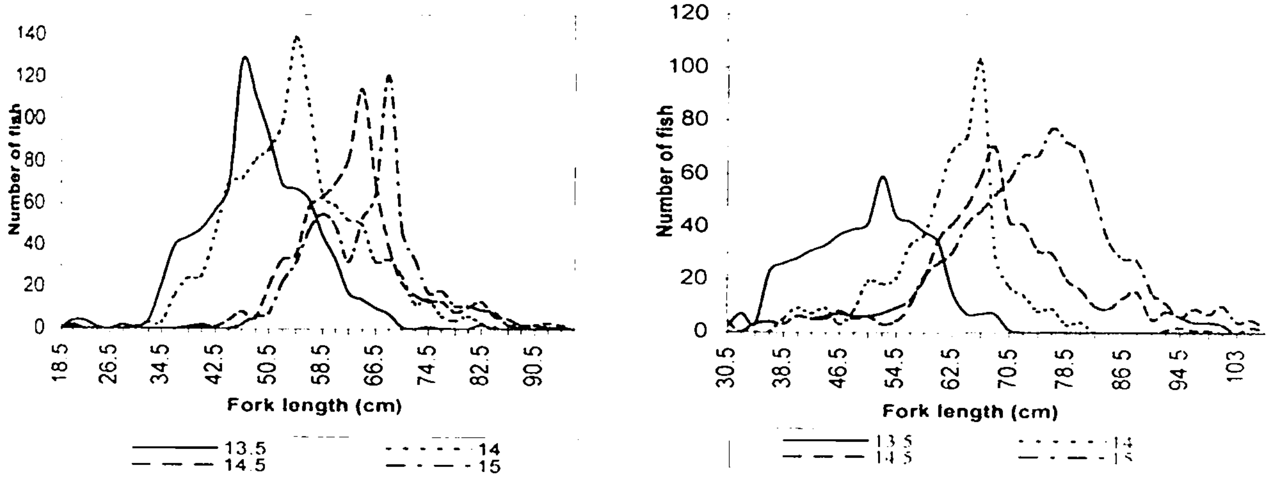
a) *Carangoides ferdau*

b) *Carangoides fulvoguttatus*

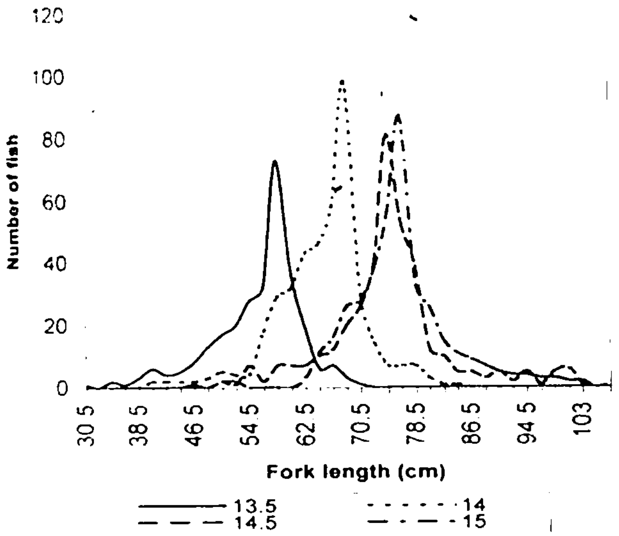


c) *Caranx heberi*

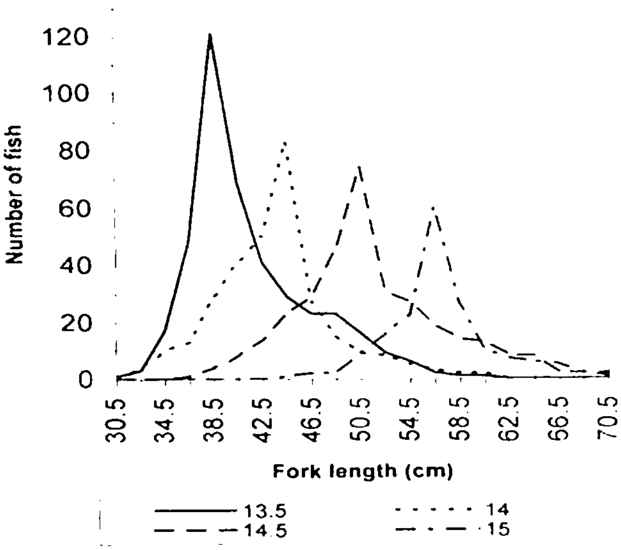
d) *Caranx ignobilis*



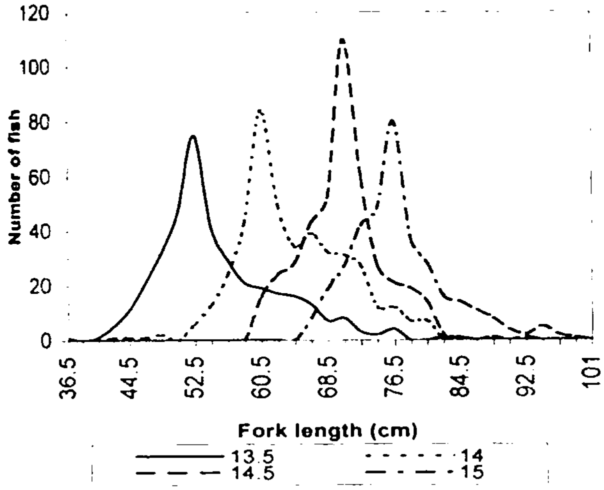
e) *Caranx papuensis*



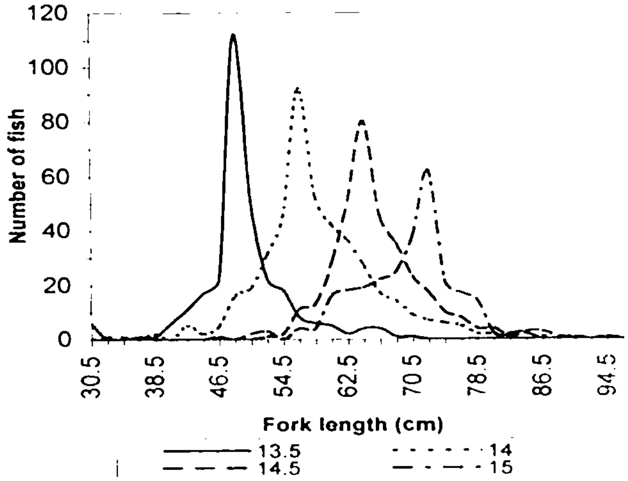
f) *Caranx sexfasciatus*



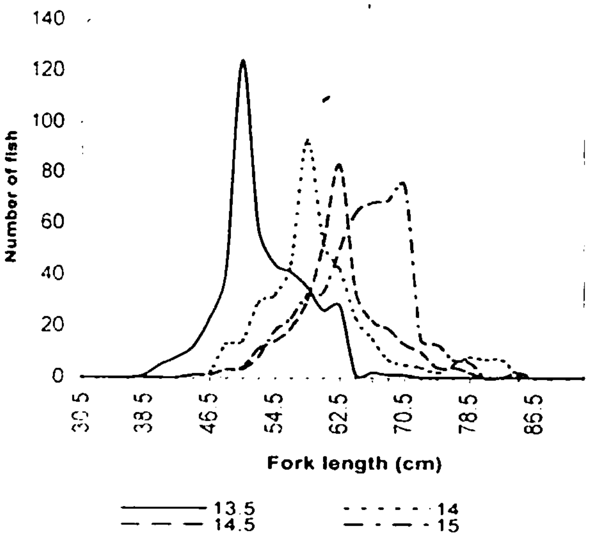
g) *Caranx tille*



h) *Scomberoides commersonnianus*



i) *Scomberoides lysan*



j) *Scomberoides tala*

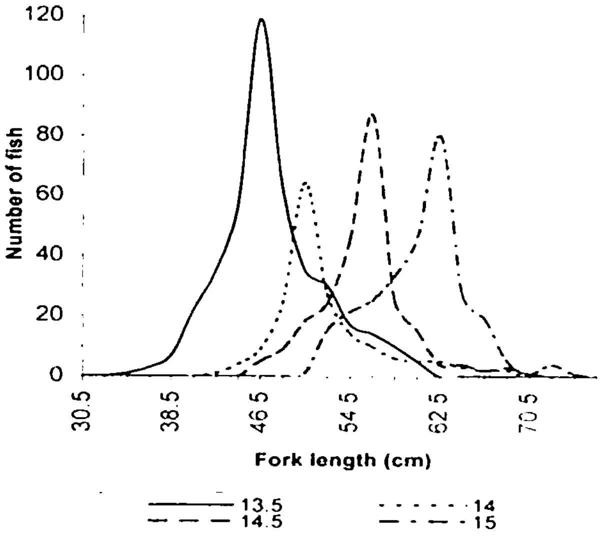


Table. 8 Percentage of length frequency data of *Caranx papuensis* caught from drift gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14	14.5	15
1	30.5	0.35	0	0	0
2	32.5	0	0	0	0
3	34.5	0.7	0	0	0
4	36.5	0.35	0	0	0
5	38.5	1.05	0	0	0
6	40.5	2.1	0.48	0	0
7	42.5	1.4	0.48	0	0
8	44.5	1.75	0.48	0	0
9	46.5	2.8	0.48	0.27	0
10	48.5	4.55	0.72	0	0
11	50.5	5.94	1.2	0.53	0.51
12	52.5	6.99	0.96	0.27	0.51
13	54.5	9.79	0.96	1.87	0
14	56.5	11.2	4.31	0.53	0
15	58.5	25.5	6.94	1.87	0
16	60.5	12.9	7.66	1.87	0
17	62.5	6.64	10.3	1.87	0.76
18	64.5	2.1	11	2.67	2.79
19	66.5	2.45	13.9	3.2	4.06
20	68.5	1.05	23.4	5.33	6.6
21	70.5	0.35	7.18	6.93	7.11
22	72.5	0	3.35	10.7	9.64
23	74.5	0	1.67	21.6	14.2
24	76.5	0	1.67	14.1	22.1
25	78.5	0	1.67	10.4	8.38
26	80.5	0	0.72	3.2	6.6
27	82.5	0	0.24	2.67	3.81
28	84.5	0	0.24	1.33	2.79
29	86.5	0	0	1.33	2.28
30	88.5	0	0	0.8	1.78
31	90.5	0	0	1.33	1.27
32	92.5	0	0	0.53	1.02
33	94.5	0	0	1.33	1.02
34	96.5	0	0	0.27	0.76
35	98.5	0	0	1.33	0.76
36	100.5	0	0	1.6	0.51
37	102.5	0	0	0.27	0.51
38	104.5	0	0	0	0
39	106.5	0	0	0	0.25

Table. 9 Percentage of length frequency data of *Caranx sexfasciatus* caught from drift gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14.0	14.5	15 0
1	30.5	0.24	0	0	0
2	32 5	0.73	1.33	0	0
3	34 5	4.15	3.32	0	0
4	36.5	11.7	4.32	0.31	0
5	38.5	29.5	9.63	1.23	0
6	40.5	16.8	13.6	2.47	0
7	42.5	10	16.6	4.32	0
8	44.5	7.07	27.6	7.1	0.59
9	46.5	5.61	8.97	8.95	1.18
10	48.5	5.61	4.98	13.9	1 18
11	50.5	3.9	2.99	22.8	5.29
12	52.5	2.2	2.66	9.57	9.41
13	54.5	1.46	1.66	8.33	13.5
14	56.5	0.49	1	5.86	35.3
15	58.5	0.24	0.66	4.32	15.3
16	60.5	0.24	0.66	4.01	5.88
17	62.5	0	0	2.47	4 12
18	64.5	0	0	2.47	3.53
19	66.5	0	0	0.62	2.94
20	68.5	0	0	0.62	1.18
21	70.5	0	0	0.62	0.59

Table. 10 Percentage of l Length frequency data of *Caranx tille* caught from drift gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14	14.5	15
1	36.5	0.27	0	0	0
2	38.5	0	0	0	0
3	40.5	0.27	0	0	0
4	42.5	1.33	0.24	0	0
5	44.5	2.93	0.24	0	0
6	46.5	5.6	0.24	0	0
7	48.5	8.53	0.47	0	0
8	50.5	12.5	0	0	0
9	52.5	20	1.41	0	0
10	54.5	10.9	3.06	0	0
11	56.5	7.73	5.65	0	0
12	58.5	5.6	10.1	0	0
13	60.5	5.07	19.8	3.82	0
14	62.5	4.53	11.5	5.73	0
15	64.5	4.27	8	6.68	0
16	66.5	3.47	9.18	10.3	2.27
17	68.5	1.87	7.53	12.4	5.4
18	70.5	2.13	7.29	26.3	7.67
19	72.5	0.8	6.35	14.6	11.9
20	74.5	0.53	2.82	6.44	13.6
21	76.5	1.07	2.82	5.01	22.7
22	78.5	0	1.65	4.53	10.5
23	80.5	0	1.65	3.34	7.95
24	82.5	0.27	0	0.48	4.55
25	84.5	0.27	0	0	3.98
26	86.5	0	0	0	3.13
27	88.5	0	0	0.24	2.27
28	90.5	0	0	0	1.14
29	92.5	0	0	0.24	0.57
30	94.5	0	0	0	1.42
31	96.5	0	0	0	0.57
32	98.5	0	0	0	0.28
33	100.5	0	0	1.33	1.02

Table.11 Percentage of Length frequency data of *Scomberoides commersonnianus* caught from drift gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14	14.5	15
1	30.5	2.02	0	0	0
2	32.5	0	0.23	0	0
3	34.5	0	0.23	0	0
4	36.5	0.34	0	0	0
5	38.5	0.34	0.45	0	0
6	40.5	2.02	0	0	0
7	42.5	3.7	1.14	0	0
8	44.5	5.72	0.45	0	0
9	46.5	7.41	1.14	0	0.36
10	48.5	37.7	3.64	0	0
11	50.5	16.8	4.32	0	0.72
12	52.5	7.41	7.05	0.3	1.08
13	54.5	6.06	10.2	0.6	0
14	56.5	2.69	20.9	3.27	1.44
15	58.5	2.02	11.8	3.87	1.44
16	60.5	1.68	9.55	8.33	5.76
17	62.5	0.67	8.18	15.2	6.47
18	64.5	1.35	6.14	23.8	6.83
19	66.5	1.35	3.86	13.4	7.91
20	68.5	0.34	3.18	10.4	8.99
21	70.5	0.34	2.05	6.85	13.7
22	72.5	0	1.59	5.06	22.3
23	74.5	0	1.36	2.98	7.55
24	76.5	0	1.14	2.38	6.12
25	78.5	0	0.45	1.19	5.04
26	80.5	0	0.45	1.19	0.72
27	82.5	0	0.23	0.3	0.72
28	84.5	0	0	0.6	1.08
29	86.5	0	0.23	0	1.08
30	88.5	0	0	0	0.36
31	90.5	0	0	0	0.36
32	92.5	0	0	0	0
33	94.5	0	0	0.3	0
34	96.5	0	0	0	0

Table. 12 Percentage of Length frequency data of *Scomberoides lysan* caught from drift gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14.0	14.5	15.0
1	36.5	0	0	0	0
2	38.5	0.22	0	0	0
3	40.5	1.11	0	0	0
4	42.5	1.78	0	0	0
5	44.5	2.67	0.25	0.31	0.2
6	46.5	5.11	0.49	0.31	0.2
7	48.5	8.89	3.2	0.92	0.61
8	50.5	27.6	3.45	1.22	0.61
9	52.5	12.9	7.14	3.36	1.64
10	54.5	9.78	7.88	4.28	3.68
11	56.5	9.11	10.8	5.81	4.7
12	58.5	7.78	22.9	9.17	6.54
13	60.5	5.78	12.8	15.9	6.75
14	62.5	6.22	10.3	25.4	10.2
15	64.5	0.22	5.67	10.1	13.1
16	66.5	0.44	3.69	6.73	13.9
17	68.5	0.22	1.72	5.81	14.1
18	70.5	0.22	1.23	3.98	15.3
19	72.5	0	0.99	3.06	3.07
20	74.5	0	0.49	1.22	2.66
21	76.5	0	1.23	1.22	1.43
22	78.5	0	1.97	0.61	1.23
23	80.5	0	1.72	0	0
24	82.5	0	1.72	0	0
25	84.5	0	0.25	0.61	0

Table. 13 Percentage of Length frequency data of *Scomberoides tala* caught from drift gillnets

Sl.No	Mid-fork length (cm)	Mesh size (cm)			
		13.5	14.0	14.5	15.0
1	30.5	0	0	0	0
2	32.5	0	0	0	0
3	34.5	0.24	0	0	0
4	36.5	0.72	0	0	0
5	38.5	1.68	0	0	0
6	40.5	5.28	0	0	0
7	42.5	8.39	0.57	0	0
8	44.5	13.7	2.27	0	0
9	46.5	28.5	5.11	2.07	0
10	48.5	14.9	13.6	3.72	0
11	50.5	8.39	36.4	7.44	0.36
12	52.5	7.19	15.3	9.92	5.4
13	54.5	4.08	7.95	18.6	7.55
14	56.5	3.36	5.68	36	8.99
15	58.5	2.4	3.41	10.3	11.9
16	60.5	1.2	2.84	6.2	16.5
17	62.5	0	2.84	1.65	28.8
18	64.5	0	1.7	1.65	9.71
19	66.5	0	1.14	0.83	6.83
20	68.5	0	1.14	1.24	1.8
21	70.5	0	0	0.41	0.36
22	72.5	0	0	0	1.44
23	74.5	0	0	0	0.36
24	76.5	0	0	0	0

Table. 14 Percentage of Length frequency data of *Carangoides fulvoguttatus* caught from drift hand lines

Sl.No	Mid-fork length (cm)	Hook size (cm)			
		No. 5	No. 6	No.7	No.8
1	36.5	0	0	0	0.56
2	40.5	0	0	0.77	0.56
3	44.5	0.99	0.87	0.77	6.74
4	48.5	0.99	1.74	8.46	21.9
5	52.5	4.95	6.96	10.8	20.8
6	56.5	11.9	7.83	12.3	18
7	60.5	6.93	24.3	30.8	14
8	64.5	19.8	29.6	15.4	11.8
9	68.5	23.8	10.4	11.5	5.06
10	72.5	10.9	6.96	6.15	0.56
11	76.5	6.93	6.96	2.31	0
12	80.5	3.96	4.35	0	0
13	84.5	1.98	0	0.77	0
14	88.5	4.95	0	0	0
15	92.5	1.98	0	0	0

Table. 15 Percentage of Length frequency data of *Caranx heberi* caught from drift hand lines

Sl.No	Mid-fork length (cm)	Hook size (cm)			
		No. 5	No. 6	No.7	No.8
1	32.5	0	0	0.73	0.6
2	36.5	0	0	0	2.38
3	40.5	0	0.8	5.11	4.17
4	44.5	0.76	2.4	19	10.7
5	48.5	0.76	5.6	17.5	35.7
6	52.5	5.3	14.4	24.8	20.8
7	56.5	11.4	5.6	10.2	11.9
8	60.5	11.4	13.6	3.65	8.33
9	64.5	2.27	12.8	5.11	2.38
10	68.5	15.2	16.8	4.38	0.6
11	72.5	18.2	12	4.38	1.79
12	76.5	19.7	6.4	2.19	0.6
13	80.5	8.33	4.8	0.73	0
14	84.5	2.27	4	2.19	0
15	88.5	0.76	0.8	0	0
16	92.5	2.27	0	0	0
17	96.5	1.52	0	0	0

Table. 16 Percentage of Length frequency data of *Caranx ignobilis* caught from drift hand lines

Sl.No	Mid-fork length (cm)	Hook size (cm)			
		No. 5	No. 6	No.7	No.8
1	40.5	0	0	0	1.27
2	44.5	0	0	1.37	1.27
3	48.5	0	2.41	2.74	7.59
4	52.5	4.21	2.41	6.85	15.2
5	56.5	6.32	9.64	16.4	11.4
6	60.5	9.47	9.64	16.4	30.4
7	64.5	10.5	10.8	20.5	20.3
8	68.5	10.5	6.02	11	8.86
9	72.5	4.21	6.02	6.85	3.8
10	76.5	3.16	10.8	5.48	0
11	80.5	5.26	22.9	1.37	0
12	84.5	8.42	9.64	5.48	0
13	88.5	17.9	4.82	4.11	0
14	92.5	10.5	3.61	1.37	0
15	96.5	5.26	1.2	0	0
16	100.5	3.16	0	0	0
17	104.5	1.05	0	0	0

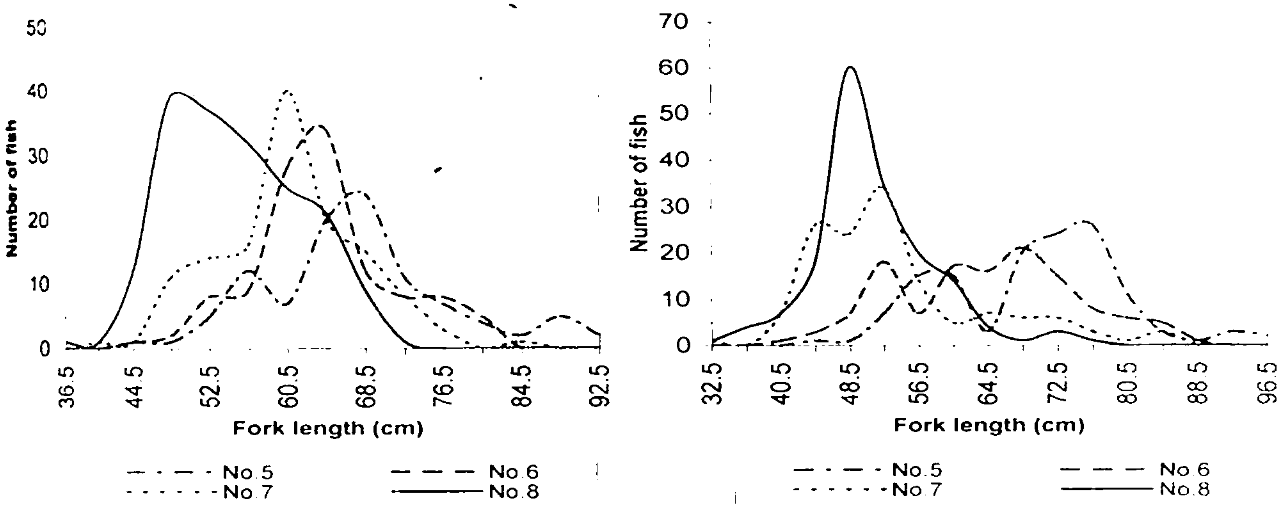
Table. 17 Percentage of Length frequency data of *Scomberoides commersonnianus* caught from drift hand lines

Sl.No	Mid-fork length (cm)	Hook size (cm)			
		No. 5	No. 6	No.7	No.8
1	36.5	0	0	1.9	4.72
2	40.5	0	0	0.95	1.89
3	44.5	1.16	0	3.81	2.83
4	48.5	1.16	5	15.2	8.49
5	52.5	8.14	13.8	16.2	18.9
6	56.5	5.81	11.3	18.1	35.8
7	60.5	16.3	12.5	21.9	17
8	64.5	15.1	18.8	15.2	10.4
9	68.5	11.6	35	6.67	0
10	72.5	23.3	2.5	0	0
11	76.5	12.8	1.25	0	0
12	80.5	3.49	0	0	0
13	84.5	1.16	0	0	0

Fig. 10 Length frequency of carangid fishes caught from drift handlines with different hooks

a) *Carangoides fulvoguttatus*

b) *Caranx heberi*



c) *Caranx ignobilis*

d) *Scomberoides commersonnianus*

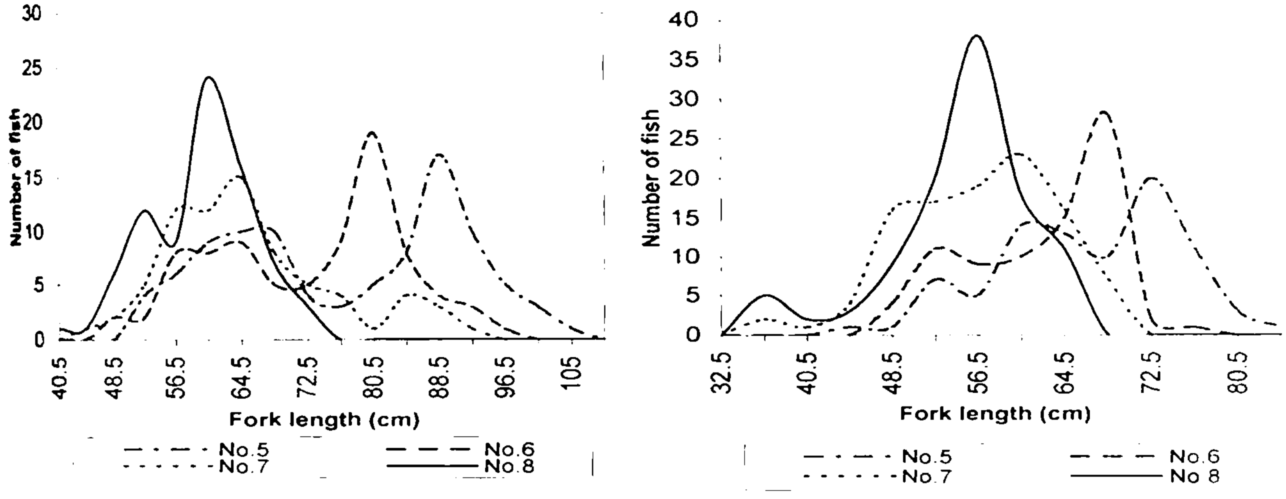


Table. 18 Meshwise minimum, maximum, mean fork lengths of carangid species caught and their total catch

Sl No	Species	Mesh size															Total catch	Gross Total catch	Over all mean
		13.5 cm			Total catch	14 cm			Total catch	14.5 cm			Total catch	15 cm					
		Fork Length (cm)				Fork Length (cm)				Fork Length (cm)				Fork Length (cm)					
		Minimum	Maximum	Mean±SD	(Nos.)	Minimum	Maximum	Mean±SD	(Nos.)	Minimum	Maximum	Mean±SD	(Nos.)	Minimum	Maximum	Mean±SD	(Nos.)		
1	*Carangoides ferdau*	30.8	82.6	51.13±6.08	248	46.8	78.2	56.84±5.98	245	42.5	88.2	68.05±5.59	202	60.5	89	72.37±4.64	211	906	61.39±10.21
2	*Carangoides fulvoguttaus*	21.2	88.2	55.45±9.95	349	23.6	96	62.8±10.34	615	31.2	101.4	73.82±31.88	753	43.2	100.3	78.88±12.2	510	2227	69.05±22.19
3	*Caranx heberi*	17.8	92.7	47.95±8.29	954	20.4	96	53.81±9.8	1143	37.9	91.3	62.16±8.22	716	20.3	91.3	64.2±8.53	651	3464	55.87±10.87
4	*Caranx ignobilis*	30.2	70.5	49.39±8.58	524	37	97	61.11±8.35	555	33.5	105.2	67.95±12.11	607	30.3	105.2	72.83±12.87	900	2586	64.42±14.05
5	*Caranx papuensis*	30.5	68.7	54.78±7	286	39.7	82.7	64.22±6.44	418	46.3	100.6	73.73±8.73	375	49.4	106	75.4±7.69	394	1473	67.8±10.84
6	*Caranx sexfasciatus*	29.4	59.5	40.52±4.89	410	31.5	59.3	42.76±4.85	301	36.5	69.6	50.24±6.65	324	43.1	68.7	55.3±4.23	170	1205	45.83±7.72
7	*Caranx tille*	36.5	84	54.29±7.69	375	41.7	80.5	63.43±6.54	425	58.6	92.4	69.39±4.92	419	64.6	97.4	76.08±5.92	352	1571	65.68±10.01
8	*Scomberoides commersonnianus*	23.5	70	48.73±6.04	297	32	84.8	57.8±7.19	440	51	93	65.11±5.51	336	46	89.6	68.9±6.64	278	1351	59.91±9.68
9	*Scomberoides lysan*	38	70	52.12±5.18	450	43.5	83.3	59.27±7.33	406	44	84	61.56±5.82	327	44	78	64.18±5.8	489	1672	59.23±7.65
10	*Scomberoides tala*	34.3	59.5	45.65±4.59	417	42	67.5	51.75±4.82	176	45.1	69.2	54.82±3.92	242	50.2	74.4	59.91±4.3	278	1113	52.54±6.86

Table. 19 Hookwise minimum, maximum, mean fork lengths of various carangid species and their total catch

Sl.No.	Species	Hook size																Gross	Over all
		No.5			Total	No.6			Total	No.7			Total	No.8			Total		
		Fork Length (cm)			catch	Fork Length (cm)			catch	Fork Length (cm)			catch	Fork Length (cm)			catch	Total catch	mean
		Minimum	Maximum	Mean±SD	(Nos.)	Minimum	Maximum	Mean±SD	(Nos.)	Minimum	Maximum	Mean±SD	(Nos.)	Minimum	Maximum	Mean±SD	(Nos.)		
1	*Carangoides fulvoguttatus*	43.1	92.2	65.96±9.81	101	43.7	80.3	61.99±7.67	115	39.7	83.6	58.91±7.58	130	35.2	71.7	53.38±7	178	524	59.36±9.17
2	*Caranx heberi*	43.7	95.8	67.89±10.42	132	39.5	87.6	62.37±10.42	125	32.2	83.4	51.82±10.31	137	31.5	75.5	49.24±7.12	168	567	57.[illegible]±12.21
3	*Caranx ignobilis*	48.6	103	75.42±14.41	95	45.2	94.7	70.86±11.83	83	42.7	90.4	63.31±10.68	73	39.5	72.1	57.43±6.62	79	330	67.29±13.37
4	*Scomberoides commersonnianus*	43.4	83.7	64.64±8.59	86	45.2	74.7	60.32±6.94	80	35.7	68.4	54.56±7.24	105	33.5	64.3	53.1±5.55	106	377	57.57±8.63

variation with respect to mesh size and hook size. Length distributions showed marginal overlapping for all the four species caught from hand lines with different hook sizes (Fig.10). Similar phenomenon of overlapping of length frequency distribution could be observed for all the species caught from gillnets and was distinct especially in two species such as *Carangoides fulvoguttatus* and *Caranx ignobilis*. Minimum, maximum and mean length of all species caught both from gillnets (Table. 18) and hand lines (Table. 19) showed variation with respect to species, mesh and hook number. The Overall mean length of fish caught from hooks was little higher than gillnets especially for the species of *C. heberi* and *C. ignobilis*. Fish sizes increased with increase in mesh and hook size. Nonetheless, there was no significant ($P>0.05$) change in the quantity of fish caught between meshes (Table. 24) except for the species *C. fulvoguttatus* ($P<0.05$) as well as hooks (Table. 25). However, there significant difference in quantity of catch between size classes in the catches of gillnets and hooks was observed almost in all species except *C. ferdau, C. sexfasciatus*, and *S. tala* caught from gillnets and *S. commersonnianus* caught from both gillnets and hooks. Length frequency distribution of almost all the species caught from gillnets were uni-modal (Fig. 9) except *C. heberi* caught at 15 cm mesh size whereas length frequency distributions of hooks exhibited bi-modal or multi-modal distributions (Fig. 10).

The mean value of gill girth and maximum girth calculated for all the ten species based on mesh size, are presented in Table. 20. The gill girth (47.91 cm) and maximum girth (50.54 cm) were highest for *Caranx papuensis* and smallest gill girth (23.31 cm) and maximum girth (29.05 cm) for *Scomberoides tala*. The net with the mesh size13.5 cm caught *Caranx tille* with maximum gill girth of 35.1 ± 3.45, followed by the net with mesh 14 cm, *Carangoides ferdau* was caught at highest gill girth of 41.97 cm. In the net with mesh of 14.5 cm and 15 cm, *Caranx papuensis* was caught at the highest gill girth of 50.79 cm. Irrespective of species, maximum girth showed positive correlation with gill girth. In all species, maximum girth increased as gill girth increased. Similarly, mean gill girth and maximum gill girth increased

Table. 20 Mean values of various girths of carangid catch obtained from experimental gillnets

S.No.	Species	Mean girths with standard deviation								Over all mean	Over all mean
		Mesh sizes (cm)									
		13.5		14		14.5		15		Gill girth (cm)	Maximum Girth (cm)
		Gill girth	Maximum girth	Gill girth	Maximum girth	Gill girth	Maximum girth	Gill girth	Maximum girth		
1	*Carangoides ferdau*	34.09 ± 5.08	36.32±6.19	41.97±3.64	44.74±4.40	50.42±6.32	52.88±6.14	54.33±1.31	57.25±2.46	42.75±9.45	45.25±9.73
2	*Carangoides fulvoguttaus*	31.12 ± 6.16	32.70±6.71	38.12±7.08	40.32±7.79	43.734±8.57	46.23±9.11	47.41± 6.67	49.87± 7.05	41.52±8.98	43.82±9.59
3	*Caranx heberi*	30.29 ± 5.98	31 65±6.33	34.79±6.31	36.49±6.77	38.15±5.15	39.75±6.31	37.65±5.60	39.53±5.81	34.52±6.84	36.12±7.20
4	*Caranx ignobilis*	31.63 ± 7.21	33.07±7.35	33.44±6.28	42.92 ± 10.13	47.94±12.54	50.31±13.37	52.60±11 08	55.03± 11.97	45.15±12.95	47.31±13.69
5	*Caranx papuensis*	33.38 ± 4.60	35.24±5.21	35.66±5.40	38.27 ±6.70	50.79±7.93	53.63±8.52	59.67±8.51	62.51±8.81	47.91±11.77	50.54±12.38
6	*Caranx sexfasciatus*	27.08 ± 2.54	28.35 ±2.72	28.25±2.89	29.92 ±3.33	30.45±2.95	31.52 ±3.40	35.02±3.66	36.88 ±4.68	29.04±3.88	30.47±4.30
7	*Caranx tille*	35.1± 3.45	37.4±3.50	38.31±4.27	39.75±4.04	42.03±4.04	43.51± 4.45	46.40 ± 5.49	47.86±5.69	40.20±5.67	41.82±5.61
8	*Scomberoides commersonnianus*	24.47 ± .26	30.10 ± 8.71	28.67±5.08	36 35±5.89	32.27±4.60	40.29 ± 4.28	30.80±4.21	38.58± 5.19	29.58±5.69	37 10±6.62
9	*Scomberoides lysan*	22.62 ±2.26	25.3± 2.55	23.72±3.43	29.59 ± 3.65	24.02±2.79	29.92 ± 3.23	22.99 ±1.95	28.37 ±2.32	23.31±2.84	29.05±3.14
10	*Scomberoides tala*	22.28 ±2.93	29.66 ±3.80	23.72±2.43	31 35 ±3.11	25.11±2.15	33 38 ±2.56	27.61±3.81	36 33±2.81	24.54±3.58	32.52±4 10

as mesh size increased except for *Scomberoides commersonnianus* and *S. lysan*. The position of maximum girth varied from species to species owing to their body shape. Difference between the gill girth and maximum girth generally ranged from 1 to 3 cm and was 8 cm in the case of *Scomberoides* spp. Minimum difference of 1cm could be observed in *Caranx sexfasciatus* and *C. tille*.

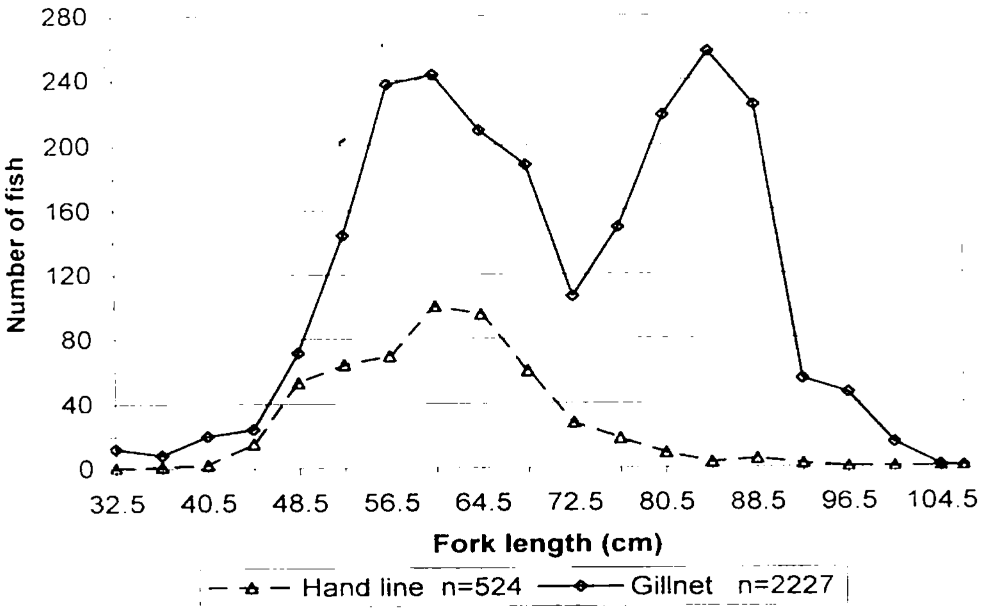
Pooled length frequency distribution of four species viz., *Carangoides fulvoguttatus, Caranx heberi, C. ignobilis* and *Scomberoides commersonnianus* from all meshes and hooks are shown in the Fig. 11. Significant difference could be observed between the pooled length frequency distribution of gillnets and that of hand lines for all four species as evidenced from Kolmogorov-smirnov test (Sigel and Castellan, 1988) (Table. 21).

Dominant size groups of various species caught from gillnets and hooks are presented in Table. 23. In the pooled catch data, the dominant size groups varied with respect to mesh size as well as hook size. In the pooled catch data, *Caranx papuensis* showed peak at two length groups viz., 66.6 - 68.5 cm and 74.6 - 76.5 cm. It coincided with the dominant size class caught from mesh sizes of 14 and 14.5 cm. The size group 80.6 - 82.5 cm was dominant in *Carangoides fulvoguttatus*. It was similar with dominant size caught from the mesh size 14.5 cm. *Caranx tille* dominated in the length group of 68.6 - 70.5 cm and coincided with dominant size class of 14.5 cm mesh. The size group 64.6 - 66.5 cm dominated in the case of *C. ignobilis* and coincided with mesh of 14 cm. *Scomberoides commersonnianus* dominated in the size group of 62.6 - 64.5 in the mesh size of 14.5 cm. The size group of 60.6 - 62.5 of *S. lysan* dominated in 14.5 cm mesh. 54.6 - 56.5 cm dominated in the species of *Carangoides ferdau* from mesh size of 14 cm, *Caranx heberi* and *S. tala* from 14.5 cm mesh and 36.6 - 38.5 cm of *C. sexfasciatus* dominated in the mesh size of 13.5 cm.

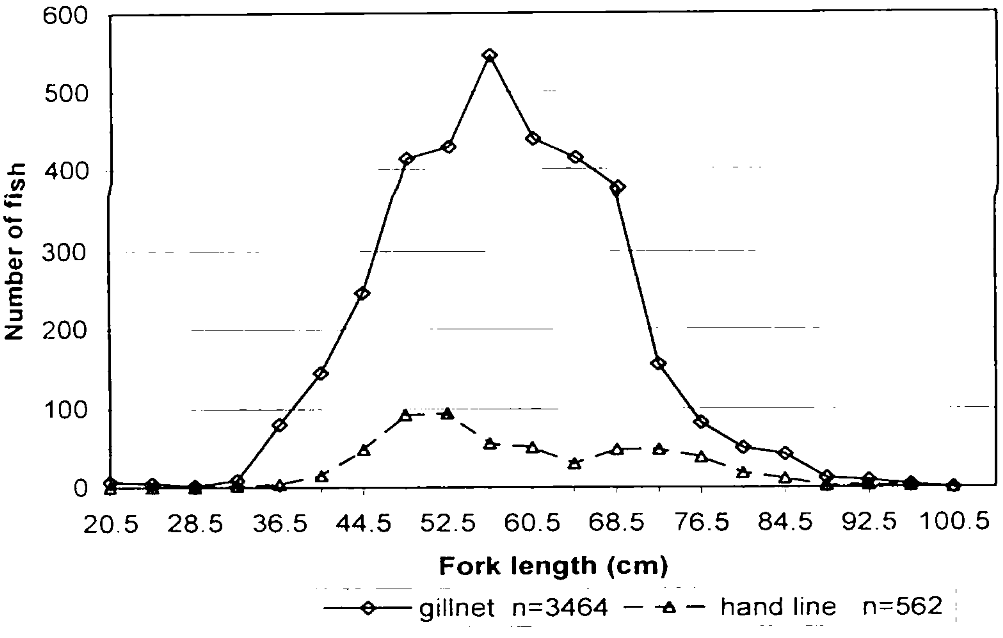
In the hand lines catch the dominant size group was 56.6 - 60.5 cm for two species namely, *Carangoides fulvoguttatus* and *Caranx ignobilis*. The size group of 52.6 - 56.5 cm of *Scomberoides commersonnianus* dominated the fishery. In the case of *C. heberi* the dominant size group was 48.6 - 52.5 cm. The maximum length of fish irrespective of species was high in gillnets than that of hook and lines.

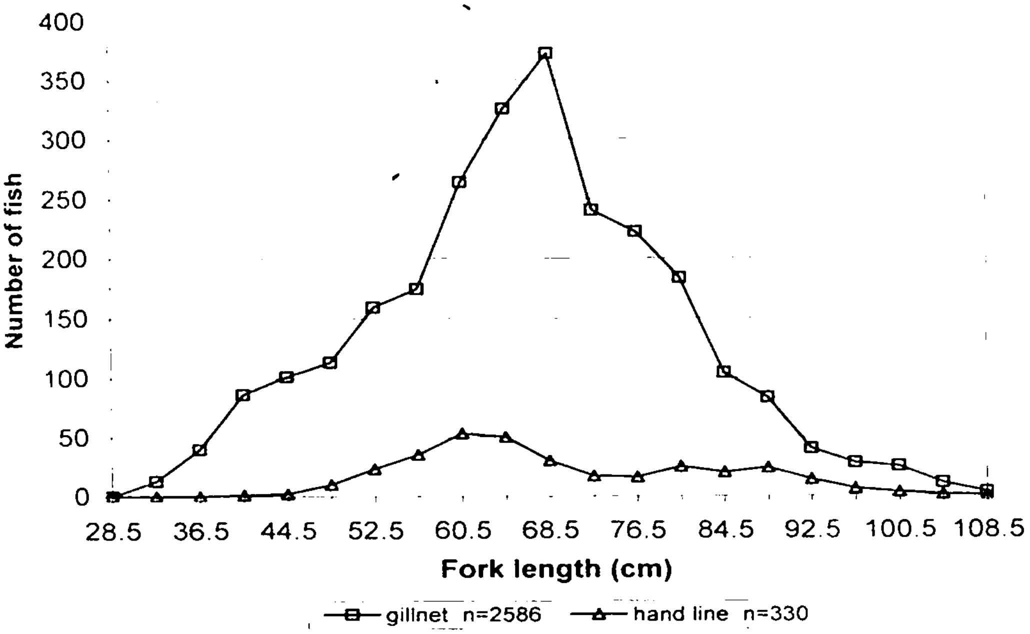
Fig. 11 **Pooled length frequency of carangid fishes caught from both gillnets and hand lines**

a) *Carangoides fulvoguttatus*

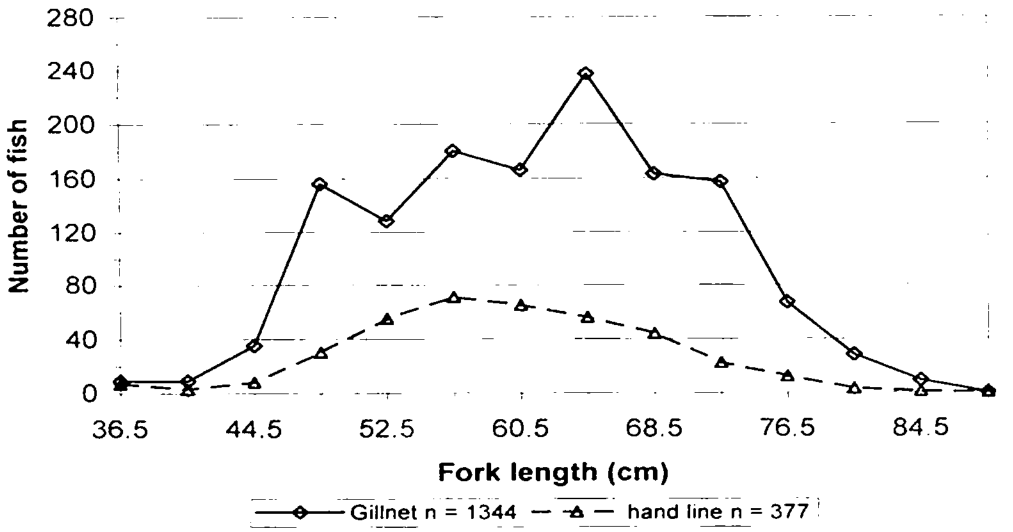


b) *Caranx heberi*





c) *Caranx ignobilis*



d) *Scomberoides commersonnianus*

ble. 21 Kolomogorov-Smirnov two sample - Two tailed test for pooled catch size frequency distributions obtained from Gillnets and hand line hooks

o.	Species	Size range (cm)	Total fish observed from gillnets (m)	Total fish observed from handlines (n)	D(max) value for m,n	Critical value of D(m,n) 0.05	0.01
1	*Carangoides fulvoguttaus*	32.5-104.5	2227	524	**0.3627	0.066	0.0791
2	*Caranx heberi*	20.5-96.5	3464	562	**0.1146	0.0619	0.0741
3	*Caranx ignobilis*	32.5-108.5	2586	330	**0.0974	0.0795	0.0953
4	*Scomberoides commersonnianus*	36.5-84.5	1351	377	**0.1258	0.0793	0.095

** significant at P<0.01

Table. 22 Percentage of capture pattern of carangids species from various gillnets

Sl.No.	Species	Numbers caught	Percentage of pattern of capture Gilling	Wedging	*entangling
1	*Carangoides ferdau*	906	81.4	17.3	1.3
2	*Carangoides fulvoguttaus*	2227	7.9	89.7	2.4
3	*Caranx heberi*	3464	61.3	7.4	31.3
4	*Caranx ignobilis*	2586	45	11.7	43.3
5	*Caranx papuensis*	1473	39.1	2.5	58.4
6	*Caranx sexfasciatus*	1205	38.4	39.1	22.5
7	*Caranx tille*	1571	75.9	22.3	1.8
8	*Scomberoides commersonnianus*	1351	12.2	85.7	2.1
9	*Scomberoides lysan*	1672	8.4	58.2	33.4
10	*Scomberoides tala*	1113	14.1	50.3	35.6

*: Includes snagging

Table. 23 Dominant size group of various carangid species caught under different mesh and hook sizes

S.No.	Species	Size groups																			
		Mesh size (cm)								Over all mesh combined		Hook size								Over all hooks combined	
		13.5	Numbers caught	14	Numbers caught	14.5	Numbers caught	15	Numbers caught	size group	Total Nos. caught	No.5	Numbers caught	No.6	Numbers caught	No.7	Numbers caught	No.8	Numbers caught	size group	Total Nos. caught
1	*Carangoides ferdau*	48.6-50.5	67	54.6-56.5	76	68.6-70.5	49	70.6-72.5	57	54.6-56.5	90										
2	*Carangoides fulvoguttaus*	56.6-58.5	54	64.6-66.5	85	80.6-82.5	107	84.6-86.5	102	80.6-82.5	162	64.6-68.5	24	50.6-64.5	34	56.6-60.5	40	44.6-48.5	39	56.6-60.5	100
3	*Caranx heberi*	44.6-46.5	128	52.6-54.5	139	62.6-64.5	114	66.6-68.5	121	54.6-56.5	274	72.6-76.5	26	64.5-68.5	21	48.6-52.5	34	44.6-48.5	60	48.5-52.5	94
4	*Caranx ignobilis*	50.6-52.5	59	64.6-66.5	102	66.6-68.5	70	74.6-76.5	77	64.6-66.5	214	84.6-88.5	17	76.6-80.5	19	60.6-64.5	15	56.6-60.5	24	56.5-60.5	53
5	*Caranx papuensis*	56.6-58.5	73	66.6-68.5	98	72.6-74.5	81	74.6-76.6	87	66.6-68.5 74.6-76.5	147 147										
6	*Caranx sexfasciatus*	36.6-38.5	121	42.6-44.5	83	48.6-50.5	74	54.6-56.5	60	36.6-38.5	154										
7	*Caranx tille*	50.6-52.5	75	58.6-60.5	84	68.6-70.5	110	74.6-76.5	80	68.6-70.5	176										
8	*Scomberoides commersonnianus*	46.6-48.5	112	54.6-56.5	92	62.6-64.5	80	70.6-72.5	62	62.6-64.5	130	68.6-72.5	20	54.6-68.5	28	56.6-60.5	23	52.6-56.5	38	52.5-56.5	71
9	*Scomberoides lysan*	48.6-50.5	124	56.6-58.5	93	60.6-62.5	83	68.6-70.5	75	60.6-62.5	203										
10	*Scomberoides tala*	44.6-46.5	119	48.6-50.5	64	54.6-56.5	87	60.6-62.5	80	54.6-56.5	136										

Table. 24 Analysis of Variance between mesh sizes and size classes of various carangid species caught in the experimental drift gillnets

NS : Not Significant

** significant difference at 99% (P<0.01)

* significant difference at 95% (P<0.05)

Carangoides ferdau						*F crit*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	6456.354839	30	215.211828	1.168999	0.2817238	1.585938492	1.91553795	NS
Between meshes	53.06451613	3	'17.688172	0.09608	0.9620153	2.705839108	4.006949439	NS
Error	16568.93548	90	184.099283					
Total	23078.35484	123						

Carangoides fulvoguttatus						*F crit*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	26315.49405	41	641.841318	**2.492701	6.029E-05	1.488184	1.751203627	**
Between meshes	2077.446429	3	692.482143	*2.689373	0.0493033	2.678306	3.944904847	*
Error	31671.05357	123	257.48824					
Total	60063.99405	167						

Caranx heberi						*F crit*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	84038.4359	38	2211.53779	3.805351	1.899E-08	1.510147	1.787725523	**
Between meshes	3928.153846	3	1309.38462	2.253033	0.0859954	2.684203	3.958177786	NS
Error	66252.84615	114	581.165317					
Total	154219.4359	155						

Caranx ignobilis						*F crit*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	28222.57692	38	742.699393	2.205561	0.0007064	1.510146674	1.787726	**
Between meshes	2287.205128	3	762.401709	2.26407	0.0848141	2.684203082	3.958178	NS
Error	38388.29487	114	336.739429					
Total	68898.07692	155						

Caranx papuensis						*F crit*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	19137.98077	38	503.631073	2.058039	0.0018375	1.510146674	1.787726	**
Between meshes	255.0961538	3	85.0320513	0.347475	0.7910376	2.684203082	3.958178	NS
Error	27897.40385	114	244.714069					
Total	47290.48077	155						

Caranx sexfasciatus						*F crit*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	11495.7381	20	574.786905	1.317255	0.2041285	1.747984868	2.197808158	**NS**
Between meshes	1408.130952	3	469.376984	1.075684	0.366272	2.75807821	4.125894293	**NS**
Error	26181.11905	60	436.351984					
Total	39084.9881	83						

Caranx tille (Kumuli)						*F crit*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	18541.4697	32	579.420928	1.720308	0.0228864	1.564048446	1.878348	*
Between meshes	112.2651515	3	37.4217172	0.111106	0.9534215	2.699394486	3.992398	**NS**
Error	32333.98485	96	336.812342					
Total	50987.7197	131						

Scomberioides commersonnianus					F critical value			Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	14779.4697	32	461.858428	1.483146	0.0735356	1.564048446	1.878348144	**NS**
Between meshes	475.4166667	3	158.472222	0.508895	0.6770831	2.699394486	3.992397524	**NS**
Error	29894.83333	96	311.404514					
Total	45149.7197	131						

Scomberoides lysan						*F crit*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	28644.42857	27	1060.90476	2.846463	0.0001569	1.62378555	1.980368	**
Between meshes	517.5	3	172.5	0.462826	0.7090179	2.717342795	4.033041	**NS**
Error	30189.5	81	372.709877					
Total	59351.42857	111						

Scomberoides tala						*F crit*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	12986.90625	23	564.648098	1.391568	0.1475969	1.686895956	2.089961981	**NS**
Between meshes	1292.53125	3	430.84375	1.061809	0.3710648	2.737493787	4.078856364	**NS**
Error	27997.71875	69	405.76404					
Total	42277.15625	95						

Table. 25 Analysis of Variance between hook sizes and size classes of various carangid species caught in the experimental drift hand line

NS Not Significant
** significant difference at 99% (P<0.01)
* significant difference at 95% (P<0.05)

Carangoides fulvoguttatus						*F critic*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	4360.73333	14	311.48095	4.805	3.6697E-05	1.93500682	2.53868393	**
Between hooks	224.4	3	74.8	1.154	0.33864785	2.82705059	4.28525482	NS
Error	2722.6	42	64.82381					
Total	7307.73333	59						

Caranx heberi						*F critic*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	3547.98529	16	221.74908	2.378	0.01062995	1.85916704	2.39850806	*
Between hooks	63.5882353	3	21.196078	0.227	0.87692585	2.79806045	4.21795221	NS
Error	4475.66176	48	93.242953					
Total	8087.23529	67						

Caranx ignobilis						*F critic*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	1011.52941	16	63.220588	3.489	0.00040292	1.85916704	2.39850806	**
Between hooks	15.2352941	3	5.0784314	0.28	0.83937021	2.79806045	4.21795221	NS
Error	869.764706	48	18.120098					
Total	1896.52941	67						

Scomberoides commersonnianus						*F critic*		Level of Significance
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	0.05%	0.01%	
Between size classes	754.5	12	62.875	0.743	0.70084695	2.03270289	2.72315503	NS
Between hooks	40.3653846	3	13.455128	0.159	0.92312995	2.86626545	4.37711378	NS
Error	3044.88462	36	84.580128					
Total	3839.75	51						

ble. 26 Analysis of Variance between species mesh/hook sizes and species caught in the experimental gears

NS Not Significant
** significant difference at 99% (P<0.01)
* significant difference at 95% (P<0.05)

ANOVA Test between species and mesh sizes						F crit		Level of Significance
urce of Variation	SS	df	MS	F	P-value	0.05%	0.01%	
etween species	1183026.9	9	131447.433	5.6705586	0.00020444	2.2501325	3.1493812	**
ween mesh sizes	15051	3	5017	0.2164302	0.88413289	2.9603484	4.60090632	NS
Error	625878.5	27	23180.6852					
Total	1823956.4	39						

ANOVA Test between species and hook sizes						F crit		Level of Significance
urce of Variation	SS	df	MS	F	P-value	0.05%	0.01%	
etween species	9434.1875	3	3144.72917	10.439657	0.00274281	3.8625387	6.99196789	**
tween hook sizes	2519.6875	3	839.895833	2.7882288	0.10176764	3.8625387	6.99196789	NS
Error	2711.0625	9	301.229167					
Total	14664.9375	15						

4.3 Capture Pattern and Catch Rate

In the present study carangid species were caught in multiple process such as gilling, wedging and entangling as evidenced from multiple modes of the length frequency distribution curves. Percentage of fish caught in various pattern is given in Table. 22. Length compositions of fish caught by various pattern of capture were different. Wedging was the common pattern of capture in the species of *Carangoides fulvoguttatus*, *S. commersonnianus* and *S. tala* while gilling was common process in the species of *Carangoides ferdau*, *Caranx heberi*, and C. tille. Entangling mainly by snagging i.e., captured at head in larger fishes was common in larger specimens viz., *C. ignobilis*, and *C. papuensis* while tangling of smaller sized fish in fins was noticed in the catch of *Caranx heberi*, *C. sexfasciatus*, *S. lysan* and *S. tala*.

The catch rate was highest for the net with mesh size of 14 cm and for hand lines with hook No.8. There was no significant difference in quantity of catch between the four meshes and hooks tested. However, the species showed significant ($P<0.01$) variation in catch under each hook size and mesh size (Table. 26). In the hand lines unlike gillnets, catch rate decreased with increase in hook size for three species. In the case of *C. ignobilis*, it was reverse.

4.4 Morphometric Relationship

Total length and Fork length and vice-versa relations for all ten species were worked out by simple linear regression model and presented in the Fig. 12 to 21 along with R^2 value. There was significant positive correlation ($r = >0.9$) found between both the lengths in all the species.

Girth-length relationships showed good fit for the all girth and length data (Fig.22 to 31). The other regression parameters such as, Standard error (SE), Confidence Interval (CI), p-values, students' t-statistic, 'r' and R^2 value were also estimated for all the species studied are presented in the Table. 27. High correlation value above 0.9 between girth and length showed good correlation in all the species and significant relationship ($P<0.01$) was found in all the species.

Fig. 12 Length - Length relationship of *Carangoides ferdau*

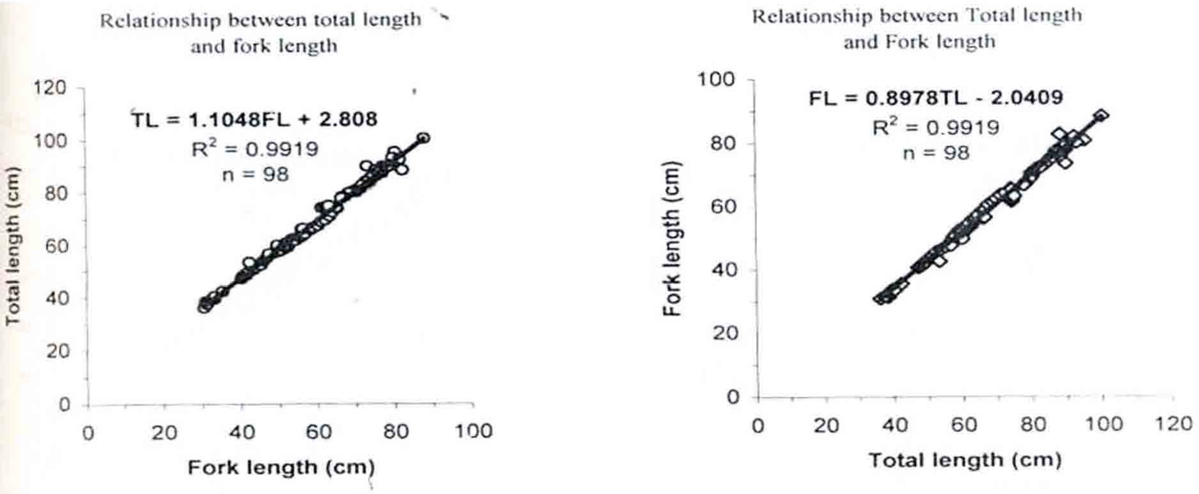


Fig. 13 Length - Length relationship of *Carangoides fulvoguttatus*

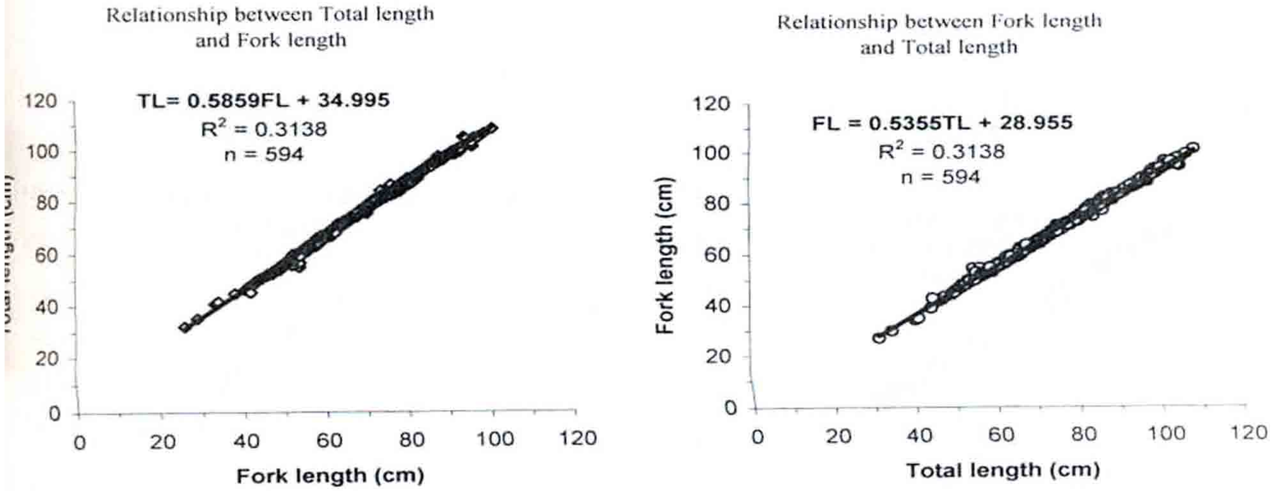


Fig. 14 Length - Length relationship of *Caranx heberi*

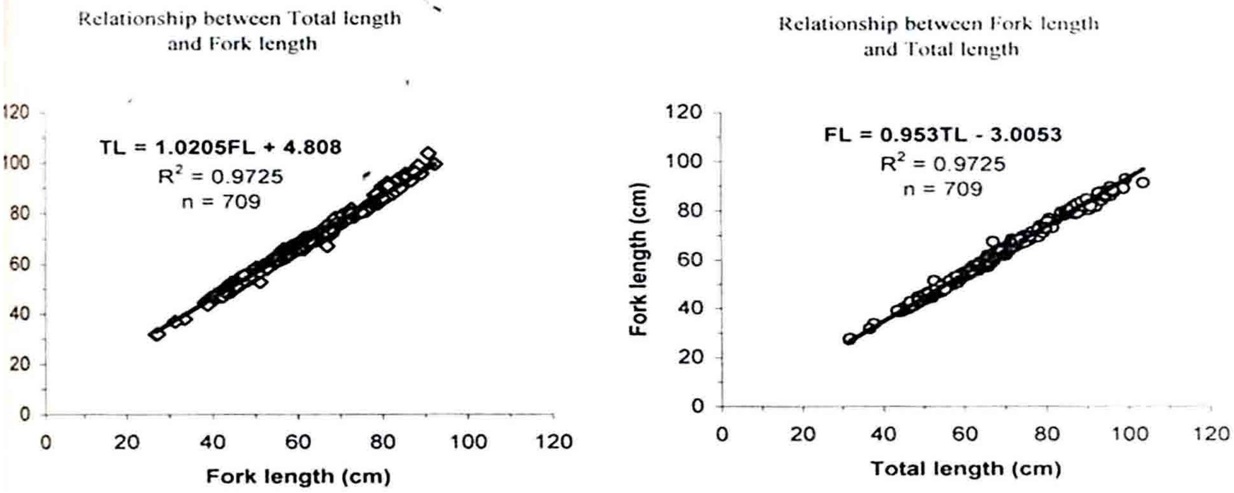


Fig. 15 Length - Length relationship of *Caranx ignobilis*

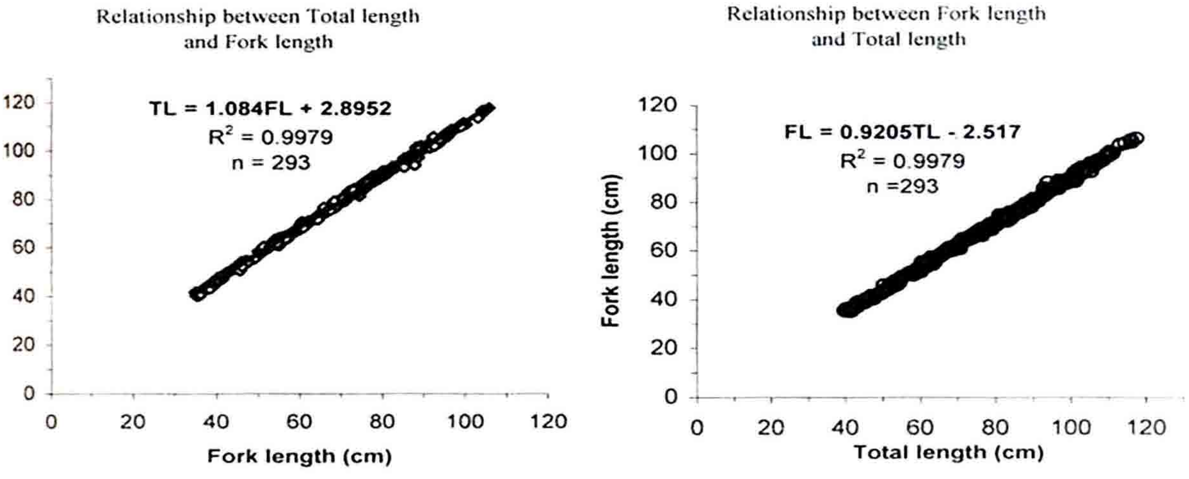
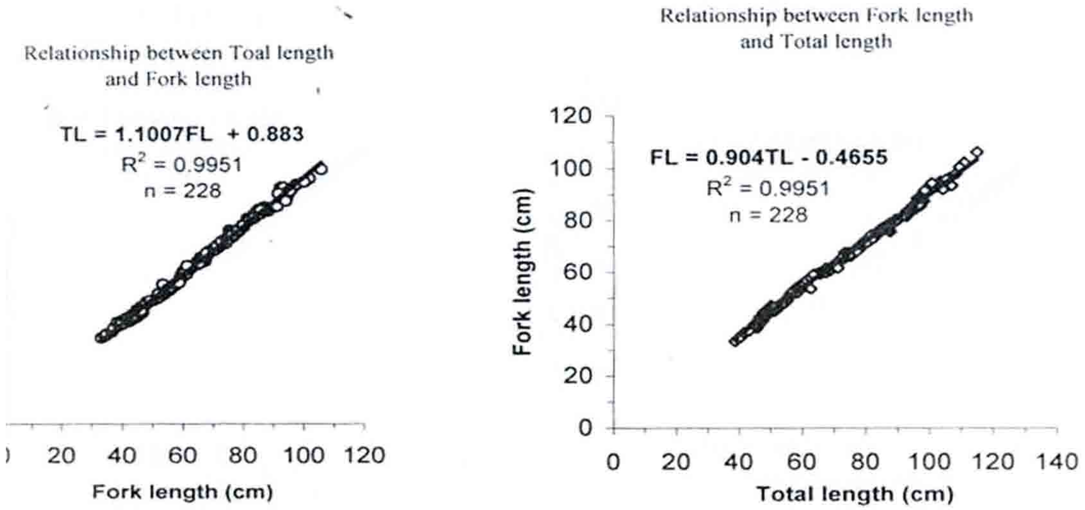


Fig. 16 Length - Length relationship of *Caranx Papuensis*



ig. 17 Length - Length relationship of *Caranx sexfasciatus*

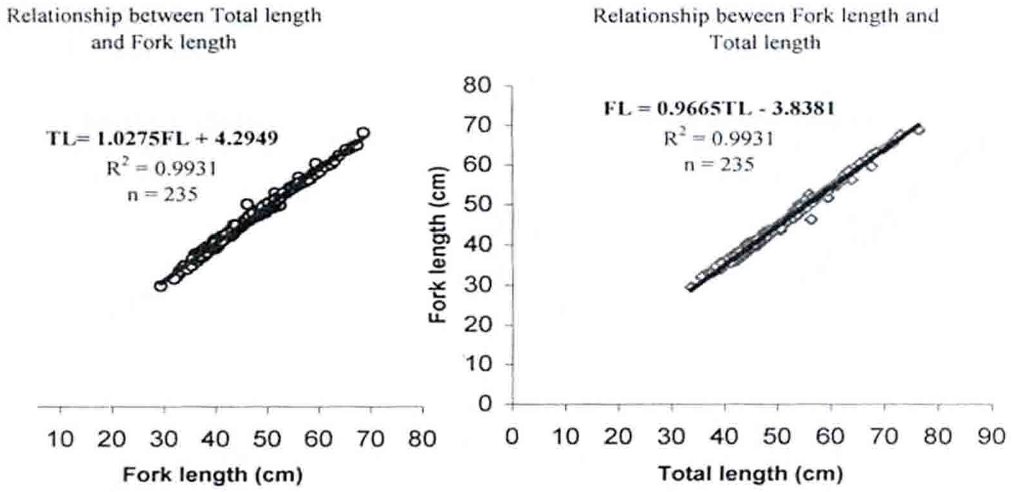
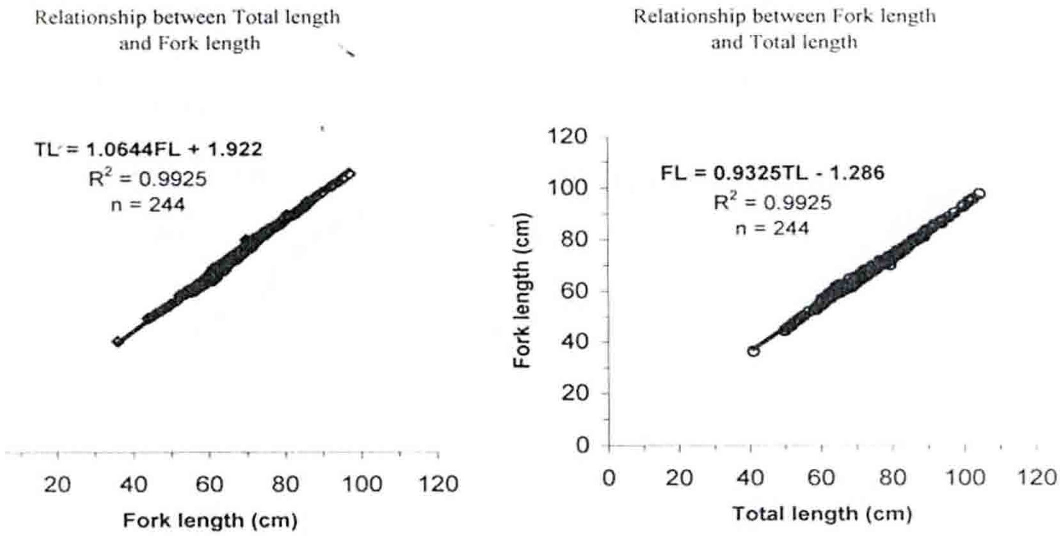


Fig. 18 Length - Length relationship of *Caranx tille*



Length - Length relationship of *Scomberoides commersonnianus*

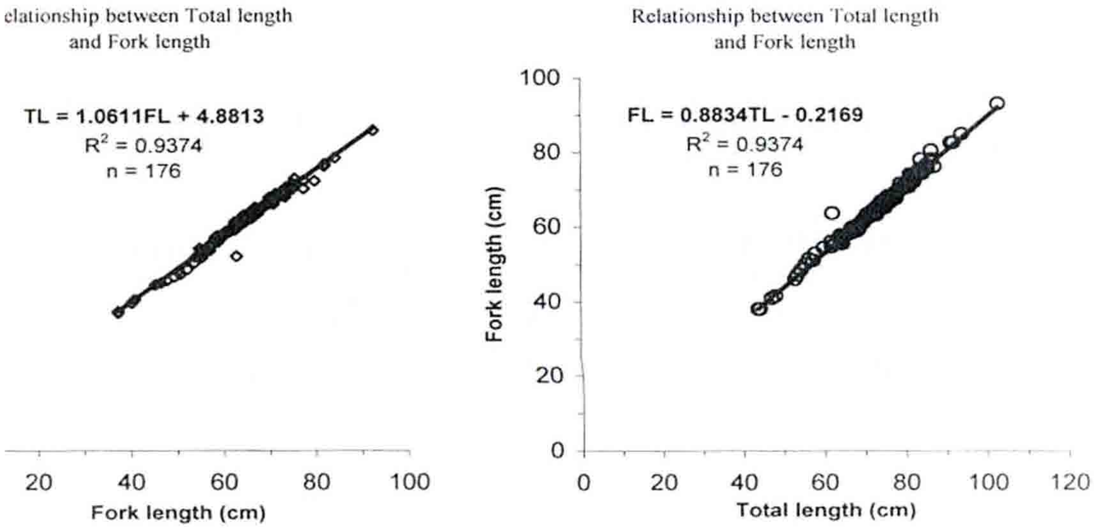
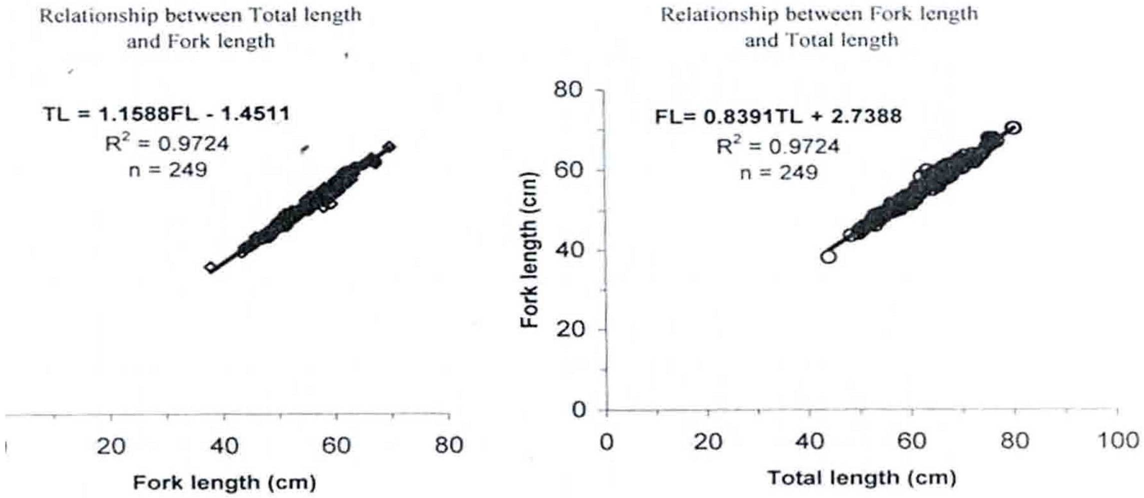
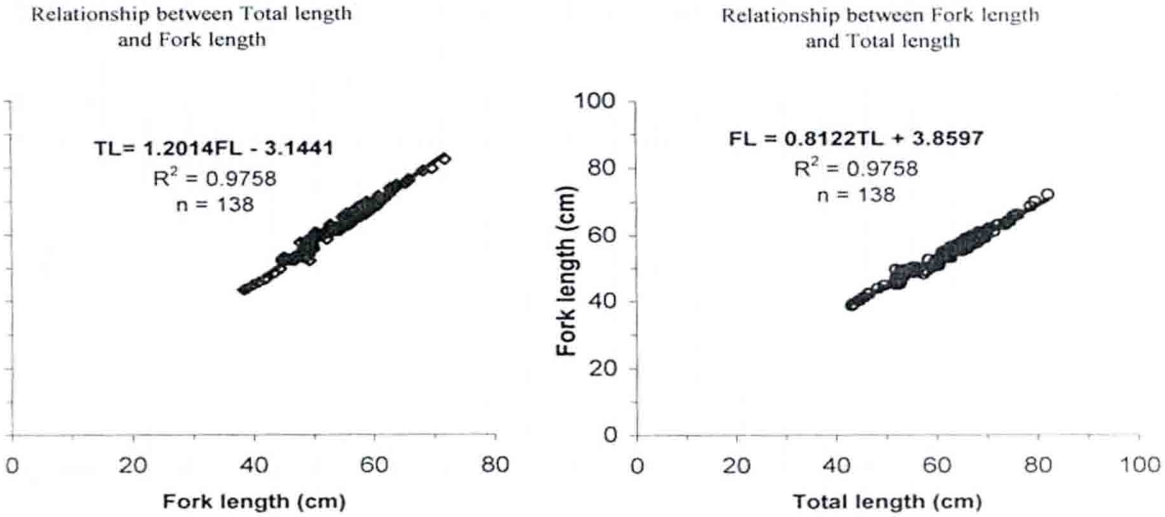


Fig. 20 Length - Length relationship of *Scomberoides lysan*


Relationship between Total length and Fork length

Relationship between Fork length and Total length

Fig. 21 Length - Length relationship of *Scomberoides tala*


Relationship between Total length and Fork length

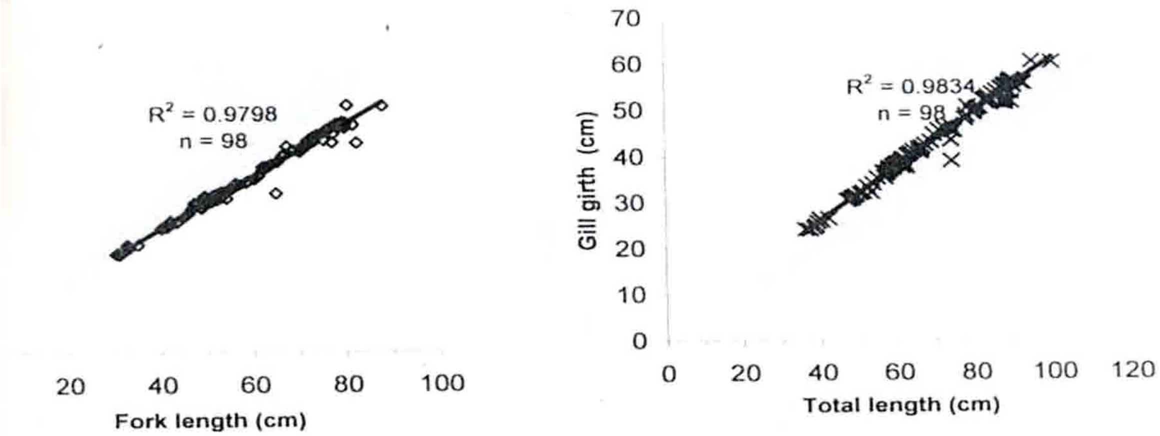
Relationship between Fork length and Total length

Table. 27 Regression statistics of different lengths and girths of various carangid species

S.No.	Name of the Species	Number of Observation	Type of Regression	Regression parameters		Known length	SE	r	R-square	't' statistic	Confidence Limit(95%)	
				'a'	'b'						LCL	UCL
1	*Carangoides ferdau*	98										
			Gc vs FL	4.38534457	0.6451847	FL	1.35	0.98985	0.97980373	68.2448025	0.62641866	0.663950672
			Gc vs TL	2.83467301	0.5826783	TL	1.2246	0.99166	0.98338162	75.3706575	0.56733269	0.598023893
			MaxG vs FL	5.92812836	0.6611605	FL	1.6969	0.98485	0.96992242	55.6394302	0.63757302	0.68474799
			MaxG vs TL	4.21727347	0.598884	TL	1.4088	0.98958	0.97926902	67.3405593	0.58123081	0.616537202
2	*Carangoides fulvoguttatus*	594										
			Gc vs FL	1.61733816	0.5810403	FL	1.2247	0.9898	0.97970677	169.057054	0.57429019	0.587790395
			Gc vs TL	-0.0591532	0.5554946	TL	1.2246	0.9898	0.97971208	169.079626	0.54904215	0.561947089
			MaxG vs FL	1.66319228	0.6144296	FL	1.7724	0.98115	0.96265402	123.530449	0.60466097	0.62419831
			MaxG vs TL	-0.117667	0.587522	TL	1.7641	0.98133	0.96300678	124.140784	0.57822707	0.596816968
3	*Caranx heberi*	709										
			Gc vs FL	4.20080418	0.5574455	FL	1.5905	0.96934	0.93962158	104.892717	0.54701151	0.567879452
			Gc vs TL	1.42751181	0.5480278	TL	1.5825	0.96965	0.94022518	105.454839	0.5378248	0.558230831
			MaxG vs FL	4.38931252	0.5827458	FL	2.0156	0.95589	0.91371717	86.5273499	0.56952312	0.595968405
			MaxG vs TL	1.52192003	0.5724003	TL	2.0273	0.95536	0.91270778	85.9780936	0.55932944	0.585471184
4	*Caranx ignobilis*	293										
			Gc vs FL	1.715658	0.692302	FL	2.513	0.97965	0.959711	83.257501	0.6759353	0.70866744
			Gc vs TL	-0.066057	0.637783	TL	2.5297	0.97937	0.9591739	82.684875	0.6226022	0.6529646
			MaxG vs FL	0.1694562	0.747299	FL	2.7725	0.97877	0.9579896	81.460769	0.7292434	0.76535394
			MaxG vs TL	-1.724219	0.688072	TL	2.8243	0.97796	0.9564056	79.900992	0.6711235	0.70502125

			Gc vs TL	0.3217282	0.633005	TL	1.578	0.99098	0.9820351	111.149	0.6217825	0.64422703
			MaxG vs FL	0.9444496	0.734062	FL	1.8787	0.98846	0.9770601	98.111421	0.7193188	0.74880531
			MaxG vs TL	0.544303	0.664401	TL	1.9798	0.98718	0.9745247	92.980396	0.6503207	0.67848171
6	*Caranx sexfasciatus*	235										
			Gc vs FL	7.831788	0.469252	FL	0.9532	0.96944	0.9398219	60.322815	0.4539256	0.48457801
			Gc vs TL	5.991004	0.454325	TL	0.9789	0.96775	0.9365409	58.640051	0.4390603	0.46958921
			MaxG vs FL	6.8720822	0.522076	FL	0.9936	0.97303	0.946785	64.385268	0.5061	0.53805119
			MaxG vs FL	4.9320362	0.50334	TL	1.0935	0.96724	0.9355524	58.157896	0.4862887	0.5203917
7	*Caranx tille*	244										
			Gc vs FL	2.2174055	0.560205	FL	1.296	0.97365	0.9479921	66.41644	0.5435902	0.57681997
			Gc vs TL	1.4971269	0.522375	TL	1.3815	0.97	0.9409072	62.07457	0.5057988	0.53895188
			MaxG vs FL	4.9884001	0.543194	FL	1.6789	0.95436	0.910809	49.711941	0.5216702	0.56471787
			MaxG vs TL	4.5563302	0.502918	TL	1.8542	0.94404	0.8912159	44.526275	0.4806694	0.52516701
8	*Scomberoides commersonnianus*	176										
			Gc vs FL	3.8200491	0.412247	FL	1.5263	0.92024	0.8468419	31.017435	0.3860147	0.43847852
			Gc vs TL	2.438353	0.382362	TL	1.5162	0.92135	0.8488769	31.26306	0.3582228	0.4065011
			MaxG vs FL	3.6825243	0.531481	FL	1.5077	0.9508	0.904016	40.482111	0.5055684	0.55739264
			MaxG vs TL	2.0988832	0.490286	TL	1.5663	0.94679	0.8964117	38.803684	0.4653483	0.51522362
9	*Scomberoides lysan*	249										
			Gc vs FL	0.9232314	0.397844	FL	0.8246	0.93662	0.8772602	42.016507	0.3791945	0.41649414
			Gc vs TL	1.7971578	0.337299	TL	0.846	0.93317	0.8708031	40.802091	0.3210165	0.35358091
			MaxG vs FL	4.1209558	0.442405	FL	0.9461	0.93292	0.8703481	40.719792	0.421006	0.46380423
			MaxG vs TL	5.1733661	0.373788	TL	0.9901	0.92629	0.8580078	38.63331	0.3547311	0.39284423
10	*Scomberoides tala*	138										
			Gc vs FL	-0.157741	0.468193	FL	1.1494	0.93858	0.8809261	31.71983	0.4390039	0.49738258
			Gc vs TL	1.5222926	0.382314	TL	1.206	0.93216	0.8689272	30.026508	0.3571345	0.40749323
			MaxG vs FL	-0.416744	0.625551	FL	1.3067	0.95439	0.9108676	37.280291	0.5923682	0.65873377
			MaxG vs TL	2.0462853	0.507264	TL	1.4775	0.9413	0.8860376	32.517323	0.4764145	0.53811361

Fig. 22 Lengths-Girths relationship of *Carangoides ferdau*



a) Relationship between Gill girth and Fork length

b) Relationship between Gill girth and Total length

Relationship between Maximum girth and Fork length

d) Relationship between Maximum girth and Total length

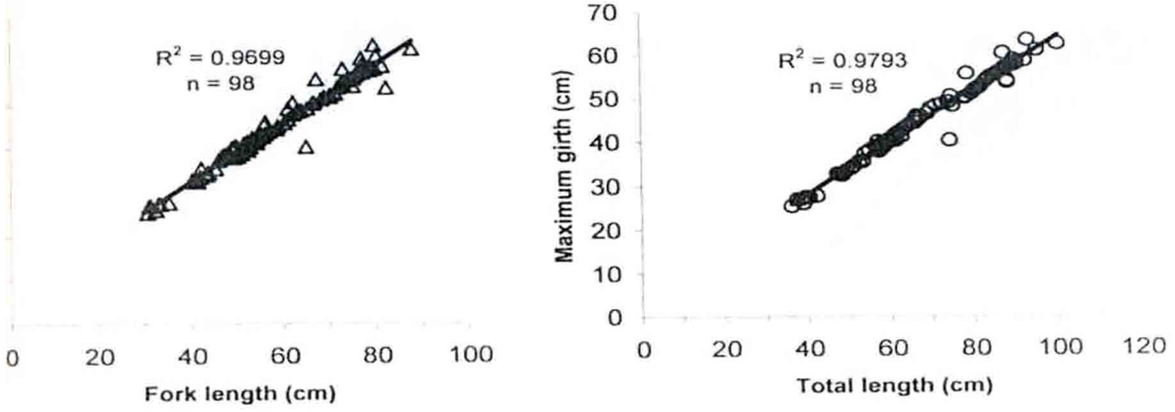
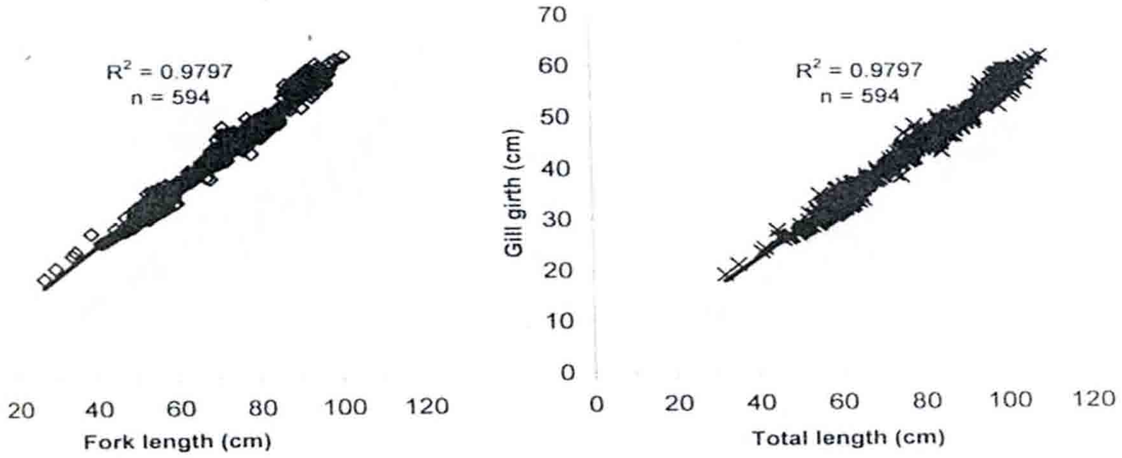
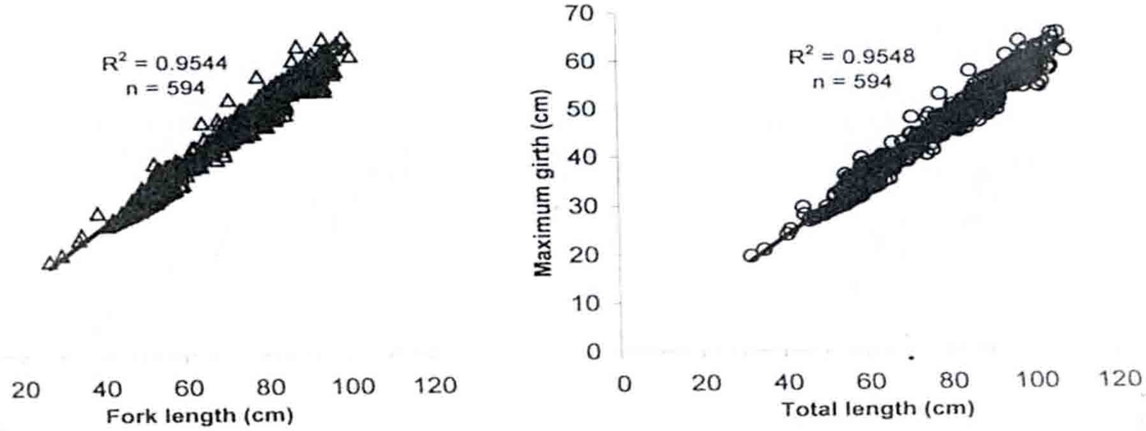


Fig. 23 Lengths-Girths relationship of *Carangoides fulvoguttatus*

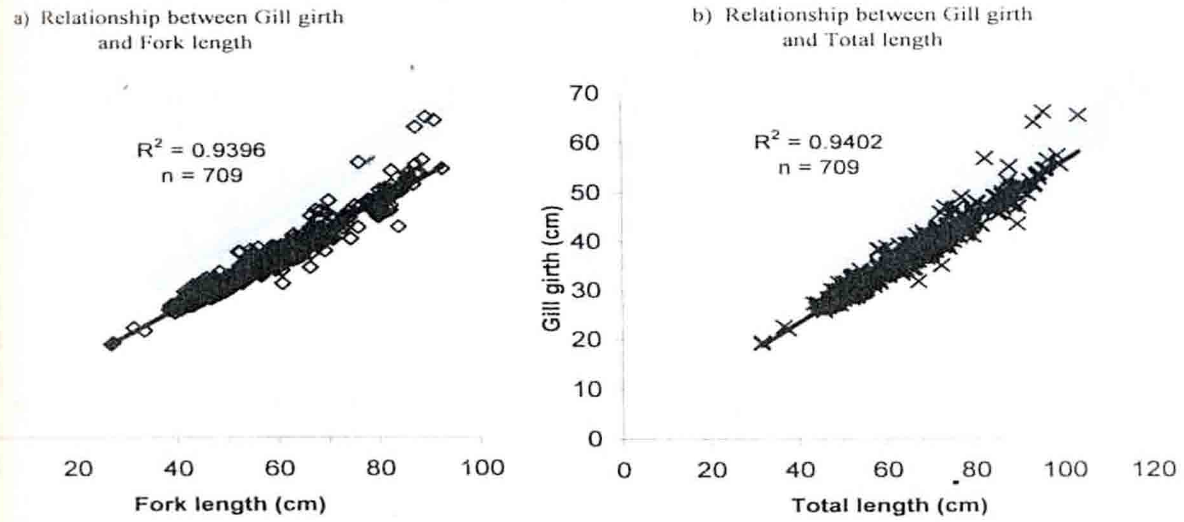

a) Relationship between Gill girth and Fork length

b) Relationship between Gill girth and Total length


c) Relationship between Maximum girth and Fork length

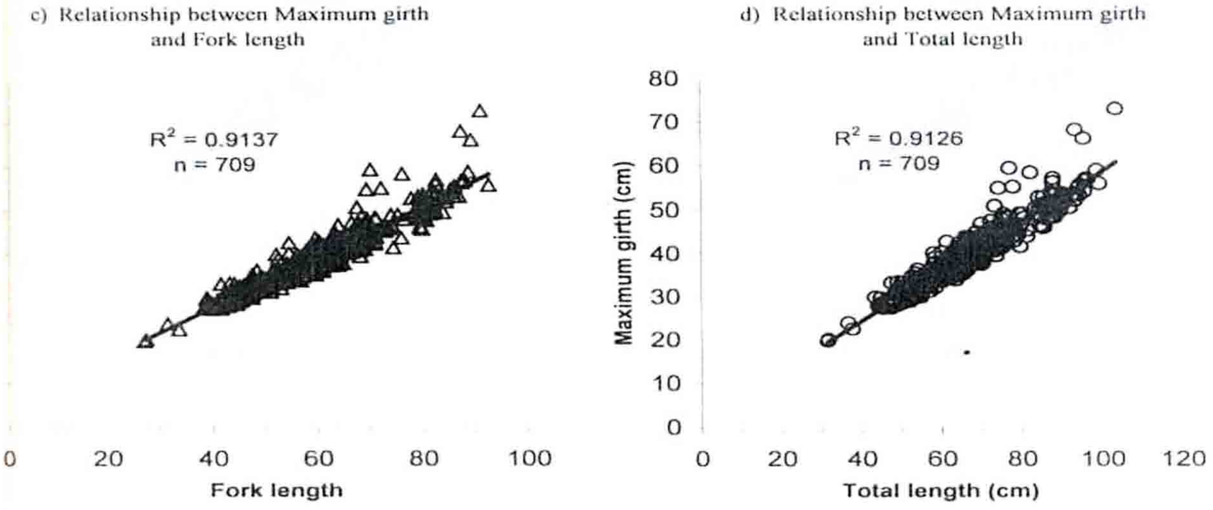
d) Relationship between Maximum girth and Total length

Fig. 24 Lengths-Girths relationship of *Caranx heberi*



a) Relationship between Gill girth and Fork length

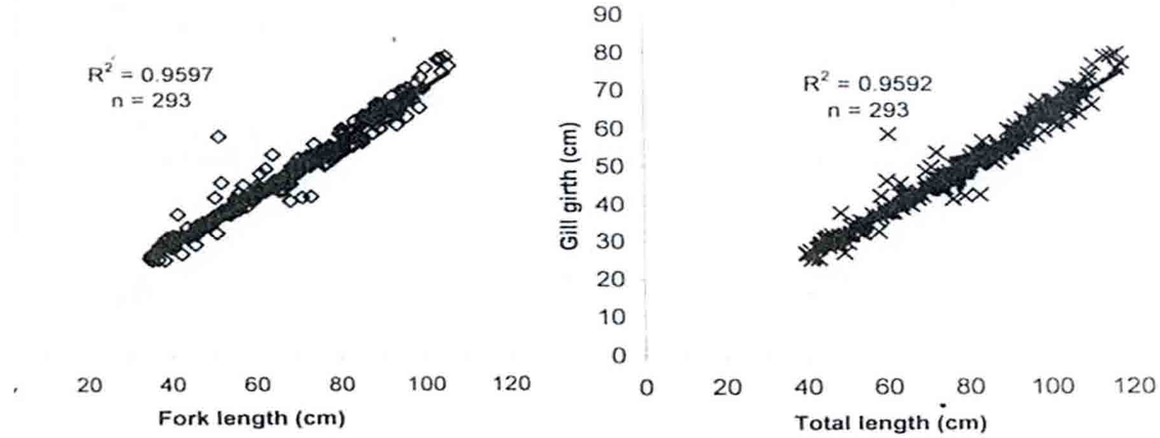
b) Relationship between Gill girth and Total length



c) Relationship between Maximum girth and Fork length

d) Relationship between Maximum girth and Total length

Fig. 25 Lengths-Girths relationship of *Caranx ignobilis*


a) Relaationship between Gill girth and Fork length

b) Relationship between Gill girth and Total length

Relationship between Maximum girth and Fork length

d) Relationship between Maximum girth and Total length

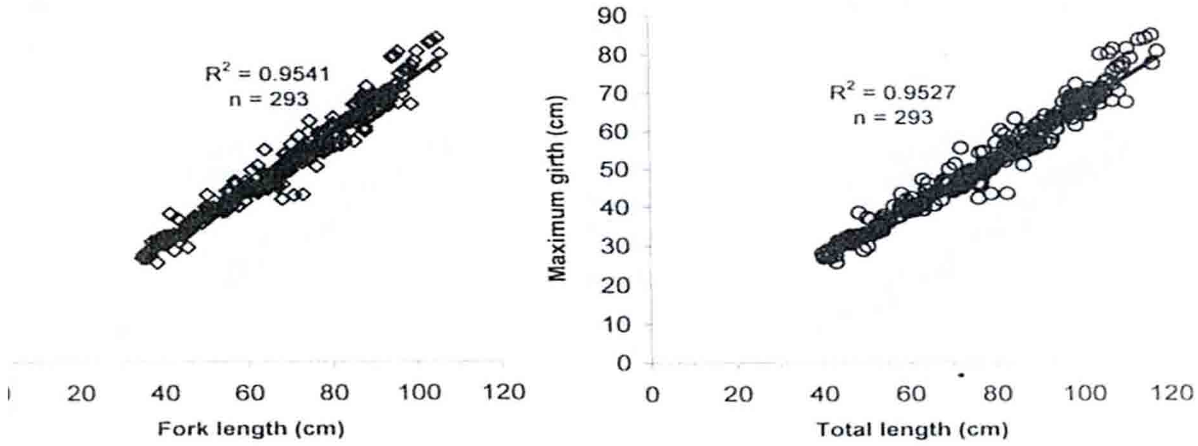
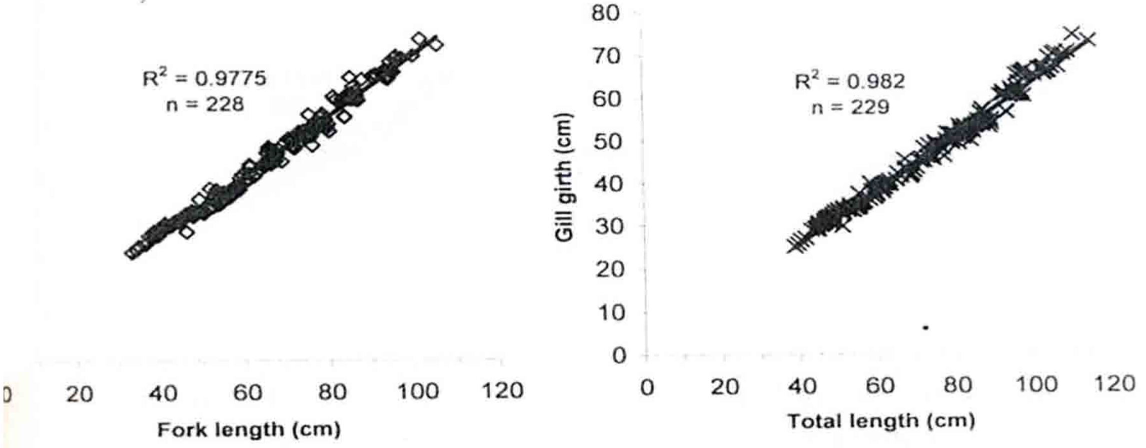


Fig. 26 Lengths-Girths relationship of *Caranx papuensis*


a) Relationship between Gill girth and Fork length

b) Relationship between Gill girth and Total length

c) Relationship between Maximum girth and Fork length

d) Relationship between Maximum girth and Total length

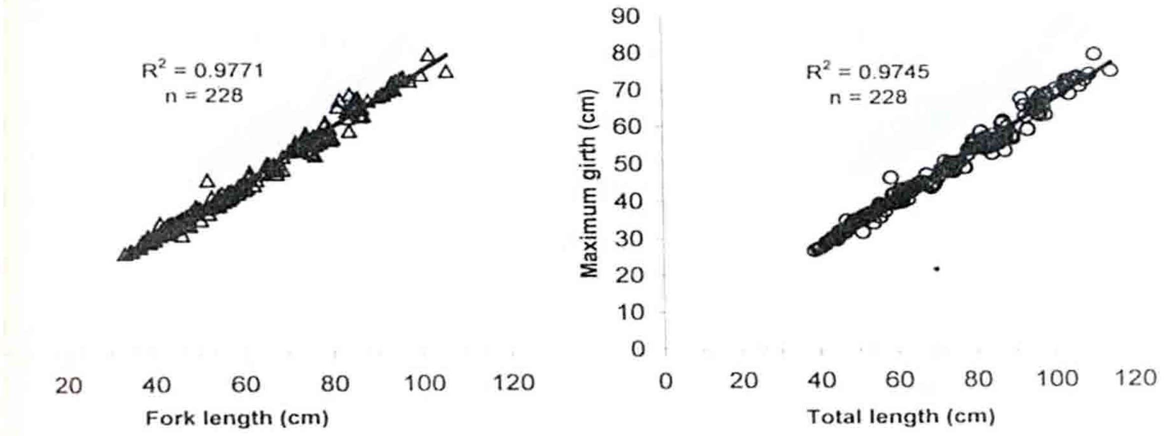
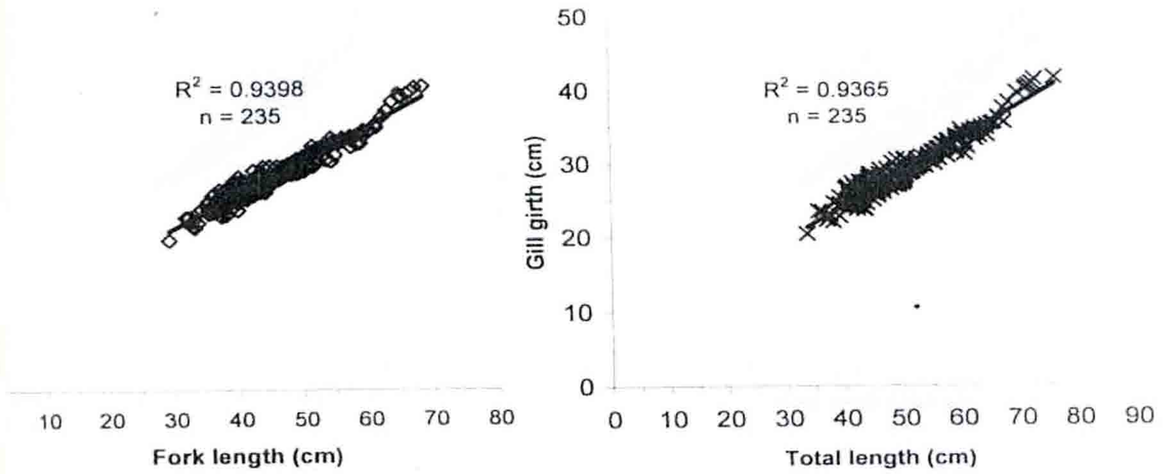


Fig. 27 Lengths-Girths relationship of *Caranx sexfasciatus*



a) Relationship between Gill girth and Fork length

b) Relationship between Gill girth and Total length

c) Relationship between Maximum girth and Fork length

d) Relationship between Maximum girth and Total length

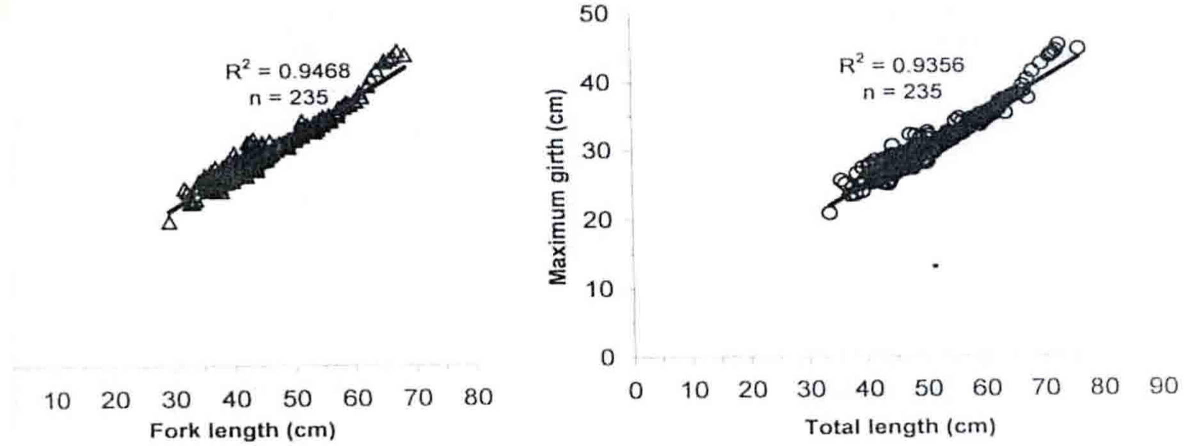
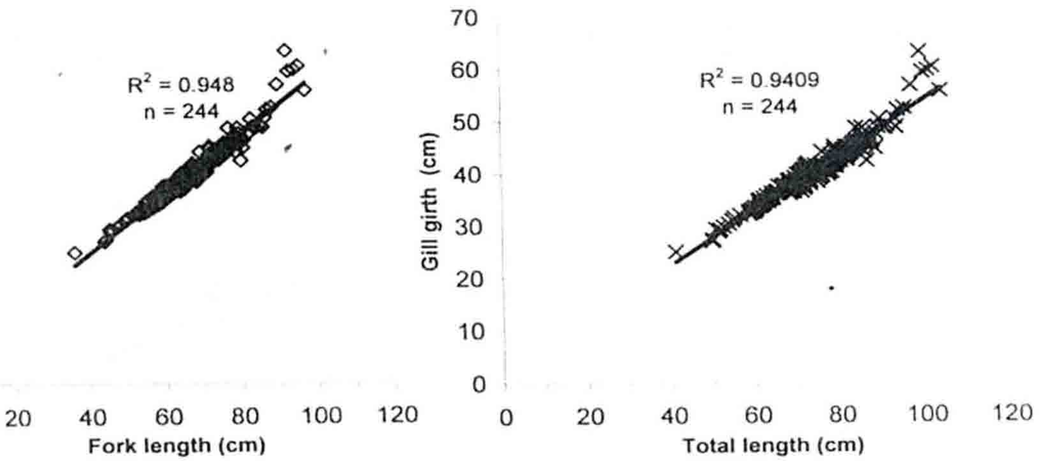
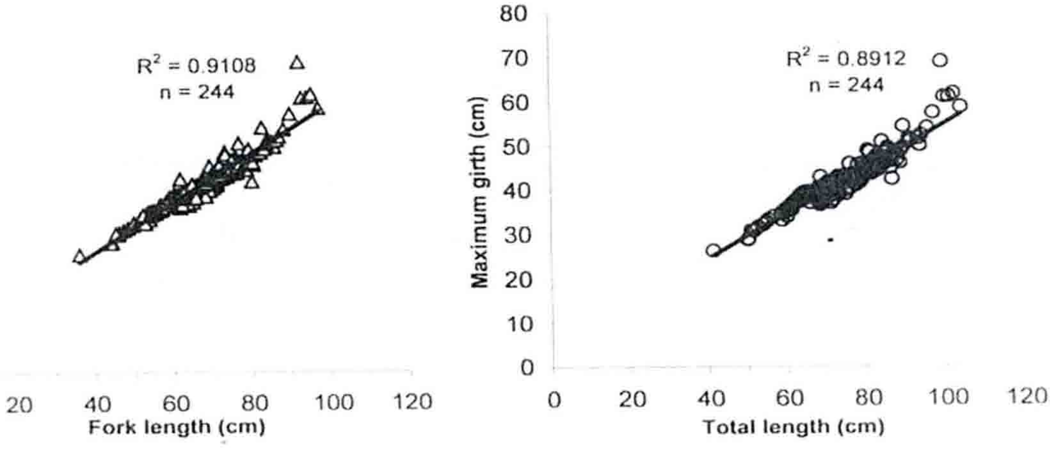


Fig. 28 Lengths-Girths relationship of *Caranx tille*



a) Relationship between Gill girth and Fork length

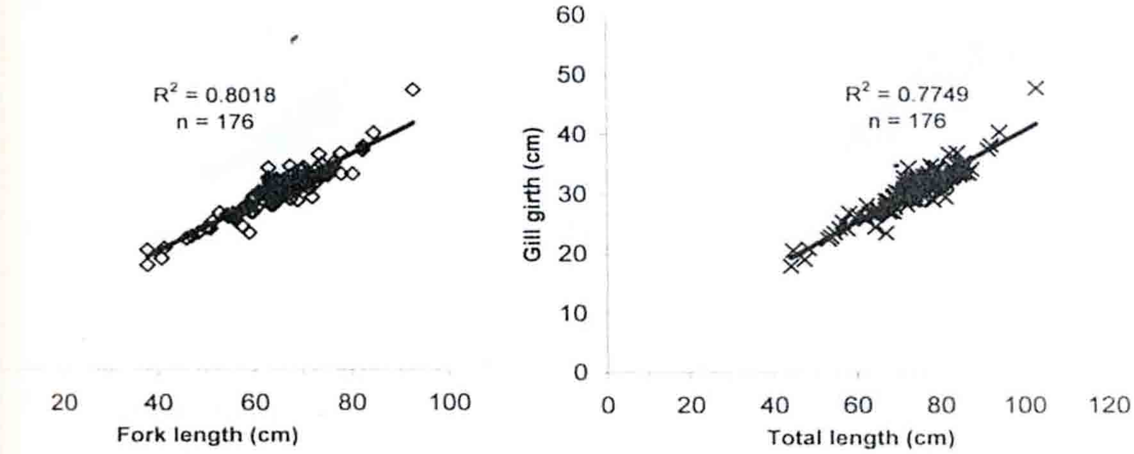
b) Relationship between Gill girth and Total length



c) Relationship between maximum girth and fork length

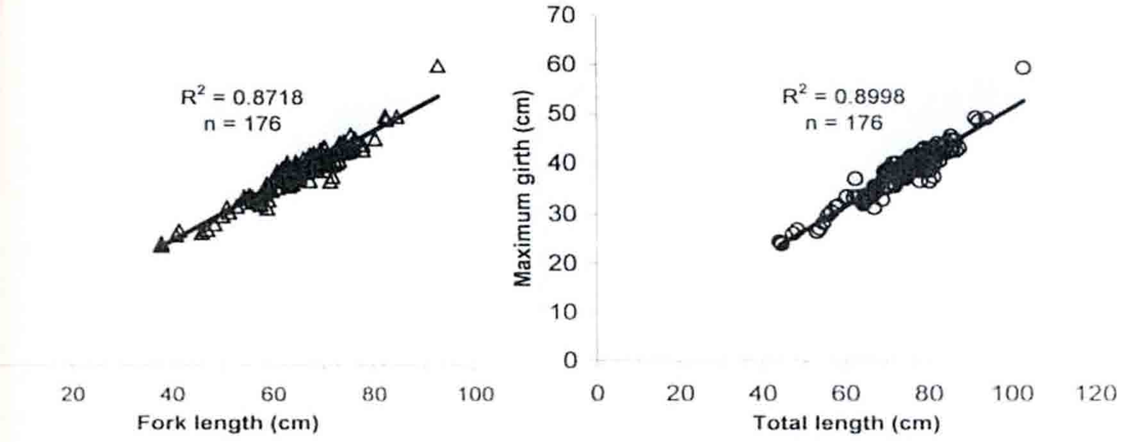
d) Relationship between Maximum girth and Total length

9 Lengths-Girths relationship of *Scomberoides commersoniannus*



a) Relationship between Gill girth and Fork length

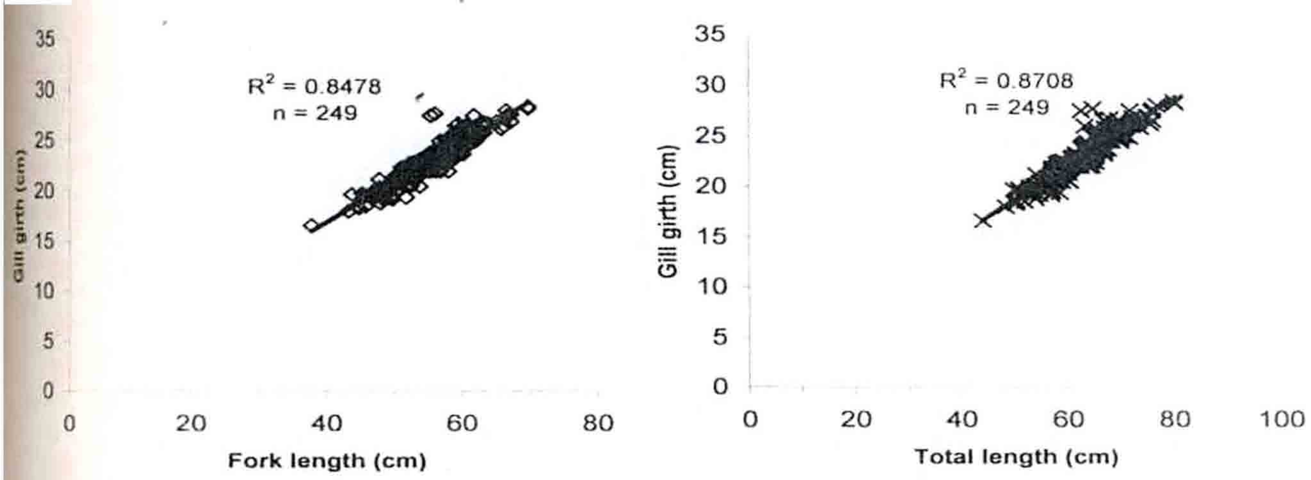
b) Relationship between Gill girth and Total length



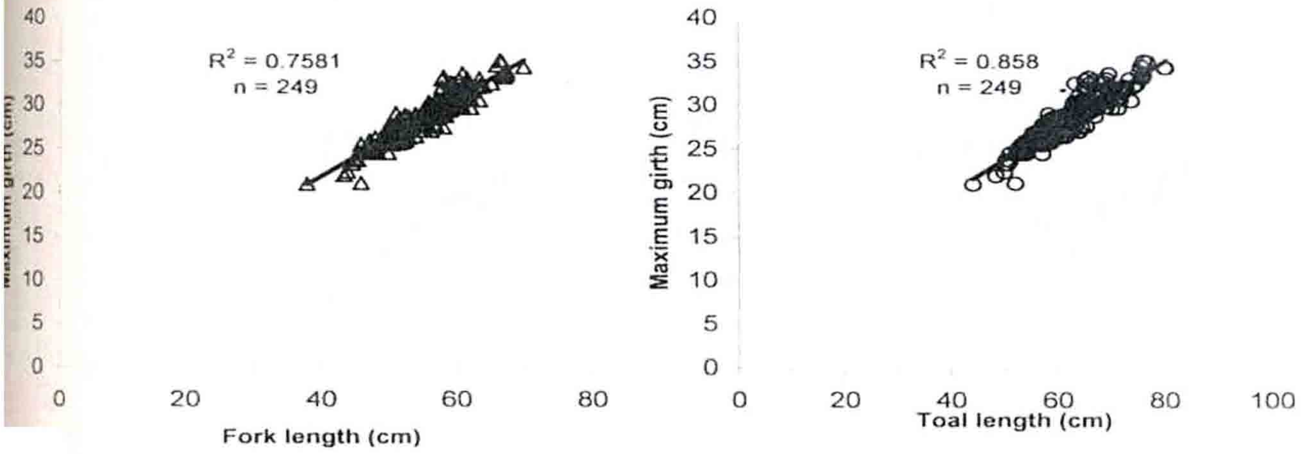
) Relationship between Maximum girth and Fork length

d) Relationship between Maximum girth and Total length

Fig. 30 Lengths-Girths relationship of *Scomberoides lysan*

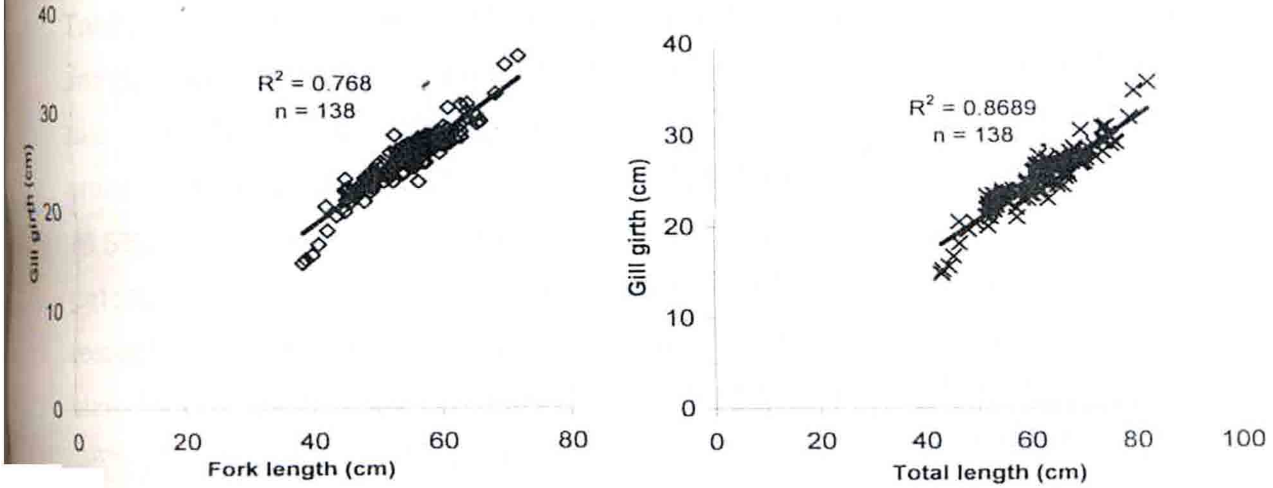

a) Relationship between Gill girth and Fork length

b) Relationship between Gill girth and Total length


c) Relationship between Maximum girth and Fork length

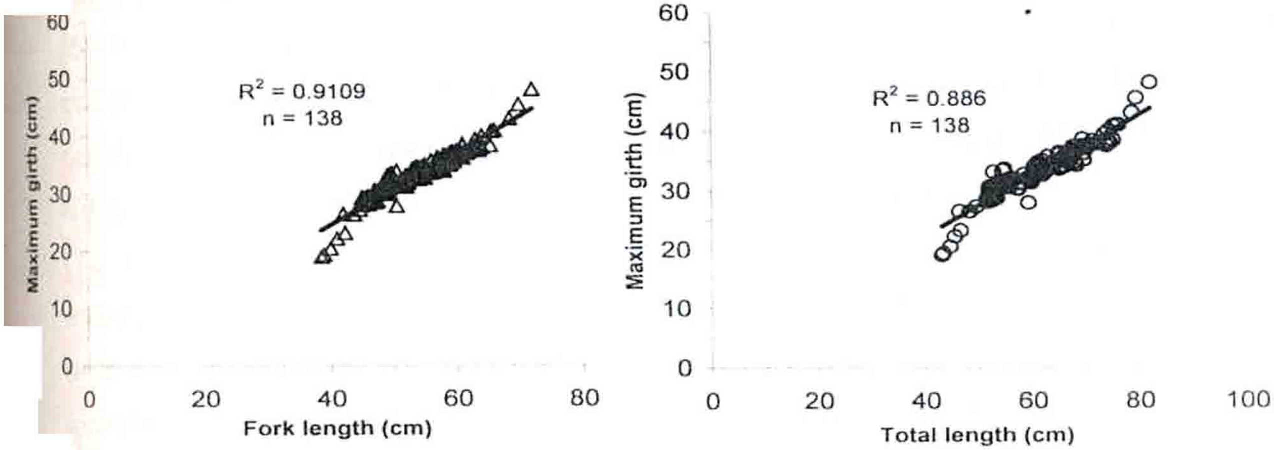
d) Relationship between Maximum girth and Total length

Fig. 31 Lengths-Girths relationship of *Scomberoides tala*



Relationship between Gill girth and Fork length

b) Relationship between Gill girth and Total length



c) Relationship between Maximum girtha and Fork length

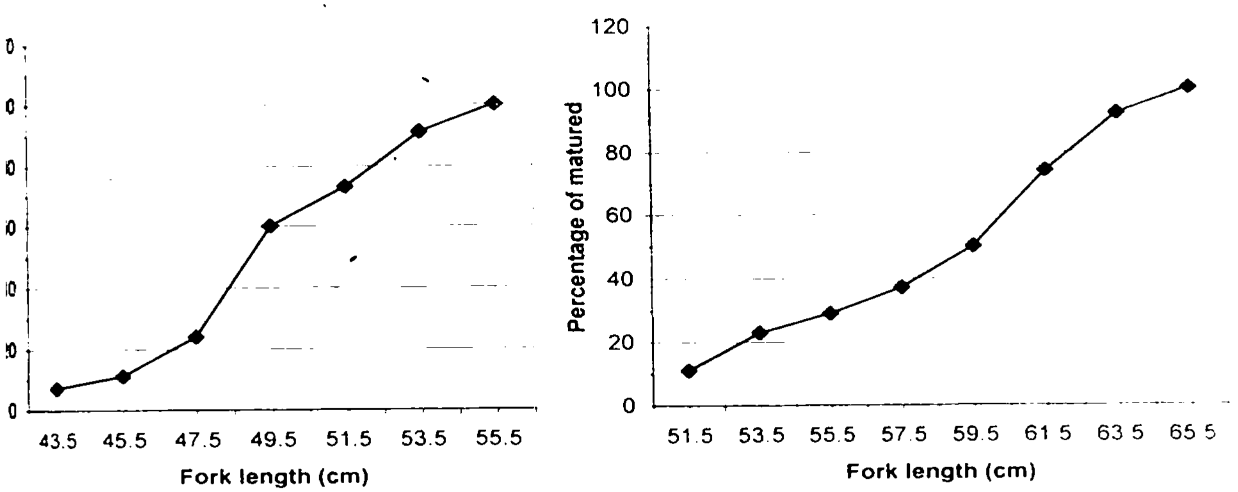
d) Relationship between Maximum girth and Total length

4.5 Length at First Maturity

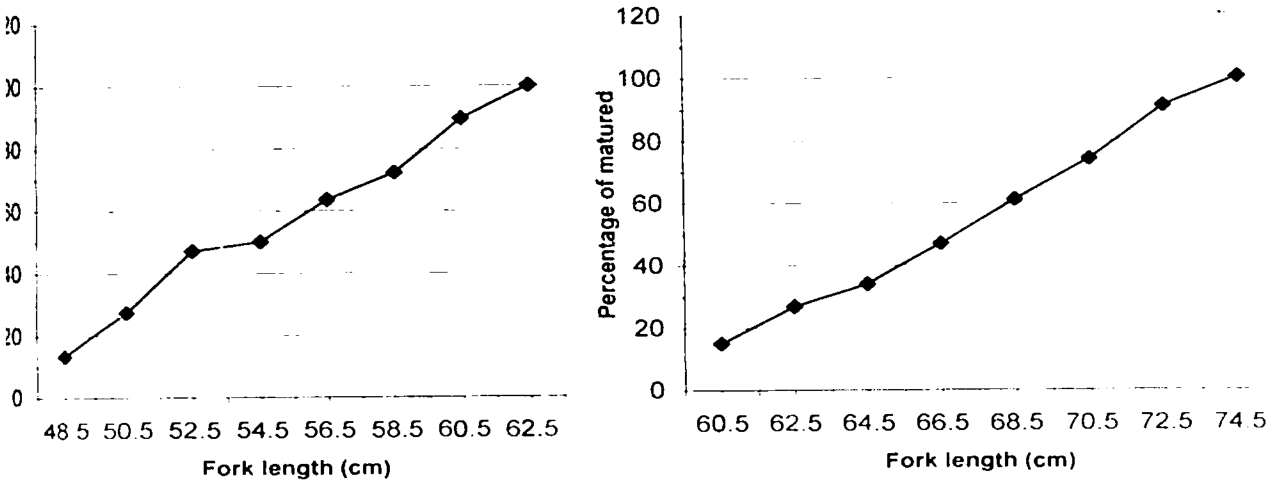
Length at first maturity (Lm50) varied between species to species. Maturity ogives for various species studied is presented in the Fig. 32. Length at first maturity`and undersized fish with the length below Lm50 caught in different meshes of gillnets and hooks are also presented in the Table 28. Percentages of below Lm50 was high in the species such as C. *sexfasciatus* (63.2%) followed by C. *ignobilis* (58.2%), C. *heberi* (45.6%), S. *tala* (42.77%), C. *fulvoguttatus* (31.3%), C. *papuensis* (28.9%), S. *commersonnianus* (24.9%), S. *lysan* (24.2%), C. *ferdau* (8.5%) and C. *tille* (6.5%). Undersized fish exceeding 50 % of catch could be noticed in the catches of the net with the mesh size of 13.5 cm in almost all the species except C. *tille* (25.9%) and C. *ferdau* (27%). In the case of net with mesh size 14 cm, undersized fish were observed to an extent of 56.9% (C. *heberi*). 58% (S. *tala*), 84.9% (C. *ignobilis*), and 88.5% (C. *sexfasciatus*). Undersized fishes not exceeding 50 % were not observed in the catches of the net with the mesh sizes of 14.5 cm and 15 cm. However, there was noundersized catch from the mesh sizes of 14.5 and 15 cm in both species C. *ferdau* and C. *tille* . The net with mesh size of 14.5 cm was no way detrimental to S. *commersonnianus* as it did not capture any fishes below Lm50.

In the case of hand line fishing, percentage of undersized fish caught by different hook sizes varied. It was high for the species C. *ignobilis* (57.6%), followed by C. *fulvoguttatus* (53.4%), C. *heberi* (50.2%), and S. *commersonnianus* (28.11%). Further, undersized fish exceeding 50 % of the catch were for the species, C. *ignobilis* (92.4%), C. *heberi* (79.8%) and C. *fulvoguttatus* (77%), from hook No. 8 and C.*ignobilis* (71.2%), C. *heberi* (72.3%) and C. *fulvoguttatus* (54.6%), from hook No.7. Undersized fish exceeding Lm50% of the catch could not be observed in the hooks sizes 5 and 6. Regarding S. *commersonnianus* all the four hooks did not pose significant problem as the undersized fishes contributed less than 50% catch.

Fig. 32 Maturity ogives of various carangid species

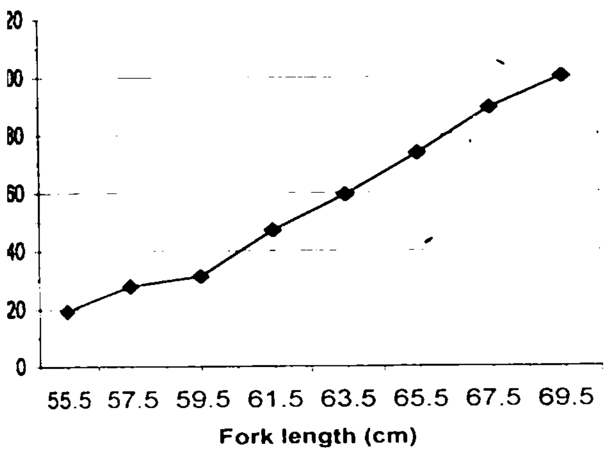

a) *Carangoides ferdau*

b) *Carangoides fulvoguttatus*

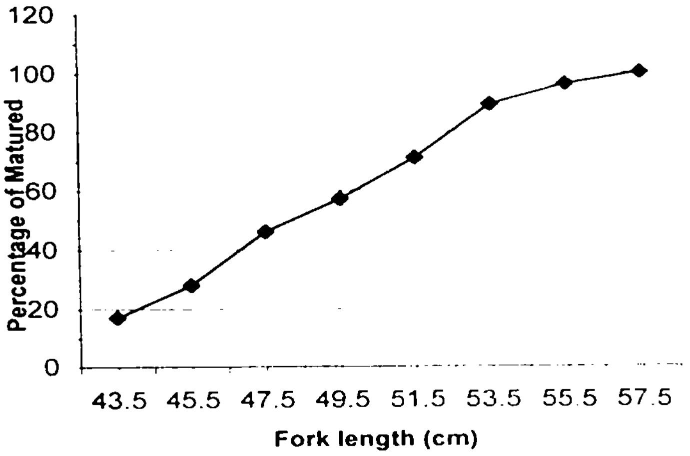

c) *Caranx heberi*

d) *Caranx ignobilis*

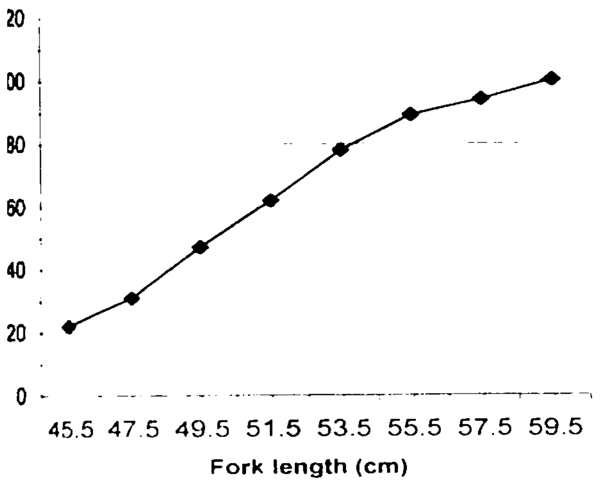
e) Caranx papuensis



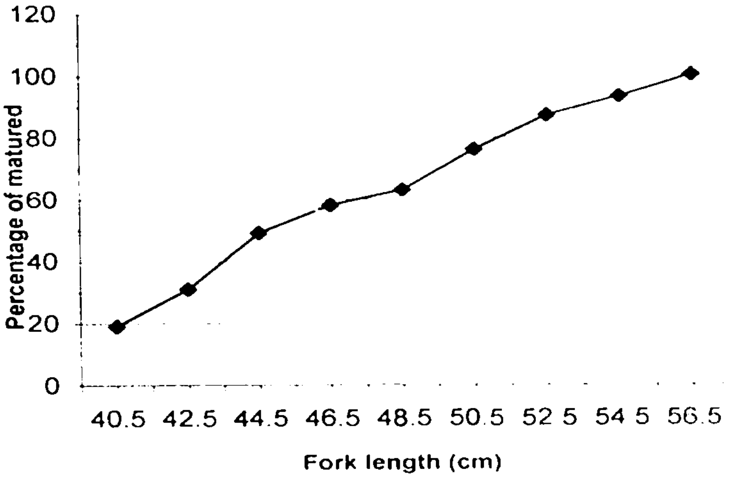
f) Caranx sexfasciatus



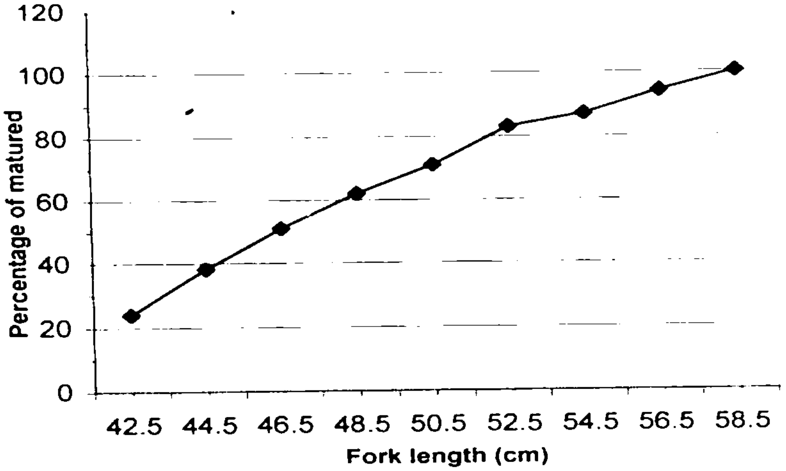
g) Caranx tille



h) Scomberoides commersonnianus



i) Scomberoides commersonnianus



j) Scomberoides tala

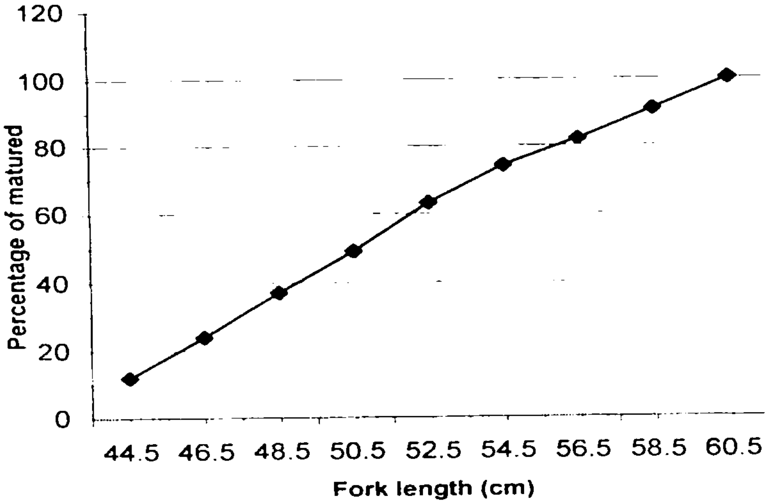


Table. 28 Length at first maturity (Lm50%) and percentage of catch obtained less than Lm50% of various carangid species

S.No.	Species	Lm50% (cm)	Percentage of catch less than Lm50%									
			mesh size (cm)				over all	Hook size				over all
			13.5	14	14.5	15	catch	No.5	No.6	No.7	No.8	catch
1	*Carangoides ferdau*	48.9	27	3.7	0	0	8.5	☆	☆	☆	☆	☆
2	*Carangoides fulvoguttaus*	59.5	69.9	39.7	20.6	11.4	31.3	23.8	41.7	54.6	77	53.4
3	*Caranx heberi*	54.5	78.7	56.9	15.1	10.9	45.6	12.9	25.6	72.3	79.8	50.2
4	*Caranx ignobilis*	66.9	98.7	84.9	46.6	26.1	58.2	35.8	37.3	71.2	92.4	57.6
5	*Caranx papuensis*	62	92	29.9	8.8	2.3	28.9	☆	☆	☆	☆	☆
6	*Caranx sexfasciatus*	48.2	91	88.5	35.2	2.4	63.2	☆	☆	☆	☆	☆
7	*Caranx tille*	49.9	25.9	1.2	0	0	6.5	☆	☆	☆	☆	☆
8	*Scomberoides commersonnianus*	52.7	83.5	18.6	0	2.2	24.9	10.5	20	39.04	37.7	28.11
9	*Scomberoides lysan*	53.4	63.3	18	7.3	4.7	24.2	☆	☆	☆	☆	☆
10	*Scomberoides tala*	50.6	81.8	58	13.2	0.36	42.77	☆	☆	☆	☆	☆

☆ *No value*

Table 29. Mean compressibility of different body positions of target species for various mesh and twine sizes

S.No.	Species	13.5 cm			14 cm			14.5 cm			15 cm			*R tex 737			*R tex 786		
		Kgill	Kgilled	Kmax	Kgill	Kgilled	Kmax	Kgill	Kgilled	Kmax	Kgill	Kgilled	Kmax	Kgill	Kgilled	Kmax	Kgill	Kgilled	Kmax
1	*Carangoides ferdau*	0.586	0.734	0.557	0.553	0.646	0.525	0.817	0.826	0.766	0.672	0.791	0.631	0.576	0.7032	0.547	0.765	0.8143	0.718
2	*Carangoides fulvoguttaus*	0.691	0.78	0.654	0.646	0.739	0.614	0.908	0.879	0.867	0.758	0.824	0.72	0.677	0.7673	0.6408	0.798	0.8384	0.759
3	*Caranx heberi*	0.779	0.866	0.747	0.812	0.906	0.773	0.904	941	0.866	0.828	0.888	0.79	0.793	0.8834	0.758	0.866	0.9137	0.828
4	*Caranx ignobilis*	0.649	0.815	0.618	0.597	0.796	0.572	0.891	1.134	0.851	0.72	0.864	0.685	0.626	0.8078	0.5981	0.79	0.8889	0.753
5	*Caranx papuensis*	0.586	0.66	0.555	0.514	0.689	0.491	0.825	0.86	0.782	0.8	0.854	0.75	0.555	0.6673	0.5273	0.817	0.858	0.773
6	*Caranx sexfasciatus*	0.961	0.962	0.93	0.865	0.876	0.826	1.01	0.989	0.961	1	0.995	0.947	0.919	0.9264	0.8848	1.004	0.9914	0.955
7	*Caranx tille*	0.696	0.774	0.672	0.655	0.758	0.635	0.777	0.806	0.728	0.741	0.804	0.712	0.681	0.7706	0.6587	0.754	0.8048	0.718
8	*Scomberoides commersonnianus*	0.914	0.852	0.728	0.993	0.936	0.792	1.002	0.929	0.818	1.015	0.898	0.796	0.948	0.888	0.7555	1.012	0.9051	0.801
9	*Scomberoides lysan*	1.22	1.01	0.981	1.314	1.09	1.065	1.201	1.034	0.961	1.2	1	0.96	1.202	1.0165	0.9605	1.266	1.0459	1.02
10	*Scomberoides tala*	1.163	0.943	0.874	1.102	0.921	0.83	1.236	1.059	0.928	1.192	1.003	0.901	1.132	0.9324	0.852	1.221	1.0405	0.919

* Pooled Kmean values of meshes 13.5 and 14 cm

** Pooled K mean values of meshes 14.5 and 15 cm

4.6 Compressibility of Fish Body and Elasticity of Netting Twine (K)

Estimated mean compressibility-elasticity factor (K) for various mesh sizes such as 13.5, 14, 14.5 and 15 cm and twine size R Tex 737 and R Tex 786 are presented in the Table. 29. The K value was highest at the gilled girth (Gc) and lowest at maximum girth (Gmax). Mean values of K factor calculated at operculum, retained position and maximum body girth position varied between species and mesh sizes. These K factors were high for the fish of *S. tala* followed by *S. lysan, C. sexfasciatus* and *S. commersonnianus*. Estimated K values for the twine size R Tex 737 were lesser than twine and R Tex 786. However, the calculated K factor for retained girth varied with respect to mesh size, twine size and species.

4.6 Selectivity

In the present study, gillnet and hook selectivity parameters were estimated using Log-linear models to fit various functional models for ten species caught with gillnets and four species caught with drift hand lines. Species caught with hand lines were also caught with gillnets also. Gillnet and hook selectivity parameters were estimated using the selectivity software GILLNET (Generalized Including Log-Linear N Estimation Technique) (Constat, 1998), based on SELECT (Share Each LEngth Catch Total) methodology. The models tried for the selectivity data in the study were uni-modal and bi-modal model (Table 3.).

Uni-modal models included Normal location (fixed spread), Normal scale (proportional spread), Log-normal, and Gamma. Each selection a curve was fitted with the assumption of equal fishing power (fishing power of each mesh size is constant) and with fishing power proportional to mesh and hook sizes. Among the uni-modal models, normal scale and normal location were influenced by fishing power while other two log-normal and gamma models were not influenced. Hence, model deviance (D) obtained under both assumption of equal fishing power and fishing power proportional to mesh or hook size for both log-normal and gamma models was same in all the species studied. All the models studied for the obtained

S.No.	Species	Model		Degrees of freedom	Equal fishing power			Fishing power α mesh size		
					Parameters	SD	Model deviance	Parameters	SD	Model deviance
1	*Carangoides ferdau*	Normal location	Fixed spread	85	(k,s) = (4.4412, 4.1250)	0.0235, 0.1013	367.03	(k,s) = (4.60, 4.1319)	0.0235, 0.1015	366.41
		Normal scale	spread α mj	85	(k1,k2) = (4.4801, 0.2903)	0.0236, 0.0070	398.91	(k1,k2) = (4.4991, 0.2896)	0.0235, 0.0070	399.08
		Lognormal	spread α mj	85	(m,s) = (4.0879, 0.0654)	0.0053, 0.0016	357.63	(m,s) = (4.0921, 0.0654)	0.0053, 0.0016	357.63
		Gamma	spread α mj	85	(k,a) = (0.0189, 234.6767)	0.0009, 11.3231	367.4	(k,a) = (0.0189, 235.6767)	0.0009, 11.3616	367.4
		Bimodal	spread α mj	82	(a1,b1) = (4.2306, 0.2042)	0.0370, 0.0154	366.69	(a1,b1) = (4.4411, 0.2622)	0.0242, 0.0077	356.02
					(a2,b2) = (4.5649, 0.2944)	0.0469, 0.0116	366.69	(a2,b2) = (5.0160, 0.3488)	0.2835, 0.0743	356.02
					w = 0.5402	0.2485	366.69	w = 0.0096	0.0086	356.02
2	*Carangoides fulvoguttatus*	Normal location	Fixed spread	121	(k,s) = (4.6538, 7.4560)	0.0368, 0.1566	693.16	(k,s) = (4.7126, 7.4997)	0.0365, 0.1584	691.39
		Normal scale	spread α mj	121	(k1,k2) = (4.7861, 0.5239)	0.0369, 0.0115	653.6	(k1,k2) = (4.8445, 0.5208)	0.0359, 0.0112	653.51
		Lognormal	spread α mj	121	(m,s) = (4.1306, 0.1136)	0.0080, 0.0025	724.22	(m,s) = (4.1432, 0.1136)	0.0079, 0.0025	724.22
		Gamma	spread α mj	121	(k,a) = (0.0585, 80.1385)	0.0025, 3.5369	686.41	(k,a) = (0.0585, 81.1385)	0.0025, 3.5426	686.41
		Bimodal	spread α mj			Not Converging				
3	*Caranx heberi*	Normal location	Fixed spread	112	(k,s) = (4.2107, 5.7289)	0.0201, 0.1002	639.13	(k,s) = (4.2491, 5.7526)	0.0204, 0.1013	637.58
		Normal scale	spread α mj	112	(k1,k2) = (4.2843, 0.3971)	0.0199, 0.0067	775.93	(k1,k2) = (4.3214, 0.3951)	0.0199, 0.0067	777.73
		Lognormal	spread α mj	112	(m,s) = (4.0376, 0.0980)	0.0050, 0.0016	621.18	(m,s) = (4.0472, 0.0980)	0.0051, 0.0016	621.18
		Gamma	spread α mj	112	(k,a) = (0.0386, 109.8448)	0.0013, 3.5476	637.76	(k,a) = (0.0386, 110.8448)	0.0013, 3.5658	637.76
		Bimodal	spread α mj	109	(a1,b1) = (4.1657, 0.3323)	0.0169, 0.0061	546.64	(a1,b1) = (4.1923, 0.3311)	0.0171, 0.0061	547.11
					(a2,b2) = (4.9949, 0.5162)	0.1199, 0.0340	546.64	(a2,b2) = (5.0502, 0.5122)	0.1159, 0.0338	547.11
					w = 0.0274	0.0081	546.64	w = 0.0330	0.0092	547.11
4	*Caranx ignobilis*	Normal location	Fixed spread	115	(k,s) = (4.2835, 5.9135)	0.0254, 0.1022	586.1	(k,s) = (4.3237, 5.9386)	0.0251, 0.1031	585.7
		Normal scale	spread α mj	115	(k1,k2) = (4.3915, 0.4100)	0.0244, 0.0075	522.79	(k1,k2) = (4.4303, 0.4082)	0.0238, 0.0074	522.81
		Lognormal	spread α mj	115	(m,s) = (4.0497, 0.0983)	0.0061, 0.0018	647.55	(m,s) = (4.0593, 0.0983)	0.0060, 0.0018	647.55
		Gamma	spread α mj	115	(k,a) = (0.0396, 108.8726)	0.0014, 4.0082	569.24	(k,a) = (0.0396, 109.8726)	0.0014, 4.020	569.24
		Bimodal	spread α mj	112	(a1,b1) = (4.3633, 0.5819)	0.0678, 0.0279	366.1	(a1,b1) = (4.4453, 0.5772)	0.0648, 0.0270	366.31
					(a2,b2) = (4.4386, 0.3344)	0.0187, 0.0071	366.1	(a2,b2) = (4.4637, 0.3337)	0.0184, 0.0071	366.31
					w = 153.5139	76.1299	366.1	w = 157.3541	77.8469	366.31

S.No.	Species	Model		of freedom	Parameters		deviance			deviance
5	*Caranx papuensis*	Normal location	Fixed spread	109	(k.s) = (4 7438. 4 8670)	0 0211 0 1077	541 78	(k.s) = (4 7684. 4 8770)	0 0210. 0 1082	540 89
		Normal scale	spread α mj	109	(k1,k2) = (4 7819. 0 3418)	0 0210. 0 0077	561 6	(k1,k2) = (4 8065. 0 3408)	0 0208. 0 0078	561 85
		Lognormal	spread α mj	109	(m.s) = (4 1572. 0 0719)	0.0045. 0 0016	525 56	(m.s) = (4 1624. 0.0719)	0 0044. 0.0016	525 56
		Gamma	spread α mj	109	(k,a) = (0 0243. 195.48)	0.0011. 8 7475	527 17	(k,a) = (0 0243. 196 4880)	0 0011. 8.7794	527 17
		Bimodal	spread α mj	106	(a1,b1) = (4 7669. 0 2843)	0.0179. 0 0080	461 41	(a1,b1) = (4 7839. 0 2838)	0 0178. 0.0079	461 6
					(a2,b2) = (5 0173. 0.4871)	0.0749. 0 0271	461 41	(a2,b2) = (5 0664. 0.4846)	0.0759. 0.0264	461.6
					w = 0 0225	0 0111	461 41	w = 0 0237	0.0113	461.6
6	*Caranx sexfasciatus*	Normal location	Fixed spread	61	(k,s) = (3 4695. 3 694)	0.0196. 0 0914	345 5	(k,s) = (3 4889. 3 7034)	0.0197. 0.0918	344 8
		Normal scale	spread α mj	61	(k1,k2) = (3.5071. 0.2556)	0 0194. 0 0060	380.51	(k1,k2) = (3 5259. 0.2549)	0.0194. 0.0060	380 74
		Lognormal	spread α mj	61	(m.s) = (3.8429. 0.0763)	0.0059. 0 0018	344.73	(m,s) = (3.8488, 0.0763)	0.0059. 0.0018	344.73
		Gamma	spread α mj	61	(k,a) = (0 0196. 177.4954)	0.0009. 8.1807	350.66	(k,a) = (0.0196. 178.4954)	0.0009. 8.2139	350.66
		Bimodal	spread α mj	58	(a1,b1) = (3.4333. 0.2229)	0.0198. 0.0074	335.02	(a1,b1) = (3.4479. 0 2224)	0.0201. 0.0074	335.06
					(a2,b2) = (3 7531. 0.3296)	0.0881. 0 0232	335.02	(a2,b2) = (3 7832. 0 3281)	0.0882. 0.0229	335.06
					w = 0 0468	0.0276.	335.02	w = 0.0511	0.028898	335.06
7	*Caranx tille*	Normal location	Fixed spread	91	(k.s) = (4.7205. 4.2649)	0 0168. 0.0862	467 75	(k.s) = (4.7394. 4.2716)	0.0168. 0.0866	466.6
		Normal scale	spread α mj	91	(k1,k2) = (4 7485. 0.2986)	0.0167. 0 006	510 58	(k1,k2) = (4 7674. 0.298)	0.0166. 0.0060	510.8
		Lognormal	spread α mj	91	(m.s) = (4.1518. 0.0642)	0.0037. 0.0013	458.56	(m,s) = (4.156,0 0642)	0 0036. 0.0013	458 56
		Gamma	spread α mj	91	(k,a) = (0.0192. 246.2453)	0.0008. 9.9843	469.95	(k,a) = (0.0192. 247 2453)	0.0008. 10.0328	469.95
		Bimodal	spread α mj	88	(a1,b1) = (4 7485. 0.2986)	0.0167,0 006	510.58	(a1,b1) = (4 7674. 0 2980)	0	510 8
					(a2 b2) = (23 2. 1 28)	☆	510.58	(a2,b2) = (23 814. 0.3858)	0	510 8
					w = 0 111	☆	510 58	w = 0 1174	0	510.8

S.No.	Species	Model		Degrees of freedom	Equal fishing power			[illegible]		
					Parameters	SD	Model deviance	Parameters	SD	Model deviance
8	*Scomberoides commersonianus*	Normal location	Fixed spread	94	(k,s) - (4.3266, 4.4476)	0.0203, 0.1008	549.22	(k,s) = (4.3492, 4.4572)	0.0204, 0.1013	548.11
		Normal scale	spread α mj	94	(k1,k2) = (4.3626, 0.3119)	0.0203, 0.0070	590.09	(k1,k2) = (4.3850, 0.3111)	0.0202, 0.0070	590.42
		Lognormal	spread α mj	94	(m,s) = (4.0637, 0.0725)	0.0048, 0.0016	531.33	(m,s) = (4.0690, 0.0725)	0.0048, 0.0016	531.33
		Gamma	spread α mj	94	(k,a) = (0.0225, 192.6148)	0.0010, 8.5928	543.09	(k,a) = (0.0225, 193.6148)	0.0010, 8.6304	543.09
		Bimodal	spread α mj	91	(a1,b1) = (4.3526, 0.3119)	0.0203, 0.0070	590.09	(a1,b1) = (4.3850, 0.3111)	0.0202, 0.0070	590.42
					(a2,b2) = (15.8, 0.8)	☆	590.09	(a2,b2) = (16.2, 1.7)	☆	590.42
					w = 0.116	☆	590.09	w = 0.105	☆	590.42
9	*Scomberoides lysan*	Normal location	Fixed spread	70	(k,s) = (4.2021, 4.5199)	0.0180, 0.1045	400.55	(k,s) = (4.2260, 4.5310)	0.0180, 0.1050	400.68
		Normal scale	spread α mj	70	(k1,k2) = (4.2397, 0.3255)	0.0187, 0.0078	455.5	(k1,k2) = (4.2648, 0.3245)	0.0186, 0.0077	455.95
		Lognormal	spread α mj	70	(m,s) = (4.0393, 0.0743)	0.0042, 0.0017	362.85	(m,s) = (4.0449, 0.0743)	0.0042, 0.0017	362.85
		Gamma	spread α mj	70	(k,a) = (0.0236, 178.7311)	0.0011, 8.1597	387.05	(k,a) = (0.0236, 179.7311)	0.0011, 8.1801	387.05
		Bimodal	spread α mj	67	(a1,b1) = (4.2005, 0.2694)	0.0143, 0.0060	223.67	(a1,b1) = (4.2178, 0.2688)	0.0142, 0.0060	223.69
					(a2,b2) = (5.4209, 0.5859)	0.2779, 0.2367	223.67	(a2,b2) = (5.4836, 0.5813)	0.2558, 0.2342	223.69
					w = 0.0026	0.0011	223.67	w = 0.0033	0.0015	223.69
10	*Scomberoides tala*	Normal location	Fixed spread	61	(k,s) = (3.8263, 2.9743)	0.0130, 0.0697	227.81	(k,s) = (3.8377, 2.9775)	0.0130, 0.0699	227.78
		Normal scale	spread α mj	61	(k1,k2) = (3.8465, 0.2098)	0.0131, 0.0048	261.4	(k1,k2) = (3.8579, 0.2094)	0.0131, 0.0048	261.53
		Lognormal	spread α mj	61	(m,s) = (3.9440, 0.0547)	0.0034, 0.0013	212.02	(m,s) = (3.9469, 0.0547)	0.0034, 0.0013	212.02
		Gamma	spread α mj	61	(k,a) = (0.0115, 334.7593)	0.0005, 15.4098	225.54	(k,a) = (0.0115, 335.7593)	0.0005, 15.4602	225.54
		Bimodal	spread α mj	58	(a1,b1) = (3.8012, 0.1833)	0.0142, 0.0058	207.07	(a1,b1) = (3.810, 0.1831)	0.0144, 0.0058	207.11
					(a2,b2) = (4.1089, 0.2438)	0.1315, 0.0314	207.07	(a2,b2) = (4.1234, 0.2433)	0.1295, 0.0315	207.11
					w = 0.0436	0.032	207.07	w = 0.0471	0.033	207.11

☆ No value

Table. 31 Modal length and spread of gillnets selectivity curves of various models for various species

S.No.	Species	Model	Mesh size (cm)															
			13.5				14				14.5				15			
			Modal length (cm)		Spread		Modal length (cm)		Spread		Modal length (cm)		Spread		Modal length (cm)		Spread	
			a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
1	*Carangoides ferdau*	Normal location	60	60.2	4.12	4.13	62.2	62.4	4.12	4.13	64.4	64.7	4.12	4.13	66.6	66.9	4.12	4.13
		Normal scale	60.5	60.7	3.92	3.91	62.7	63	4.06	4.05	65	65.2	4.21	4.2	67.2	67.5	4.35	4.34
		Lognormal	59.4	59.6	3.91	3.93	61.6	61.8	4.06	4.08	63.8	64	4.2	4.22	66	66.2	4.35	4.37
		Gamma	59.7	60	3.91	3.92	62	62.2	4.05	406	64.2	64.4	4.2	4.21	66.4	66.7	4.34	4.35
		Bimodal	57.1	60	2.76	3.54	59.2	62.2	2.86	3.67	61.3	64.4	2.96	3.8	63.5	66.6	3.06	3.93
2	*Carangoides fulvoguttatus*	Normal location	62.8	63.6	7.46	7.5	65.2	66	7.46	7.5	67.5	68.3	7.46	7.5	69.8	70.7	7.46	7.5
		Normal scale	64.6	65.4	7.07	7.03	67	67.8	7.33	7.29	69.4	70.2	7.6	7.55	71.8	72.7	7.86	7.81
		Lognormal	61.4	62.2	7.13	7.22	63.7	65	7.4	7.46	66	66.9	7.66	7.76	68.2	69.1	7.92	8.03
		Gamma	62.5	63.3	7.03	7.07	64.8	65.6	7.29	7.33	67.1	68	7.55	7.59	69.4	70.3	7.81	7.85
		Bimodal					Not converging											
3	*Caranx heberi*	Normal location	56.8	57.4	5.73	5.75	59	59.5	5.73	5.75	61.1	61.6	5.73	5.75	63.2	63.7	5.73	5.75
		Normal scale	57.8	58.3	5.36	5.33	60	60.5	5.56	5.53	62.1	62.7	5.76	5.73	64.3	64.8	5.96	5.93
		Lognormal	56.1	56.7	5.6	5.65	58.2	58.8	5.8	5.86	60.3	60.9	6.01	6.07	62.4	63	6.22	6.28
		Gamma	56.7	57.2	5.43	5.46	58.8	59.3	5.64	5.66	60.9	61.5	5.84	5.86	63	63.6	6.04	6.07
		Bimodal	56.2	56.6	4.49	4.47	58.3	58.7	4.65	4.64	60.4	60.8	4.82	4.8	62.5	62.9	4.99	4.97
4	*Caranx ignobilis*	Normal location	57.8	58.4	5.91	5.94	60	60.5	5.91	5.94	62.1	62.7	5.91	5.94	64	64.9	5.91	5.94
		Normal scale	59.3	59.8	5.54	5.51	61.5	62	5.74	5.71	63.7	64.2	5.95	5.92	65.9	66.5	6.15	6.12
		Lognormal	56.8	57.4	5.68	5.74	58.9	59.5	5.89	5.95	61	61.6	6.1	6.16	63.1	63.8	6.31	6.37
		Gamma	57.7	58.3	5.56	5.58	59.9	60.4	5.76	5.79	62	62.6	5.97	6	64.1	64.7	6.18	6.2
		Bimodal	58.9	60	7.86	7.79	61.1	62.2	8.15	8.08	63.3	64.5	8.44	8.37	65.4	66.7	8.73	8.66
5	*Caranx papuensis*	Normal location	64	64.4	4.87	4.88	66.4	66.8	4.87	4.88	68.8	69.1	4.87	4.88	71.2	71.5	4.87	4.88
		Normal scale	64.6	64.9	4.61	4.6	66.9	67.3	4.78	4.77	69.3	69.7	4.96	4.94	71.7	72.1	5.13	5.11
		Lognormal	63.6	63.9	4.61	4.63	66	66.3	4.78	4.8	68.3	68.6	4.95	4.98	70.6	71	5.12	5.15
		Gamma	64	64.2	4.58	4.59	66.3	66.6	4.75	4.76	68.6	69	4.92	4.93	71	71.4	5.09	5.1
		Bimodal	64.4	64.6	3.84	3.83	66.7	67	3.98	3.97	69.1	69.4	4.12	4.11	71.5	71.8	4.26	4.26
6	*Caranx sexfasciatus*	Normal location	46.8	47.1	3.69	3.7	48.6	48.8	3.69	3.7	50.3	50.6	3.69	3.7	52	52.3	3.69	3.7
		Normal scale	47.3	47.6	3.45	3.44	49	49.4	3.58	3.57	50.9	51.1	3.71	3.7	52.6	52.9	3.83	3.82
		Lognormal	46.4	46.7	3.58	3.6	48.1	48.4	3.71	3.73	49.8	50.1	3.84	3.86	51.5	51.8	3.97	4
		Gamma	46.7	47	3.52	3.53	48.4	48.7	3.65	3.66	50.2	50.5	3.78	3.79	51.9	52.2	3.91	3.92
		Bimodal	46.4	46.5	3.01	3	48.1	48.3	3.12	3.11	49.8	50	3.23	3.22	51.5	51.7	3.34	3.34

S.No.	Species	Model	Mesh size (cm)															
			13.5				14				14.5				15			
			Modal length (cm)		Spread		Modal length (cm)		Spread		Modal length (cm)		Spread		Modal length (cm)		Spread	
			a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
7	*Caranx tille*	Normal location	63.7	64	4.26	4.27	66.1	66.4	4.26	4.27	68.4	68.7	4.26	4.27	70.8	71.1	4.26	4.27
		Normal scale	64.1	64.4	4.03	4.02	66.5	66.7	4.18	4.17	68.9	69.1	4.33	4.32	71.2	72	4.48	4.47
		Lognormal	63.3	63.6	4.09	4.11	65.6	66	4.24	4.26	68	68.3	4.39	4.41	70.3	70.6	4.55	4.56
		Gamma	63.6	63.8	4.06	4.07	66	66.2	4.21	4.22	68.3	68.6	4.36	4.37	70.6	71	4.51	4.52
		Bimodal	64.1	64.4	4.03	4.02	66.5	66.7	4.18	4.17	68.9	69.1	4.33	4.32	71.2	71.5	4.48	4.47
8	*Scomberoides* commersonnianus	Normal location	58.4	58.7	4.45	4.46	60.6	60.9	4.45	4.46	62.7	63.1	4.45	4.46	64.9	65.2	4.45	4.46
		Normal scale	58.9	59.2	4.21	4.2	61.1	61.4	4.37	4.35	63.3	63.6	4.52	4.51	65.4	65.8	4.68	4.67
		Lognormal	57.9	58.2	4.24	4.26	60	60.3	4.39	4.42	62.2	62.5	4.55	4.57	64.3	64.7	4.71	4.73
		Gamma	58.2	58.5	4.21	4.22	60.4	60.7	4.36	4.37	62.5	62.9	4.52	4.53	64.7	65	4.67	4.69
		Bimodal	58.9	59.2	4.21	4.2	61.1	61.4	4.37	4.35	63.3	63.6	4.52	4.51	65.4	65.8	4.68	4.67
9	*Scomberoides lysan*	Normal location	56.7	57.1	4.52	4.53	58.8	59.2	4.52	4.53	61	61.3	4.52	4.53	63	63.4	4.52	4.53
		Normal scale	57.2	57.6	4.39	4.38	59.4	59.7	4.56	4.54	61.5	61.8	4.72	4.7	63.6	64	4.88	4.87
		Lognormal	56.5	56.8	4.24	4.26	58.6	58.9	4.39	4.42	60.7	61	4.55	4.58	62.8	63.1	4.71	4.73
		Gamma	56.7	57.1	4.26	4.27	58.8	59.2	4.41	4.43	61	61.3	4.57	4.58	63	63.4	4.73	4.74
		Bimodal	56.7	57	3.64	3.63	58.8	59	3.77	3.76	60.9	61.2	3.91	3.9	63	63.3	4.04	4.03
10	*Scomberoides tala*	Normal location	51.7	51.8	2.97	2.98	53.6	53.7	2.97	2.98	55.5	55.6	2.97	2.98	57.4	57.6	2.97	2.98
		Normal scale	52	52.1	2.83	2.83	53.9	54	2.94	2.93	55.8	56	3.04	3.04	57.7	57.9	3.15	3.14
		Lognormal	51.5	51.6	2.83	2.84	53.4	53.5	2.94	2.94	55.3	55.4	3.04	3.05	57.2	57.4	3.15	3.16
		Gamma	51.6	51.8	2.83	2.83	53.5	53.7	2.93	2.93	55.4	55.6	3.03	3.04	57.4	57.5	3.14	3.14
		Bimodal	51.3	51.4	2.47	2.47	53.2	53.3	2.57	2.56	55.1	55.2	2.66	2.65	57	57.2	2.75	2.75

a Equal fishing power

b Fishing power α Mesh size

selectivity data followed geometrical similarity except normal location. Estimated parameters of each functional model are presented in Table 30 and 32 and the modal lengths and spreads are presented in the Table 31 and 33. In all the model analysis for all the species, DF was greater than deviance.

4.7.1 Fitting of Various Models for Gillnet Selectivity Data for Various Species

Species-wise estimated results of selectivity data collected from gillnets are given as follows;

4.7.1.1 *Carangoides ferdau*

Over all total catch of *Carangoides ferdau* obtained from four mesh sizes was 906 numbers. Of which, 248 specimens were caught from mesh size 13.5 cm, 245 from 14 cm, 202 from 14.5 cm and 211 from 15 cm (Table 18).

Selection curves were fitted to the data (Table. 4) using four uni-modal functions such as Normal location, Normal scale, Log-normal and Gamma. Models fitted under the assumption of equal fishing power and fishing power is proportional to mesh size are presented in Fig. 33. Total degrees of freedom (DF) for uni-modal curves were 85. Standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve were estimated and presented in the Table 30 and 31.

After fitting the various uni-modal curves, goodness of fit was validated using statistic tool, called model deviance (D). Selection curves of all normal curves were symmetrical in shape and almost similar in all the models without skew ness. Model deviance of each model was observed to find out the best fit of the model. While analyzing the deviance and selection curves of all the models, the entire selection curve gave good fit. Log-normal model yielded better fit than other models having a small model deviance (357.63) in both the assumption of equal fishing power and fishing power is proportional to mesh size. There was no significant difference between models ($P>0.05$) except with normal scale ($P<0.95$) for the difference between

3 Selectivity curves of various models for different mesh sizes and fishing powers for *Carangoides ferdau*

a : Equal fishing power **b : Fishing power α mesh size**

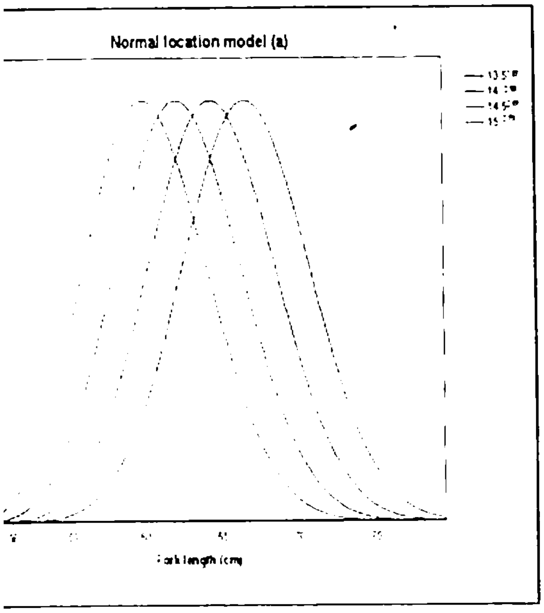


Fig. 33.1

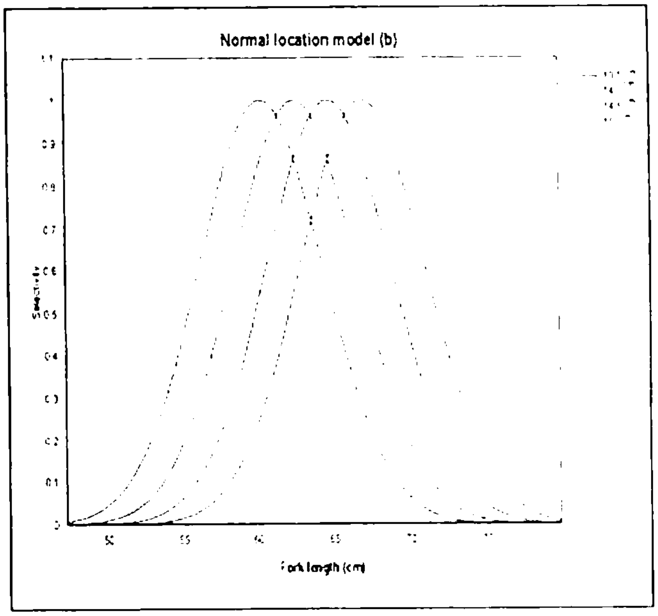


Fig. 33.2

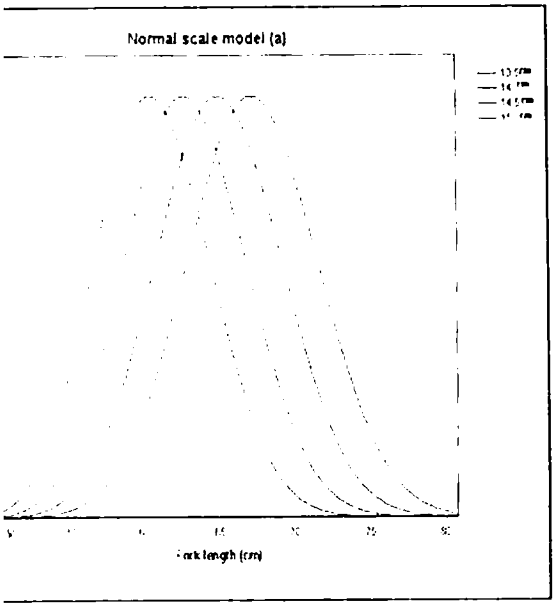


Fig. 33.3

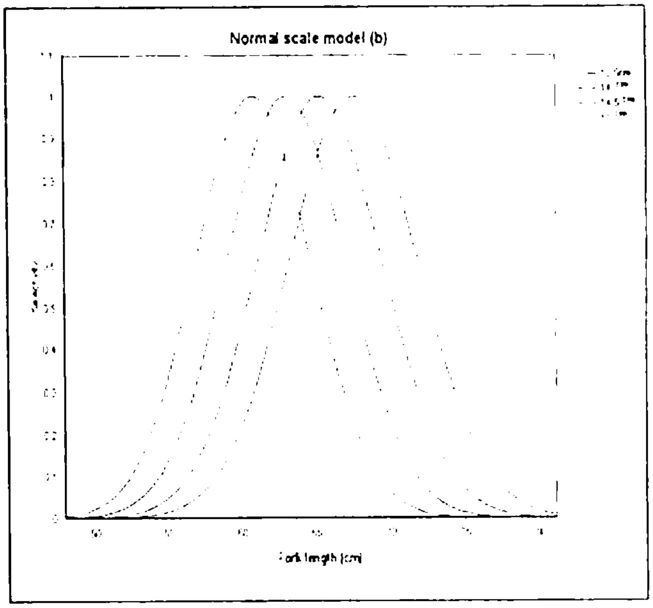


Fig. 33.4

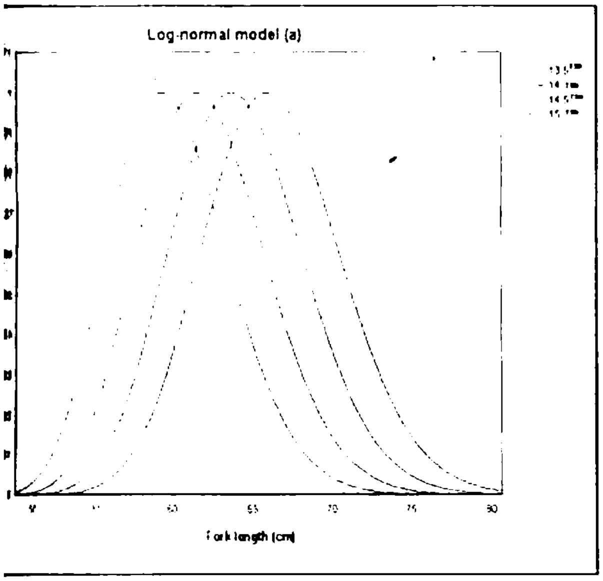


Fig. 33.5

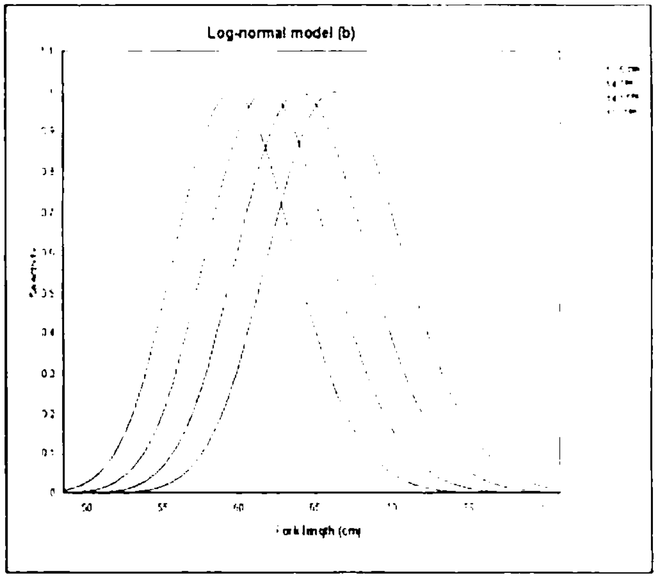


Fig. 33.6

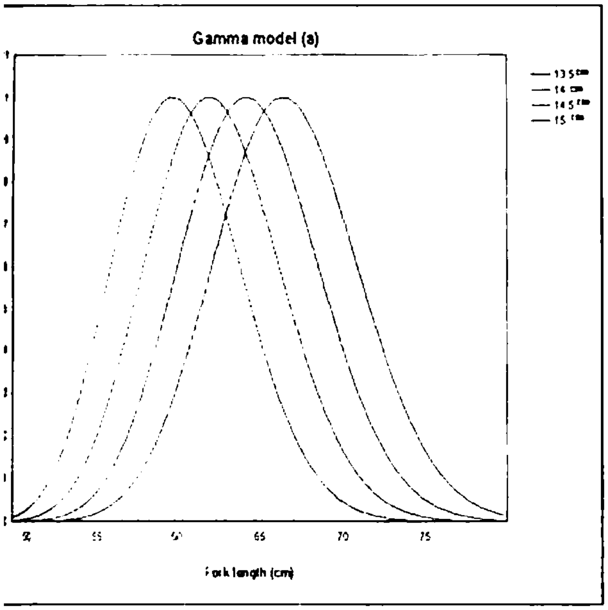


Fig. 33.7

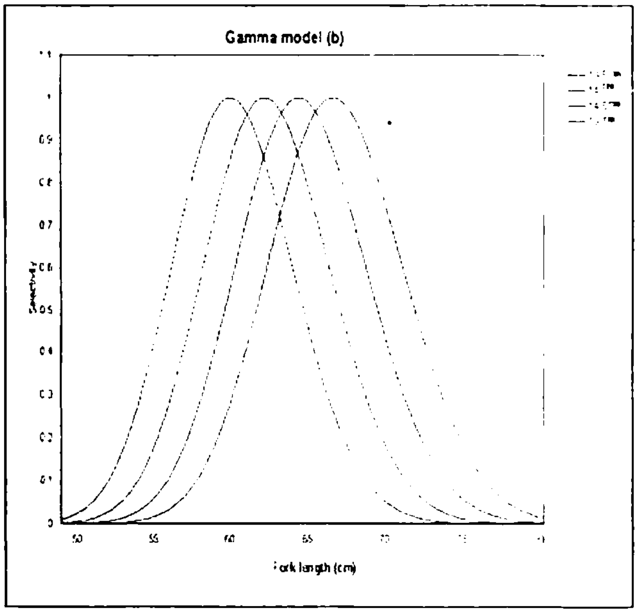


Fig. 33.8

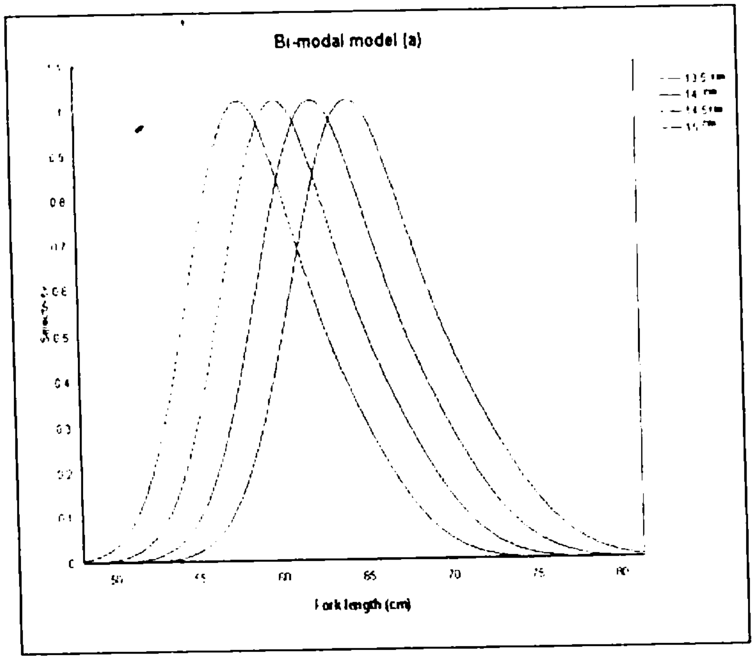


Fig. 33.9

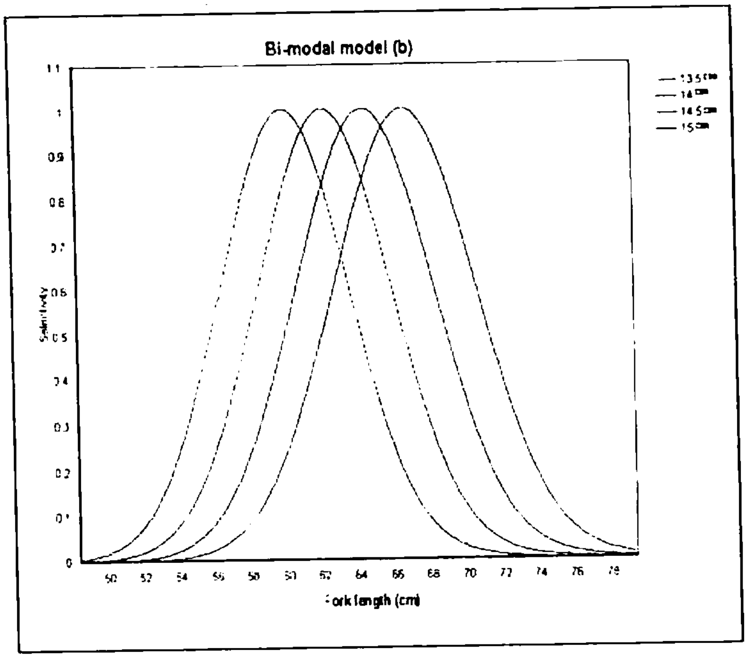


Fig. 33.10

deviances with degrees of freedom given by number of non-zero length classes present in the data minus number of parameters to be estimated. Other better fits followed by log-normal model based on deviance value were normal location (366.41) under the assumption of equal fishing power, gamma (367.4), and normal scale (398.08) under fishing power proportional to mesh size.

The deviance of models fitted was evaluated further for a precision fit using another tool called Dispersion parameter (D / DF). Hence, dispersion parameters for all the models including better log-normal were estimated and they were 4.21 for log-normal, 4.31 for normal location with respect to constant fishing power, 4.32 for gamma model and 4.7 for normal scale model. Over dispersion was found in all the models including better-fit log-normal model owing to dispersion parameter was greater than one. Residual plots of the all models for the species *Carangoides ferdau* were evaluated since model deviance and dispersion were alone need not indicate lack of fit of modeled curve (Mcullagh and Nelder, 1989) (Fig. 34).

Residual plots revealed the fishing powers of 13.5 cm 14 cm and 14.5 cm were greater than mesh size 15 cm due to predominance of positive residuals. Of these, three meshes, mesh size of 14.5 cm ranked first in all the models followed by 14 cm except in the normal scale model and 13.5 cm. Fishing power was equal in both the normal location and gamma model by the presence of equal number of positive residuals in respective mesh sizes. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models. It is seen in the better-fit lognormal model also. Residual plots showed middle length class group of fish which were caught from mesh size of 14.5 cm (60.5 to 82.5) and 14 cm (32.5 to 82.5) and overlapping of catch were also observed in these mesh sizes.

Model length and spread of the selection curves of different models for the different mesh sizes are presented in Table 31. Modal length and spread of the selection curves increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they varied between assumptions of equal fishing power and

Fig. 34 Residuals plots of selectivity curves of various models for different mesh sizes and fishing powers for *Carangoides ferdau* (Area of the circle is proportional to square of the residual)

a : Equal fishing power

b : Fishing power α mesh size

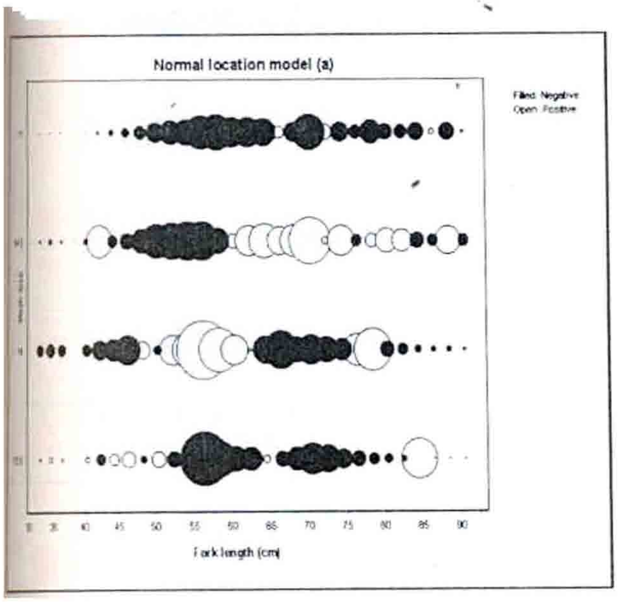


Fig. 34.1

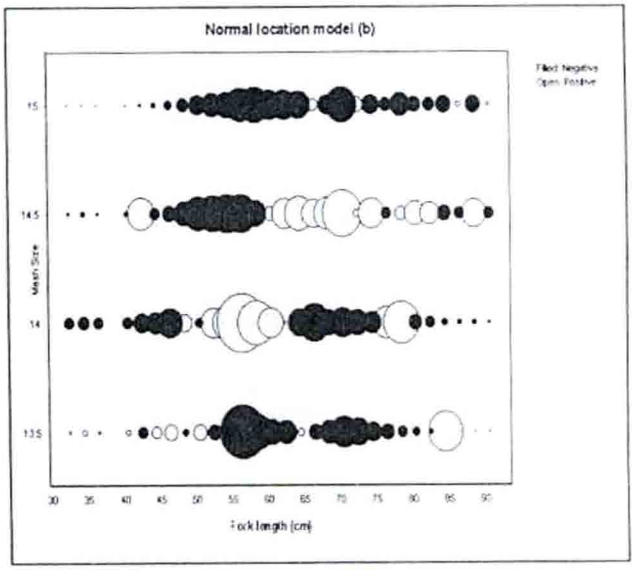


Fig. 34.2

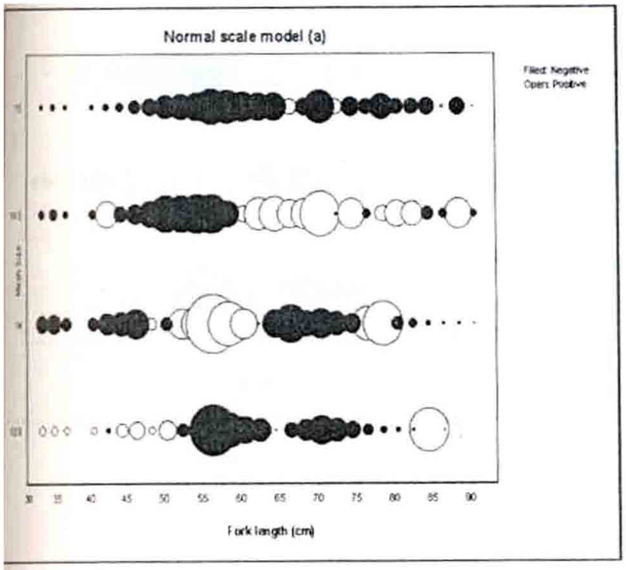


Fig. 34.3

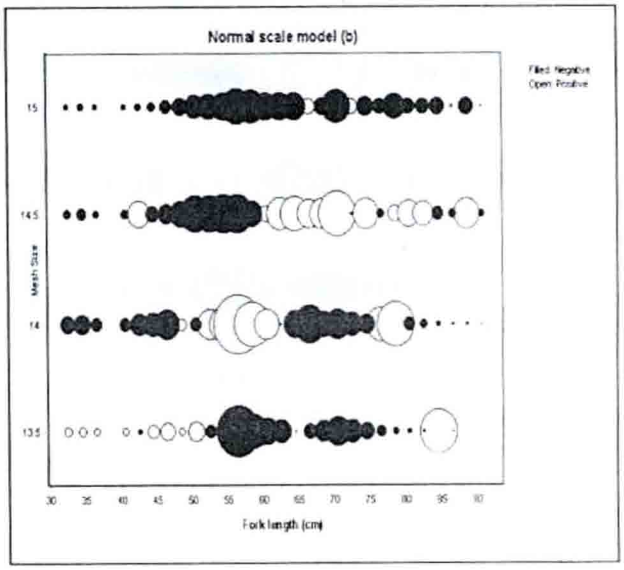


Fig. 34.4

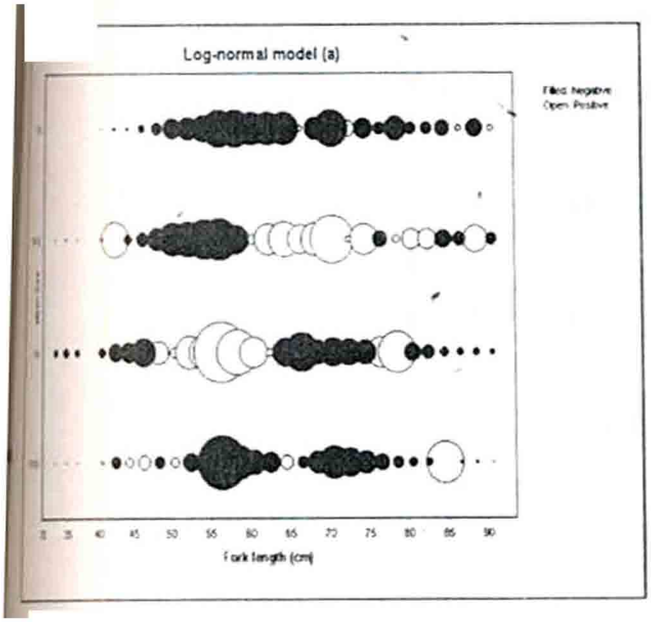


Fig. 34.5

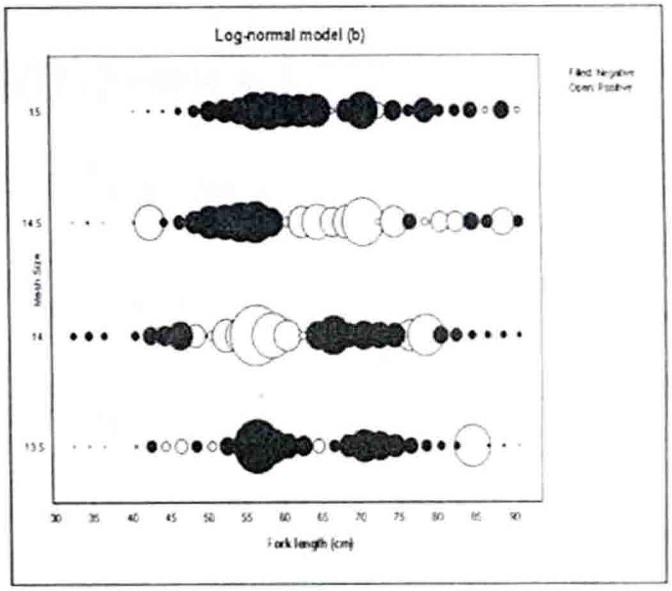


Fig. 34.6

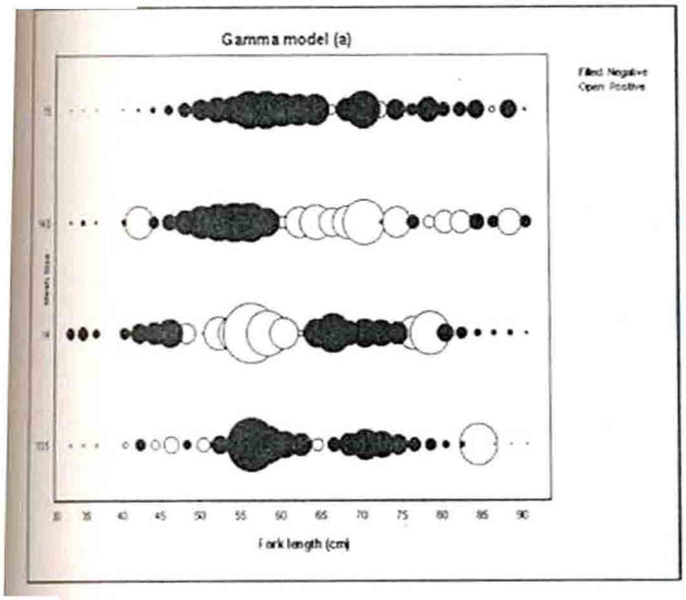


Fig. 34.7

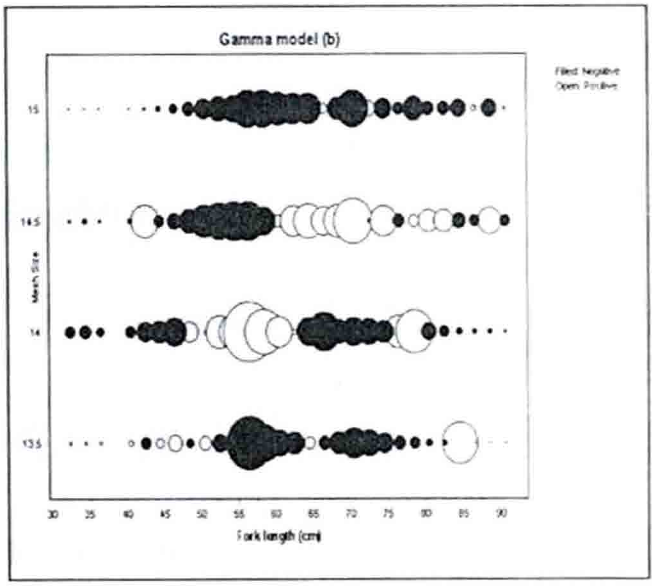


fig. 34.8

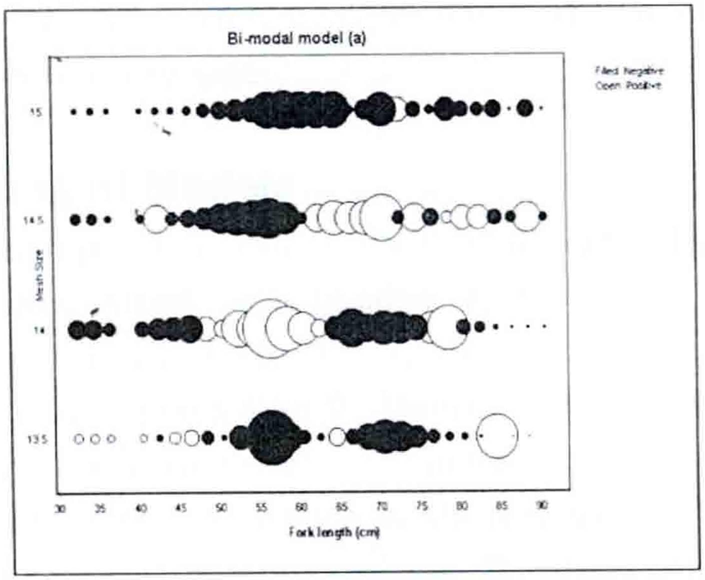


Fig. 34.9

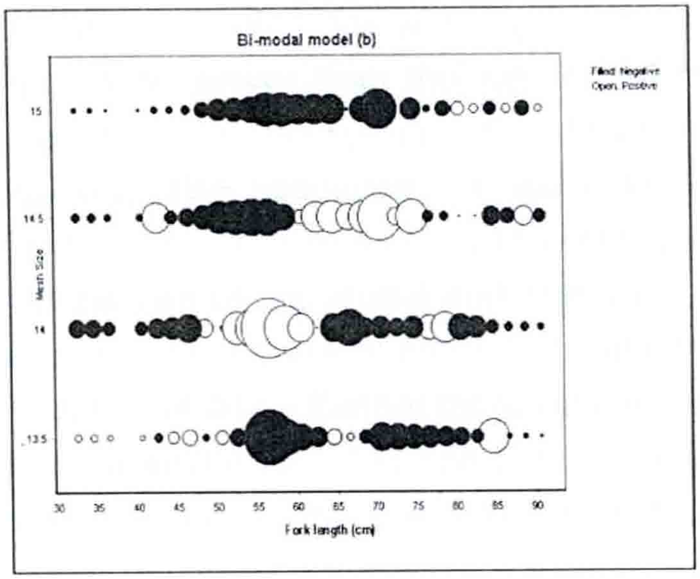


Fig. 34.10

fishing power is proportional to mesh size. Estimated modal length and spread of the better fit model were 59.4 cm to 66 cm and 3.91 to 4.37 for the equal fishing power and 59.6 cm to 66.2 cm and 3.93 to 4.37 when the fishing power is proportional to mesh size.

4.7.1.1.1 Refitting of Models

Residual plot of better-fit log-normal model showed lack of fit by the presence of large sized both positive and negative residuals in and systematic occurrence of residuals instead of random order. Besides, value of all the residuals was not less than 2. Hence, refitting of the selectivity data for an improved model is required i.e., model that decreases the model deviance and avoids systematic trends in the residuals. Thus the uni-modal log-normal was extended to bi-modal model. Bi-modal selectivity curves and their parameters were also estimated under the assumption of equal fishing power and fishing power proportional to mesh size (Table. 30). DF for the bi-modal was 82.

Model deviance of bi-modal model was slightly reduced to 356.02 for the assumption of fishing power proportional to mesh size despite the reduction was very meager compared to uni-modal log-normal model (357.63). However, deviance (366.69) was higher for the bi-modal under assumption of equal fishing power than the log-normal model under equal fishing power. In order to find out goodness of fit of the bi-modal curve, dispersion parameter was also estimated. It was 4.47 and 4.34 for equal fishing power and fishing power proportional to mesh size respectively. It revealed that over dispersion of the model and moreover, it was little higher than the value of uni-modal log-normal fit dispersion parameter (4.21), gamma (4.32), and normal location (4.31). Further there was no significant difference between deviances of bi-modal (356.02) and log-normal model (357.63) for the degrees of freedom given by the difference between number of parameters.

Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to mesh size and they were 57.1 cm - 63.5 cm with the spread range of 2.76 - 3.06 and 60 - 66.6 cm with the spread of 3.54 - 3.93 respectively.

Residual plots of bi-modal function under both the assumption were presented in Fig. 34.9-34.10. Plots explained that the mesh sizes of 13.5, 14, and 14.5 cm were greater than modeled with the presence of more positive residuals. Residual plots of both uni-modal log-normal and bi-modal were almost similar despite the variation in the order of rank of efficient mesh size. In this model, the mesh size 14.5 cm ranked first as existed in the log-normal model but the next effective mesh size was 13.5 followed by 14 cm. It was reverse in the log-normal model. Much difference was not shown with log-normal model in terms of the size groups caught. Residual plots were almost similar for both bi-modal and log-normal model though a slight reduction observed in the deviance of bi-modal than the uni-modal log-normal model selection.

4.7.1.2 *Carangoides fulvoguttatus*

Over all total catch of *Carangoides fulvoguttatus* obtained from four mesh sizes was 2227numbers. Of which, 349 specimens were caught from mesh size 13.5 cm, 615 from 14 cm, 753 from 14.5 cm and 510 from 15 cm (Table. 18)

All four uni-normal curves were fitted to the selectivity data (Table. 5) under the assumption such as equal fishing power and fishing power is proportional to mesh sizes. They were presented in Fig. 35. Total degrees of freedom (DF) for uni-modal curves were 121. Standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve were estimated and presented in the Table 30 and 31.

After fitting the various uni-modal curves, goodness of fit was validated using the estimated model deviance (D). Selection curves of all normal curves were symmetrical in shape and almost similar in all the models without skewness. While analyzing the deviance, it was found that all selection curves of all the models gave good fit. However, normal scale model yielded better fit than other models having a small model deviance

35 Selectivity curves of various models for different mesh sizes and fishing powers for *Carangoides fulvoguttatus*

a : Equal fishing power

b : Fishing power α mesh size

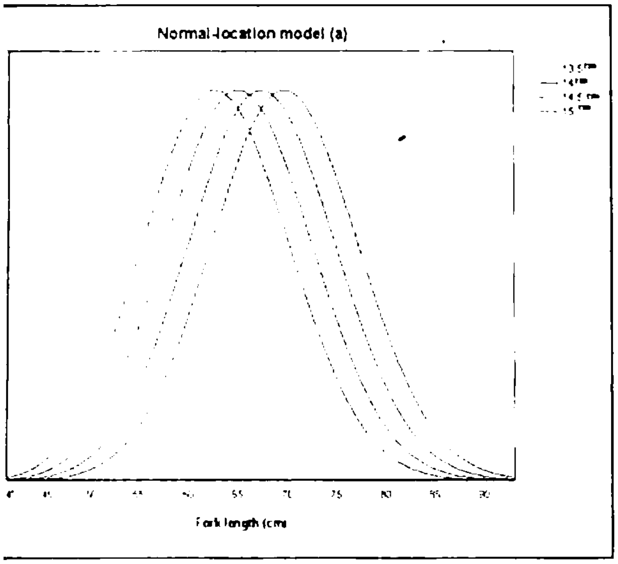


Fig.35.1

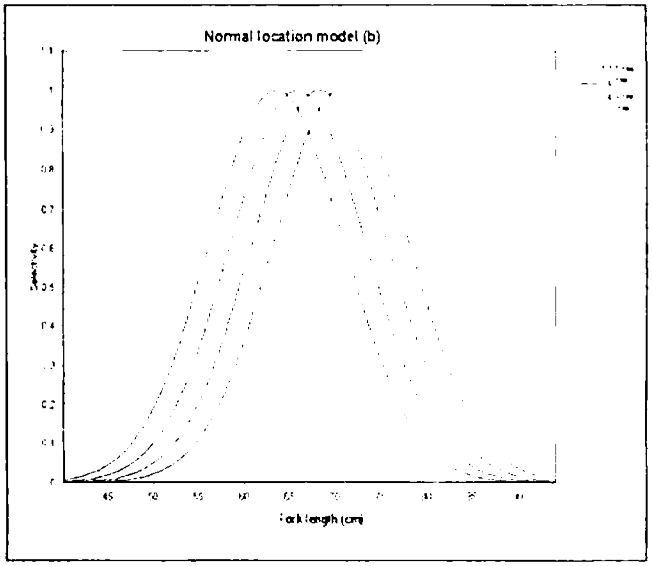


Fig. 35.2

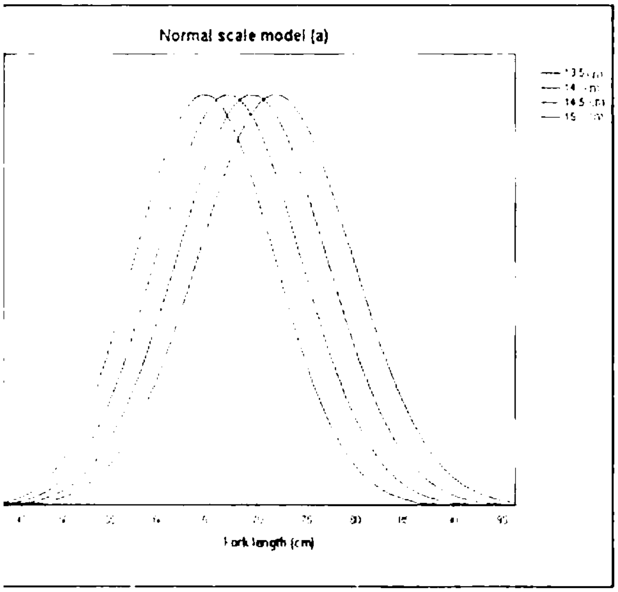


Fig. 35.3

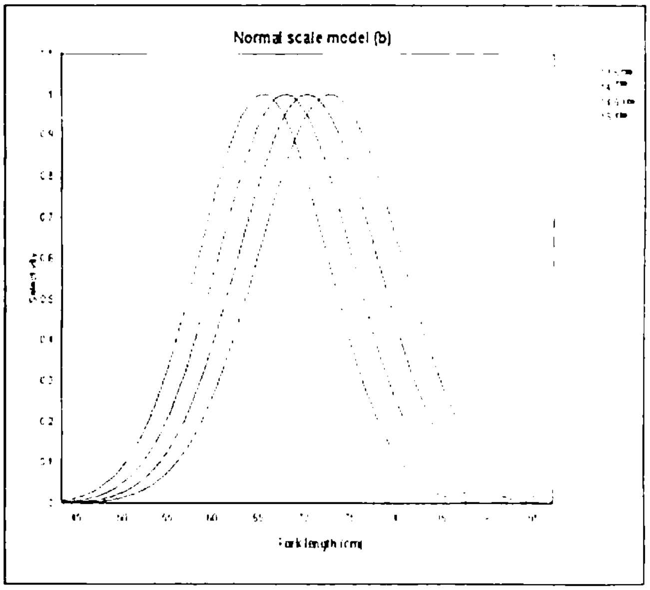


Fig. 35.4

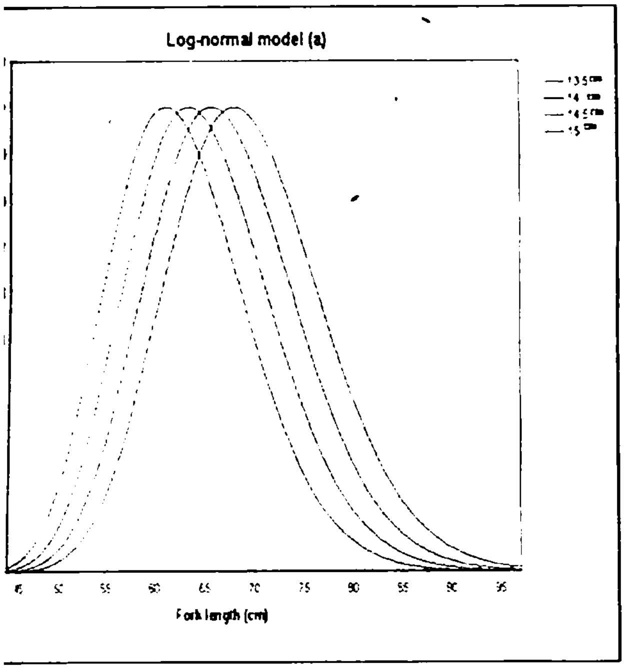


Fig. 35.5

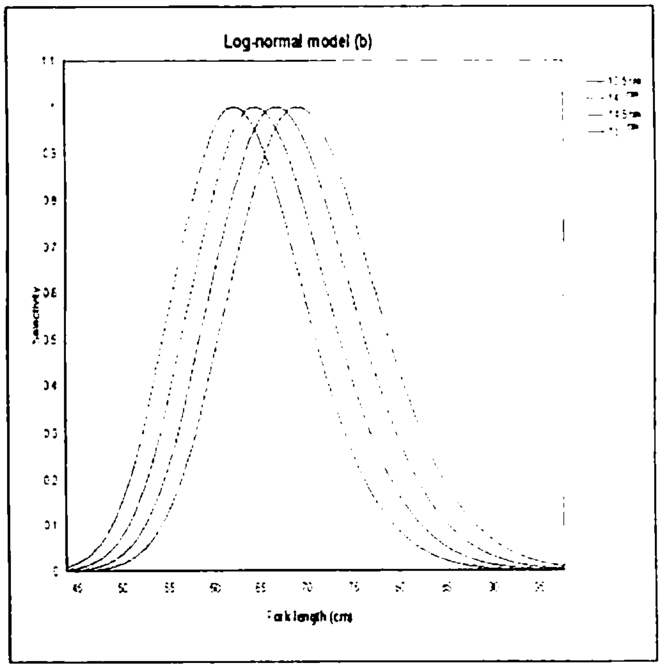


Fig. 35.6

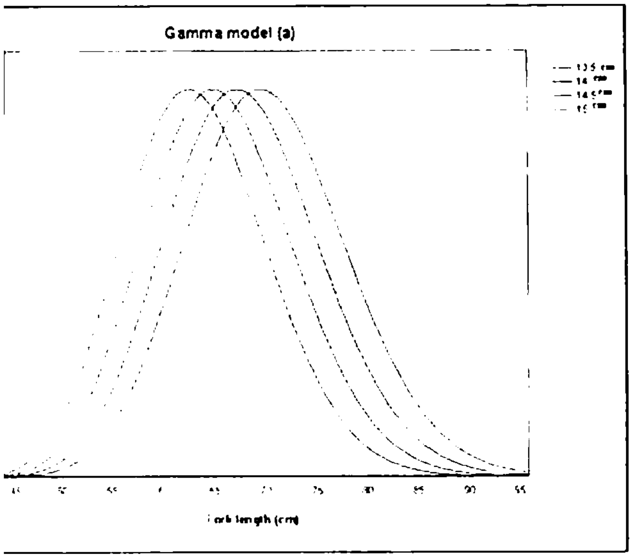


Fig. 35.7

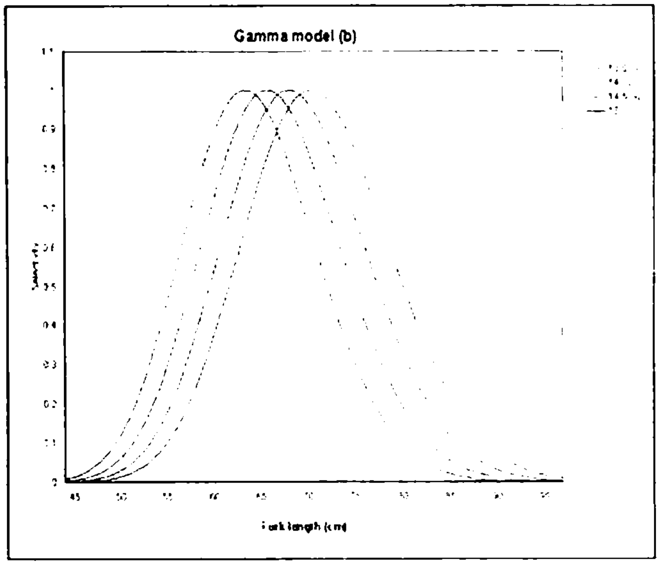


Fig. 35.8

(653.60) and (653.5) with the assumption of equal fishing power and fishing power is proportional to mesh size respectively. Significant difference was found between the models (P<0.01). Other better fits followed by normal scale model based on deviance value were gamma (686.41), normal location (691.39) under the assumption of fishing power proportional to mesh size and log-normal model (724.22).

All the model including better-fit normal scale model were validated by dispersion parameter since, D was higher than DF. Estimated dispersion values were 5.4 for normal scale, 5.67 for gamma 5.73 and 5.71 for normal location with respect to constant fishing power and fishing power proportional to mesh size, 6.13 for log-normal model. All the models including better-fit normal scale model showed over dispersion since the dispersion parameter was higher than one and it indicated lack of fit in normal scale model.

Evaluated residual plots of the all models for the species *Carangoides fulvoguttatus* (Mcullagh and Nelder, 1989) (Fig. 36) under both the assumptions of equal fishing power and fishing power proportional to mesh size revealed that the fishing powers of 13.5cm 14 cm and 14.5 cm were greater than mesh size 15 cm due to predominance of positive residuals. Of these three meshes, mesh size of 14.5 cm ranked first in all the models followed by 14 cm and 13.5 cm. However, fishing powers of the mesh size 13.5 cm was equal with 15 cm in the normal location and gamma by the presence of equal number of positive residuals in both the assumptions in all the models except better fit model. Deviance residuals were equal for both equal fishing intensity and fishing power proportional to mesh size in all the uni-models. But it was not true in the better-fit normal scale model by the presence of little more positive residuals in 14.5 cm mesh alone under equal fishing power and remaining meshes had equal residuals.

Residual plots showed small length class group to higher length class (44.5 – 102.5 cm) of fish were caught from the mesh 14.5 cm, middle length group (44.5 - 72.5 & 90.5 – 96.5 cm) from 14 cm and smaller group (28.5 – 42.5 cm) from 13.5 cm and overlapping of catch were also observed in these mesh sizes.

g. 36 Residuals plots of selectivity curves of various models for different mesh sizes and fishing powers for *Carangoides fulvoguttatus* (Area of the circle is proportional to square of the resisual)

a : Equal fishing power

b : Fishing power α mesh size

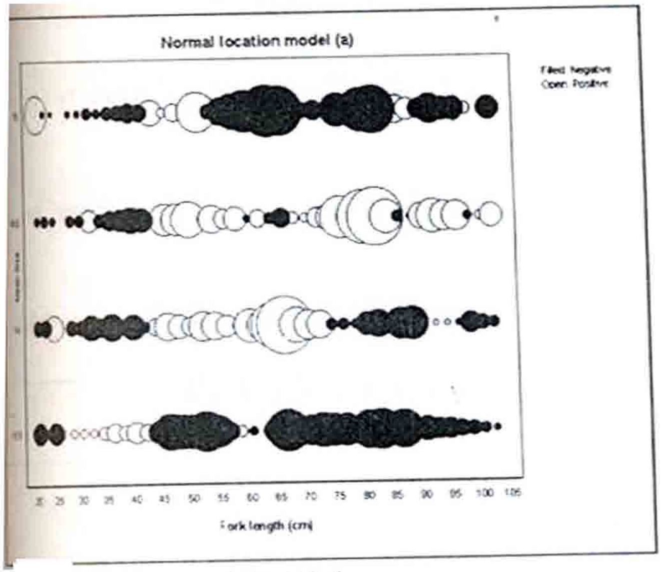


Fig. 36.1

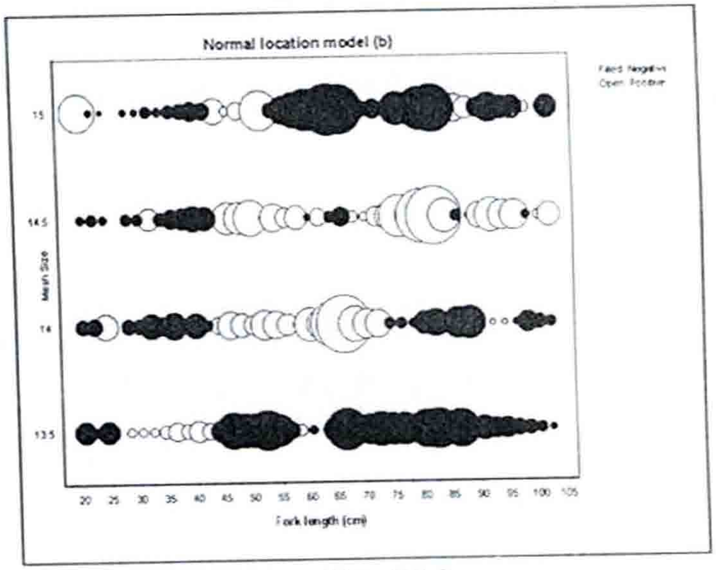


Fig. 36.2

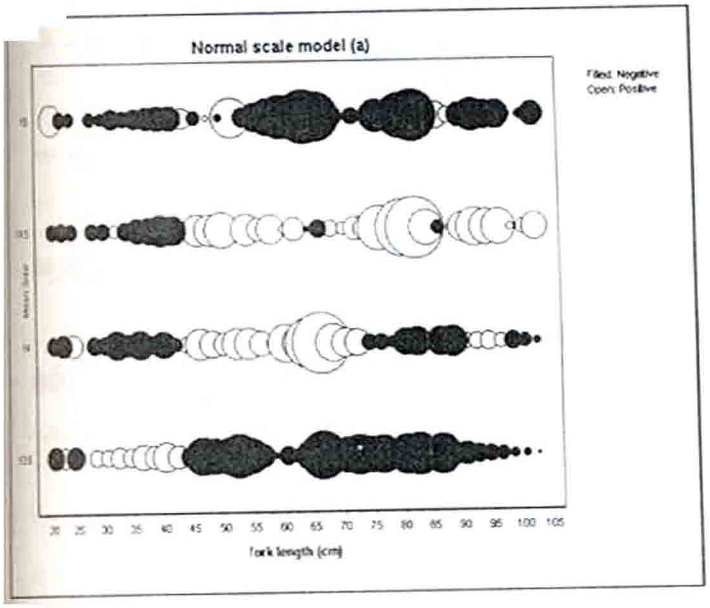


Fig. 36.3

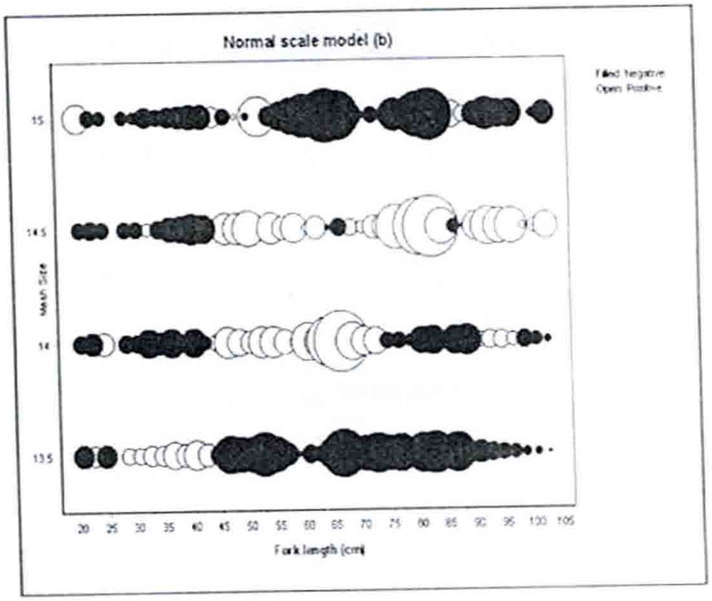


Fig. 36.4

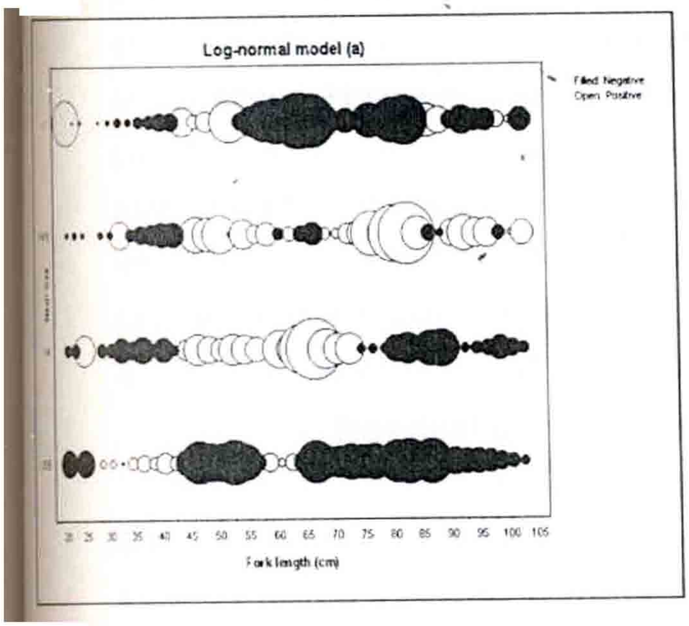


Fig. 36.5

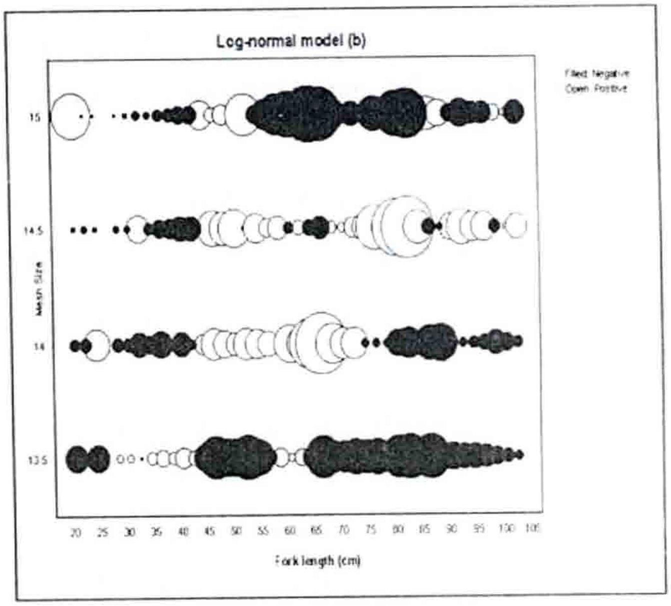


Fig. 36.6

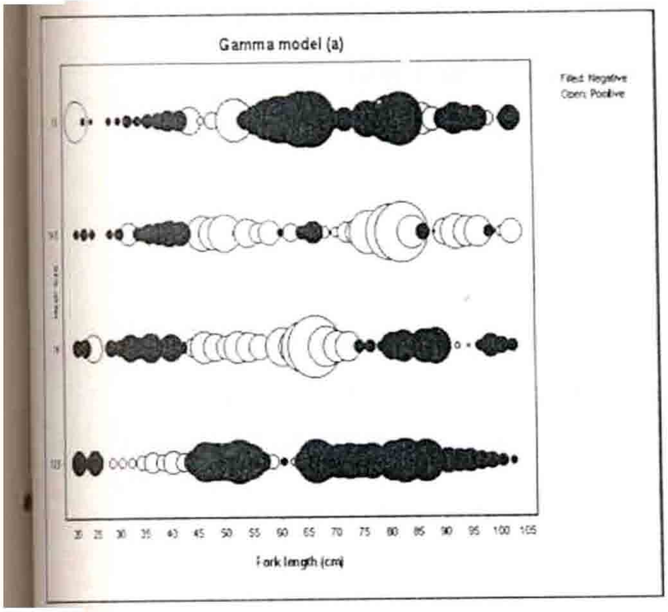


Fig. 36.7

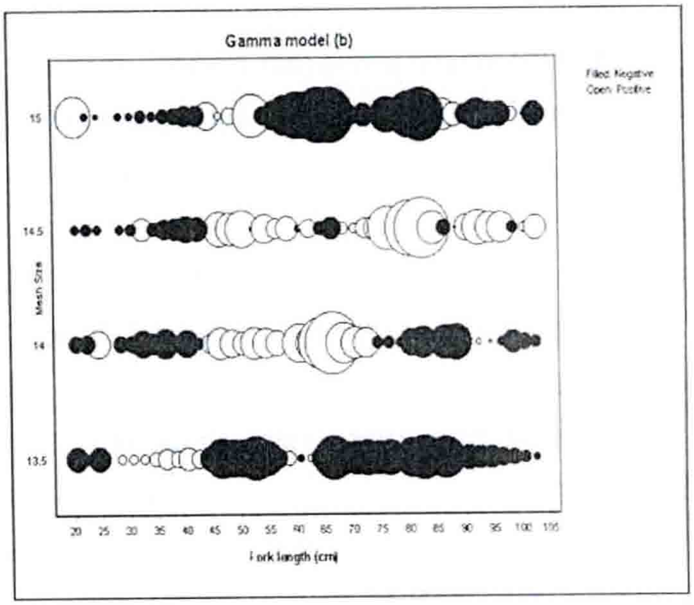


Fig. 36.8

Model length and spread of the selection curves of different models for the different mesh sizes were presented in the Table 31. Modal length and spread of the selection curves were increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they varied between assumptions of equal fishing power and fishing power is proportional to mesh size. Estimated modal length and spread of the better fit model were 64.6 - 71.8 cm and 7.07 - 7.86 for the equal fishing power and 65.4 - 72.7 cm and 7.03 - 7.81 for the fishing power is proportional to mesh size.

4.7.1.2.1 Refitting of Models

Residual plot of better-fit normal scale model showed lack of fit by the presence of large sized residuals in both positive and negative and their systematic occurrence of residuals instead of random order. Besides. value of all the residuals was not less than 2. Hence, refitting of the selectivity data for an improved model is required. Thus an attempt was made to extend the uni-modal normal scale into bi-modal. But the selectivity data did not converge into bi-normal model.

4.7.1.3 *Caranx heberi*

Over all total catch of *Caranx heberi* obtained from four mesh sizes was 3464 numbers. Of which, 954 specimens were caught from mesh size 13.5 cm, 1143 from 14 cm, 716 from 14.5 cm and 651 from 15 cm (Table. 18).

Four uni-normal families of selection curves fitted to the data (Table. 3) under the assumptions of equal fishing power and fishing power is proportional to mesh sizes were presented in Fig. 37. Total degrees of freedom (DF) for uni-modal curves was 112 and other estimated parameters such as, standard deviation (SD), model deviance (D), other parameters and other selectivity statistics viz., modal length and spread of selection curve were presented in the Table 30 to 31. Selection curves of all normal curves were symmetrical in shape and almost similar in all the models without skew ness.

Selection curves of all the models, the entire selection curve gave good fit. However, Log-normal model yielded better fit than other

.37 Selectivity curves of various models for different mesh sizes and fishing powers for *Caranx heberi*

a : Equal fishing power

b : Fishing power α mesh size

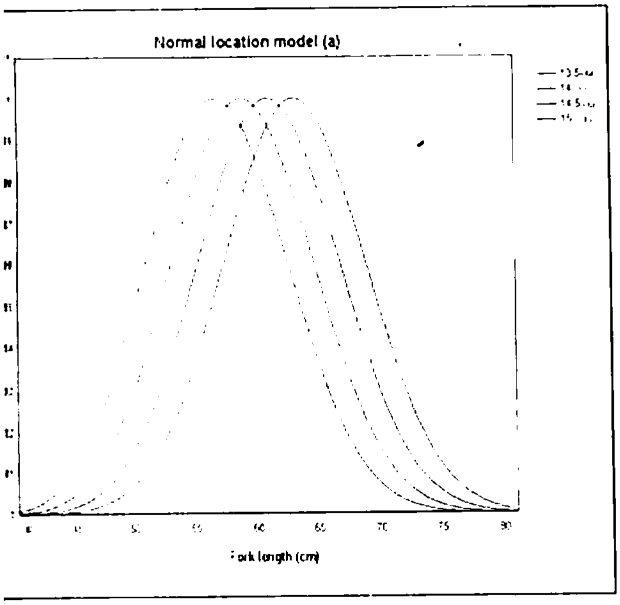


Fig 37.1

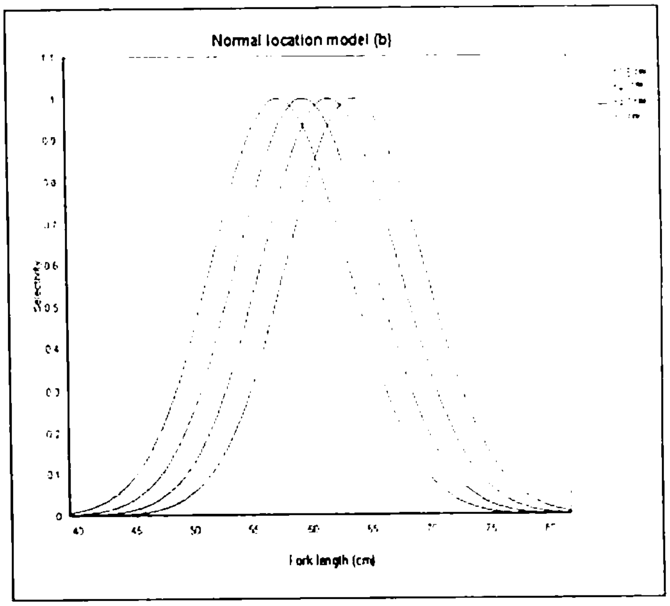


Fig. 37.2

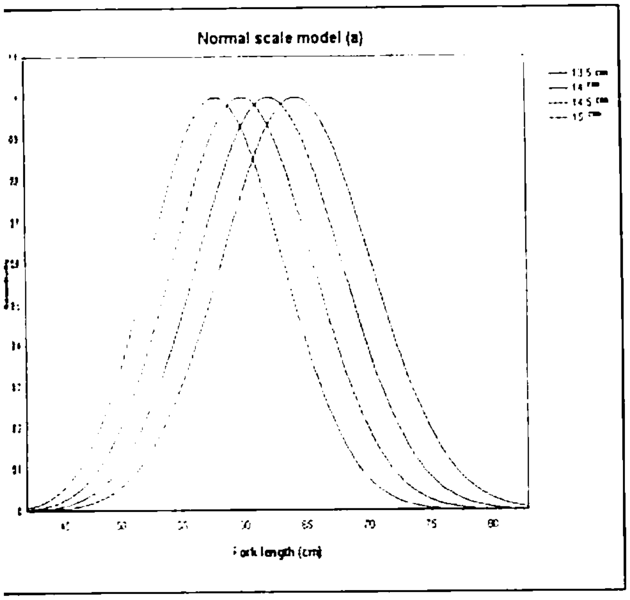


Fig. 37.3

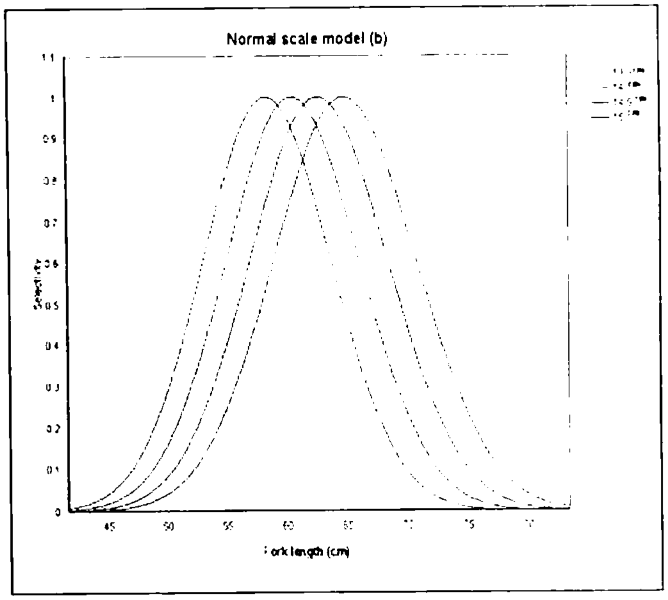


Fig. 37.4

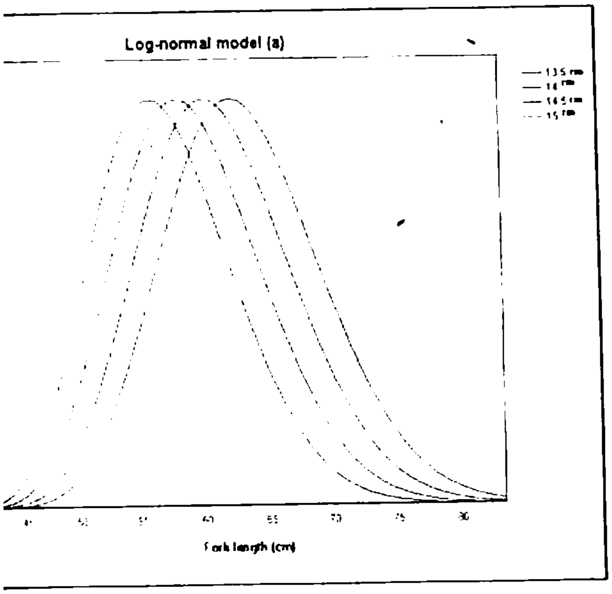


Fig. 37.5

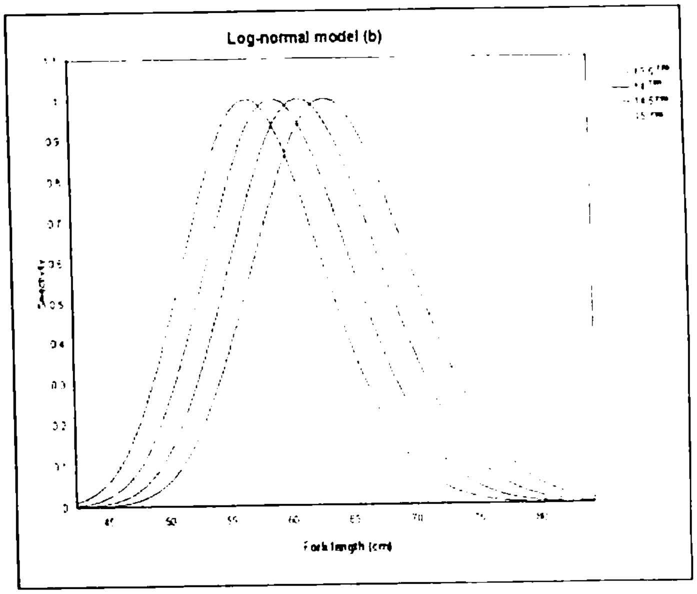


Fig. 37.6

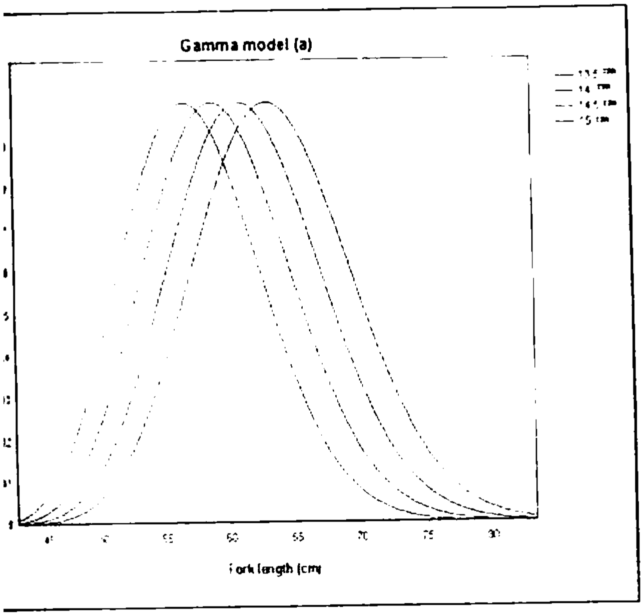


Fig. 37.7

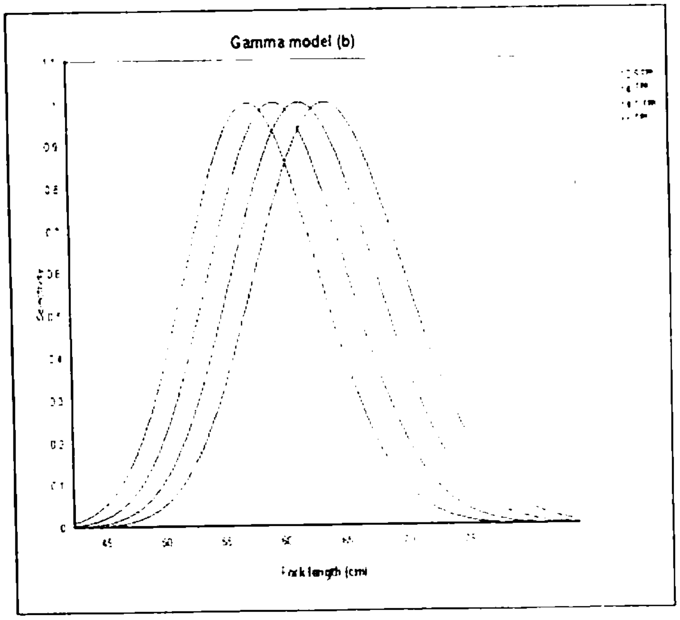


Fig. 37.8

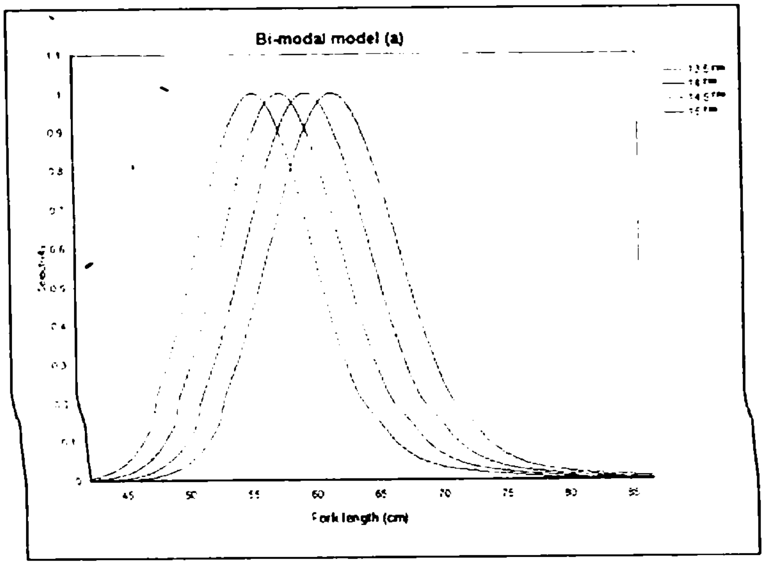


Fig. 37.9

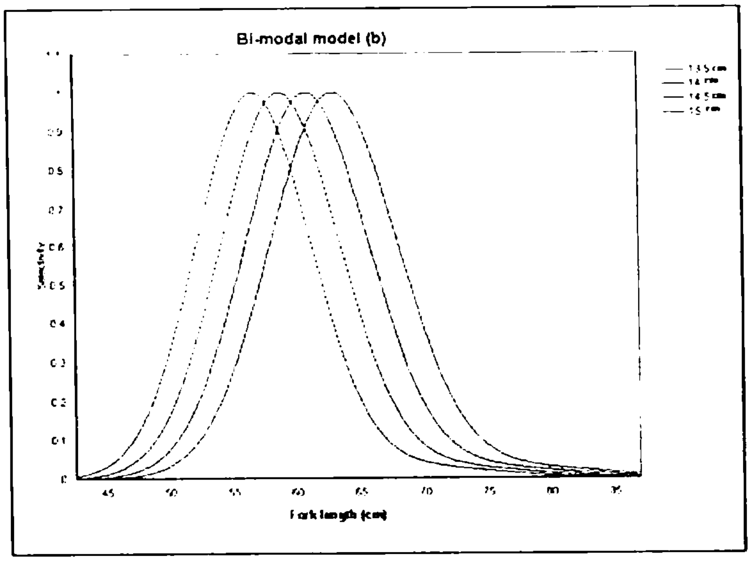


Fig. 37.10

models having a small model deviance (621.18) in both the assumption of equal fishing power and fishing power is proportional to mesh size. There was no significant difference between models (P>0.05) except with normal scale (P<0.01) for the difference between deviances. Deviance value for both the assumption was equal in the cases of log-normal and gamma model. Other better fits followed by log-normal model based on deviance value were normal location (637.58) under the assumption of fishing power is proportional to mesh size, gamma (637.76), and normal scale (775.93) under equal fishing power.

All models including better-fit log-normal model were validated using dispersion parameter for further precision fit. Estimated dispersion values were 5.55 for log-normal, 5.71 and 5.69 for normal location with respect to constant fishing power and proportional to mesh size respectively. 5.69 for gamma model and 6.93 and 6.94 for normal scale model under the equal fishing power and fishing power proportional to mesh size respectively. All the models including better-fit log-normal model showed over dispersion since, dispersion parameter was higher than '1' and in turn represented lack of fit in log-normal model.

Plotted deviance residuals (Mcullagh and Nelder, 1989) of the all models under both the assumptions of equal fishing power and fishing power proportional to mesh size for the species *Caranx heberi* were evaluated to obtain precision of the fit (Fig. 38). Residual plots revealed the fishing powers of 13.5cm 14 cm and 14.5 cm were greater than mesh size 15 cm due to predominance of positive residuals. Of these three meshes, mesh size of 14 cm ranked first in all the models followed by 14.5 cm and 13.5 cm. Fishing powers were almost equal in both the log-normal and gamma model by the presence of equal number of positive residuals in respective mesh sizes. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models. It became true in the better-fit lognormal model also. Residual plots showed that almost all length class group of fish were caught in the mesh size of 14.0 cm (30.5 - 96.5 cm) and 14.5 cm captured the larger length group (58.5 - 92.5 cm) and overlapping of catch were also observed in these mesh sizes.

Fig. 38 Residuals plots of selectivity curves of various models for different mesh sizes and fishing powers for *Caranx heberi* (Area of the circle is proportional to square of the residual)

a : Equal fishing power

b : Fishing power α mesh size

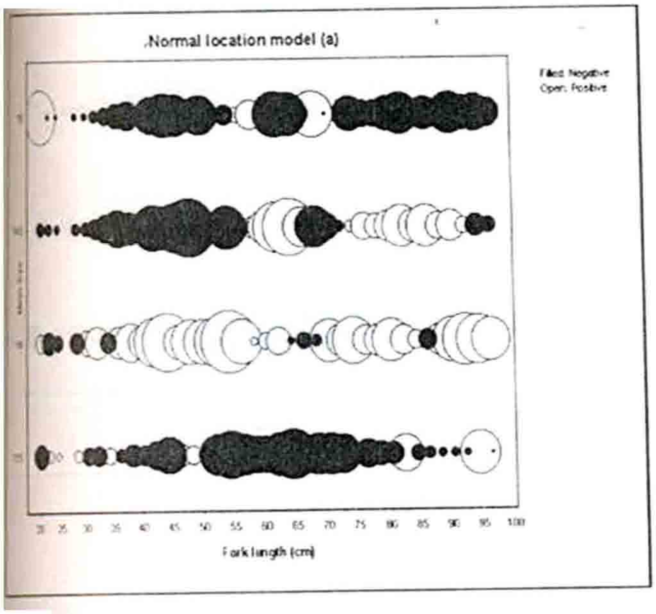


Fig. 38.1

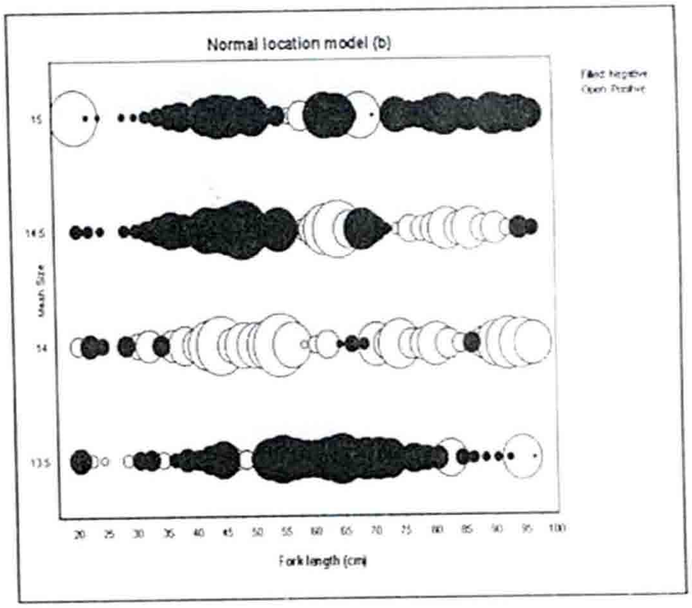


Fig. 38.2

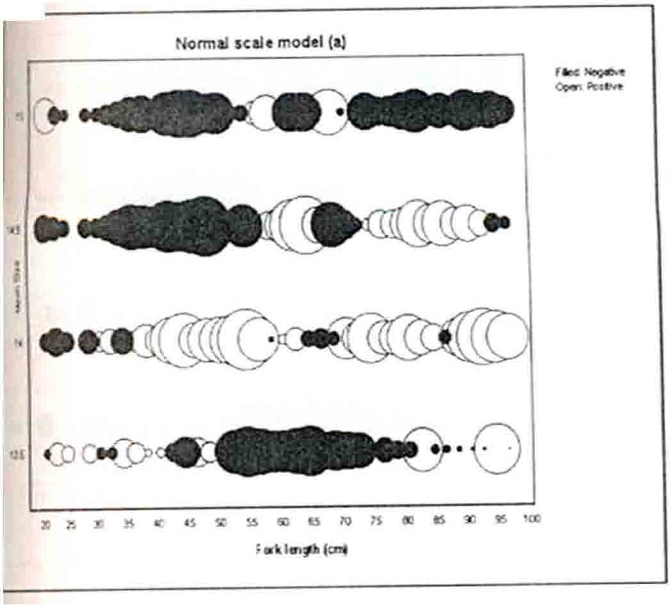


Fig. 38.3

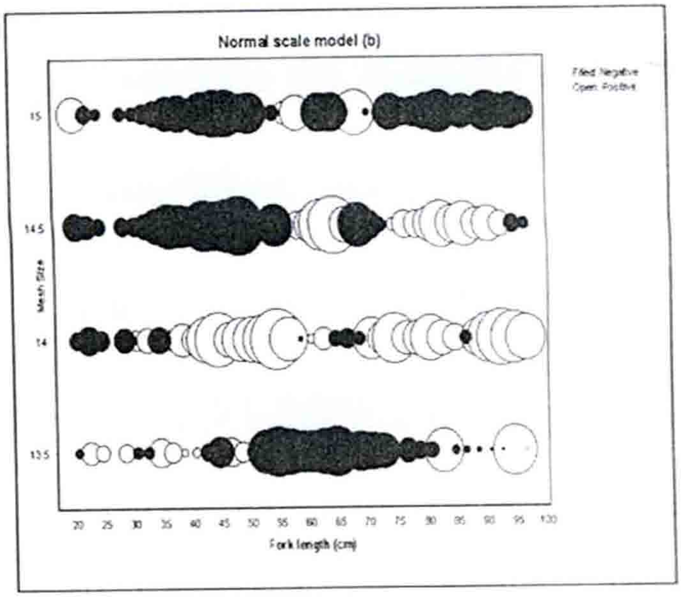


Fig. 38.4

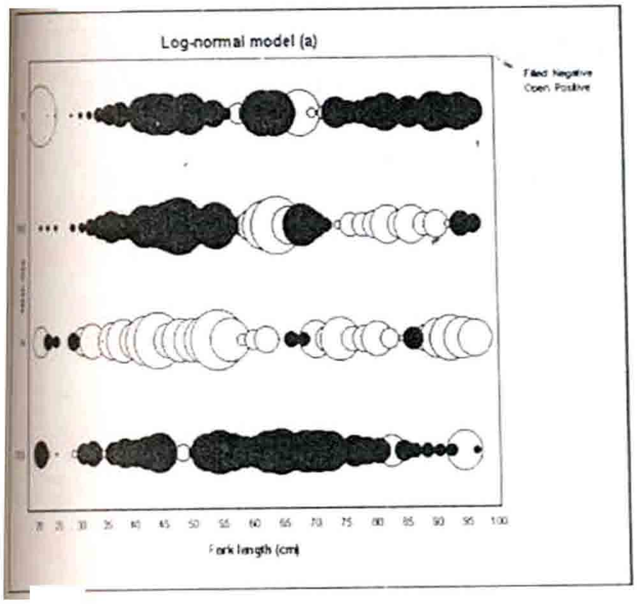


Fig. 38.5

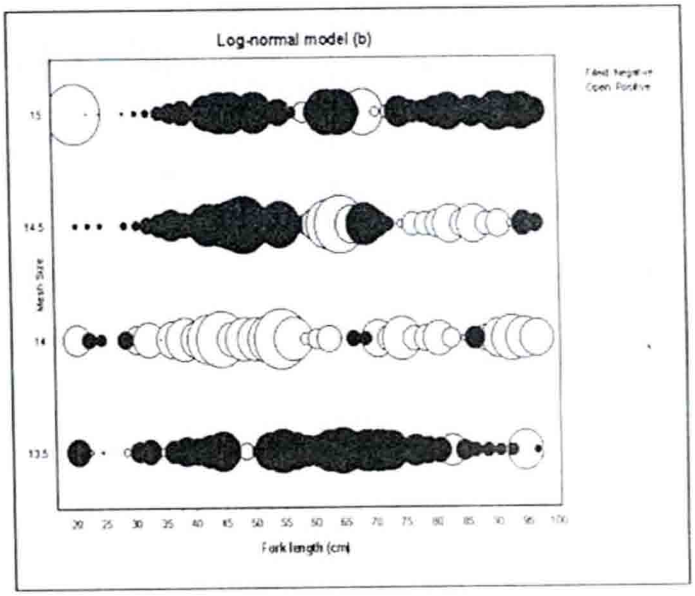


Fig. 38.6

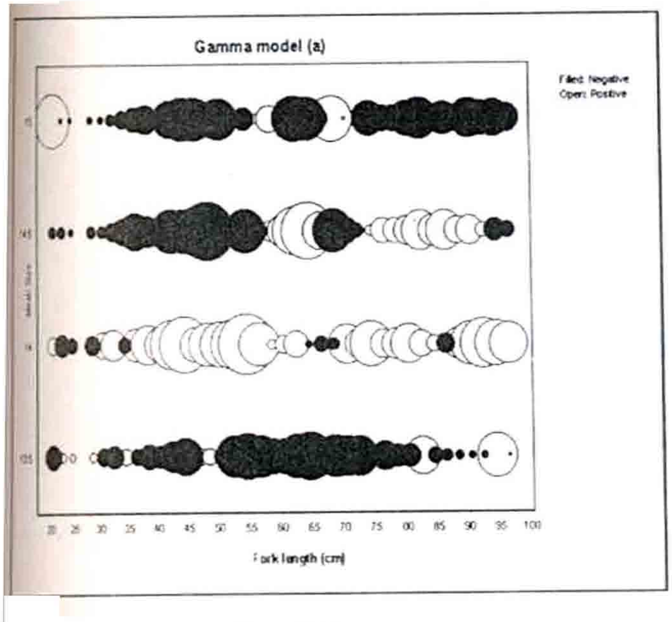


Fig. 38.7

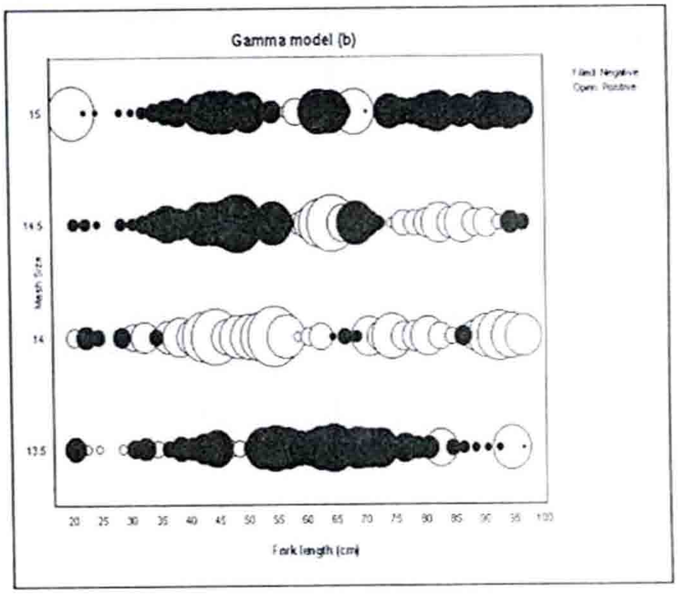


Fig. 38.8

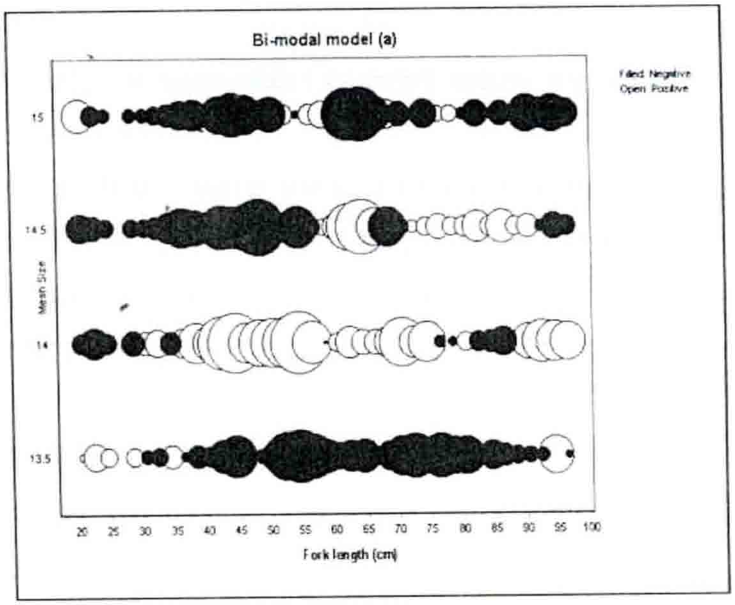


Fig. 38.9

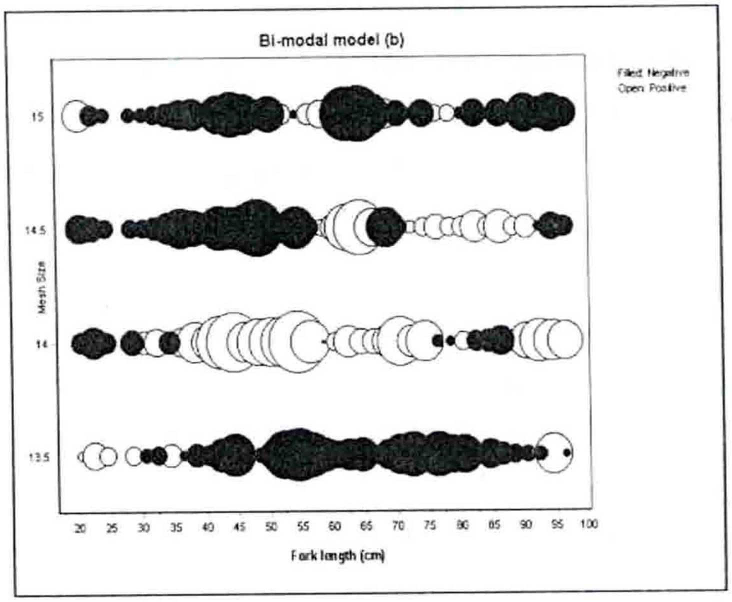


Fig. 38.10

Model length and spread of the selection curves of different models for the different mesh sizes were presented in the Table 31. Modal length and spread of the selection curves were increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they were varied between assumptions of equal fishing power and fishing power is proportional to mesh size. Estimated modal length and spread of the better fit model were 56.2 - 62.5 cm and 4.49 - 4.99 for the equal fishing power and 56.6 - 62.9 cm and 4.47 - 4.97 for the fishing power is proportional to mesh size.

4.7.1.3.1 Refitting of Models

The uni-modal log-normal was extended to bi-modal or bi-normal model since it exhibited lack of good fit by the presence of large sized positive residuals in systematic way. Estimated bi-modal selectivity curves and their parameters are presented in Table 30 and Fig.37.9 - 37.10. DF for the bi-modal was 109.

Model deviance of bi-modal model was drastically reduced to 546.64 for the assumption of equal fishing power despite the value of deviance was slightly high (547.11) for the assumption of fishing power proportional to mesh size. Estimated dispersion parameter was 5.02 for both equal fishing power and fishing power proportional to mesh size. It revealed over dispersion of the model and moreover, it was little lesser than value of uni-modal fits including log-normal fit. Further there was significant difference between deviances of bi-modal (546.64) and log-normal model (621.18) for the degrees of freedom given by the difference between number of parameters.

Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to mesh size and they were 56.2 to 62.5 cm with the spread range of 4.49 to 4.99 and 56.6 to 62.9 cm with the spread of 4.47 to 4.97 respectively. Modal length obtained from bi-modal was higher than log-normal model under the assumption of equal fishing power and lesser in the case of fishing power is proportional to mesh size. But, the spread of bi-modal curve was lesser than log-normal model in both the assumptions.

Residual plots of bi-modal function under both the assumption were presented in Fig. 38.9 and 38.10. Plots explained that the mesh sizes of 13.5, 14, and 14.5 cm were greater than modeled with the presence of more positive residuals. Residual plots of both uni-modal log-normal and bi-modal were almost similar despite number of positive residuals present was lower in 14 cm and higher in 15 cm than log-normal fit. There was no great difference was shown with log-normal model in terms of size groups caught except in the mesh size 15 cm. Residual plots of both bi-modal and log-normal model could not be distinguished though there was drastic reduction observed in the deviance of bi-modal from the uni-modal log-normal model selection.

4.7.1.4 *Caranx ignobilis*

Over all total catch of *Carangoides ignobilis* obtained from four mesh sizes was 2586 numbers. Of which, 524 specimens were caught from mesh size 13.5 cm, 555 from 14 cm, 607 from 14.5 cm and 900 from 15 cm (Table. 18).

Five families of uni-modal selection such as Normal location, Normal scale, Log-normal and Gamma curves were fitted to the data (Table. 7) were presented in Fig. 39. Total degrees of freedom (DF) for uni-modal curves was 115 and other parameters such as standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve were estimated and presented in the Table 30 & 31.

After analyzing the model deviance of each model and selection curves, it was found that all selection curve gave good fit. However, normal scale model yielded better fit than other models by having a small model deviance (522.79) under the assumption of equal fishing power. There was significant difference between models ($P<0.01$) for the difference between deviances. Deviance value for both the assumption was equal in the cases of log-normal and gamma model. Other better fits followed by normal scale model based on deviance value were gamma (569.34), normal location

39 Selectivity curves of various models for different mesh sizes and fishing powers for *Caranx ignobilis*

a : Equal fishing power

b : Fishing power α mesh size

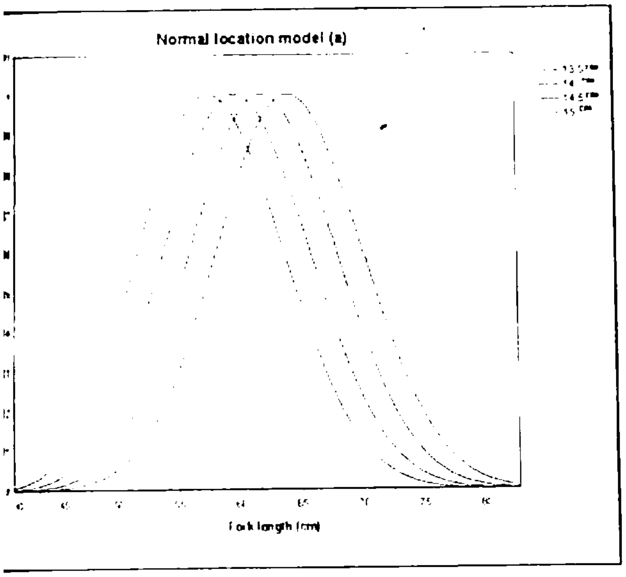


Fig. 39.1

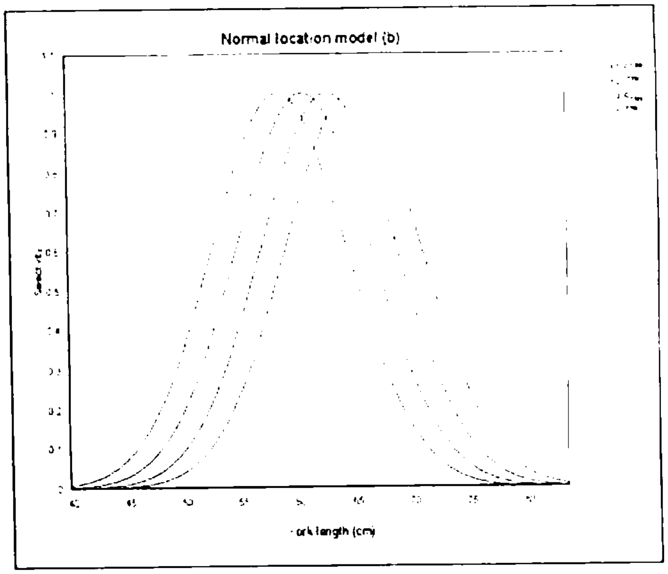


Fig. 39.2

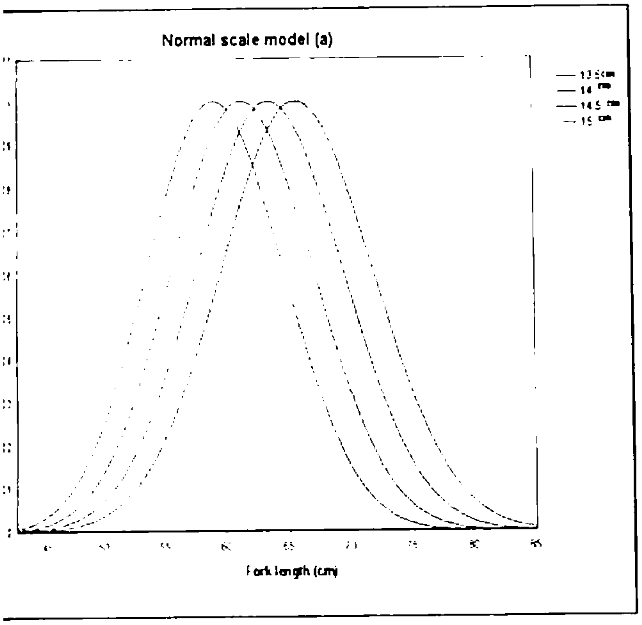


Fig. 39.3

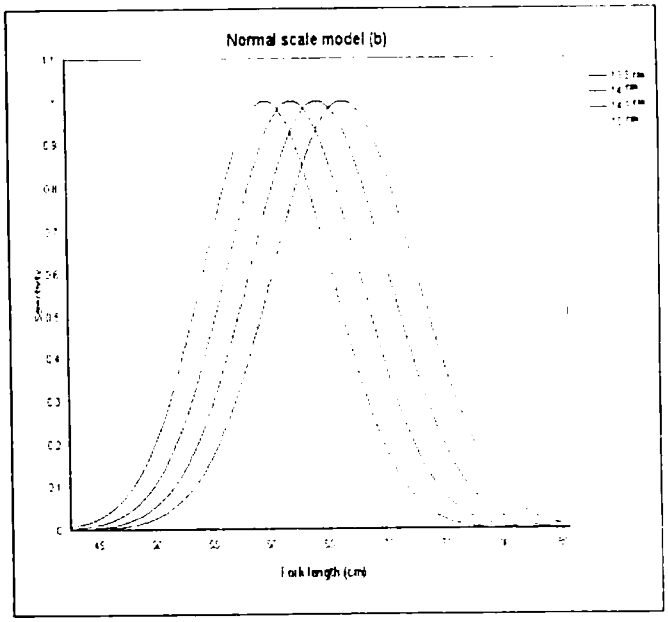


Fig. 39.4

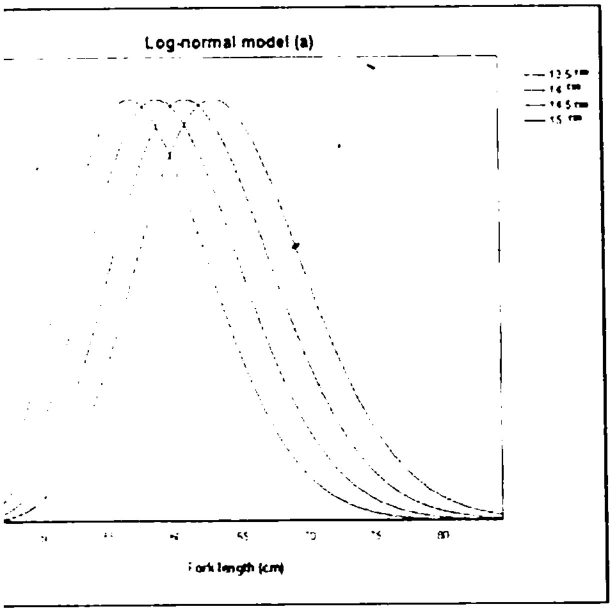


Fig. 39.5

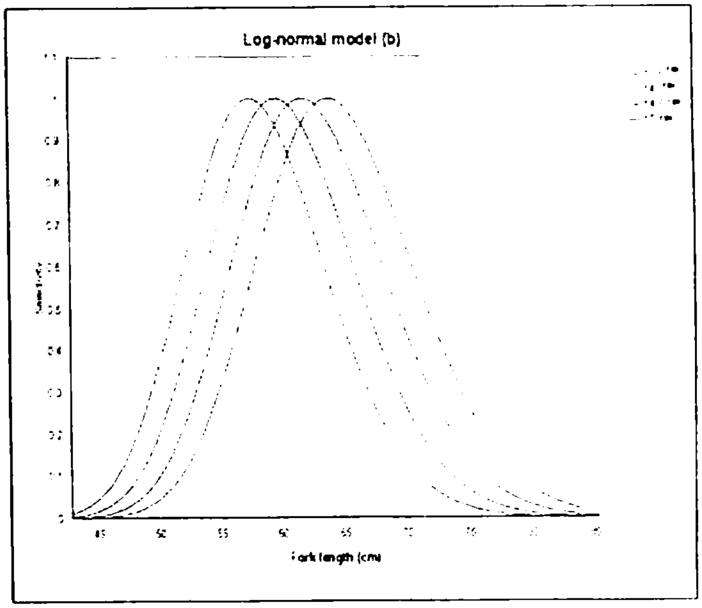


Fig. 39.6

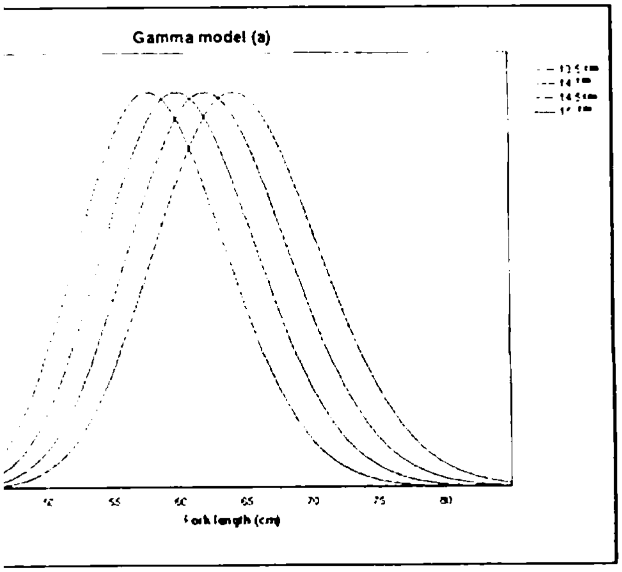


Fig. 39.7

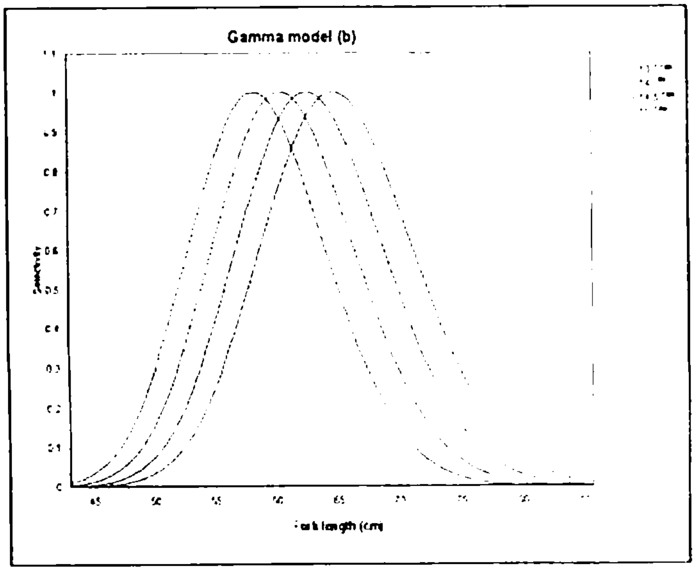


Fig. 39.8

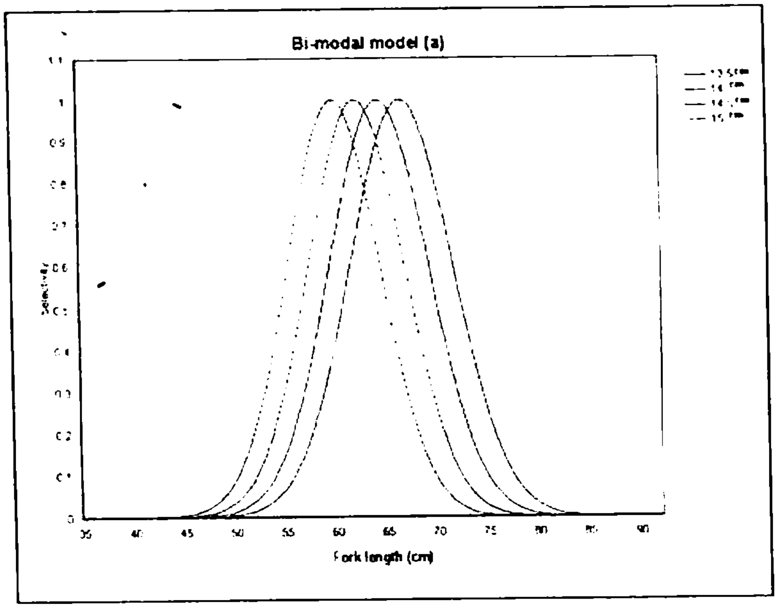


Fig. 39.09

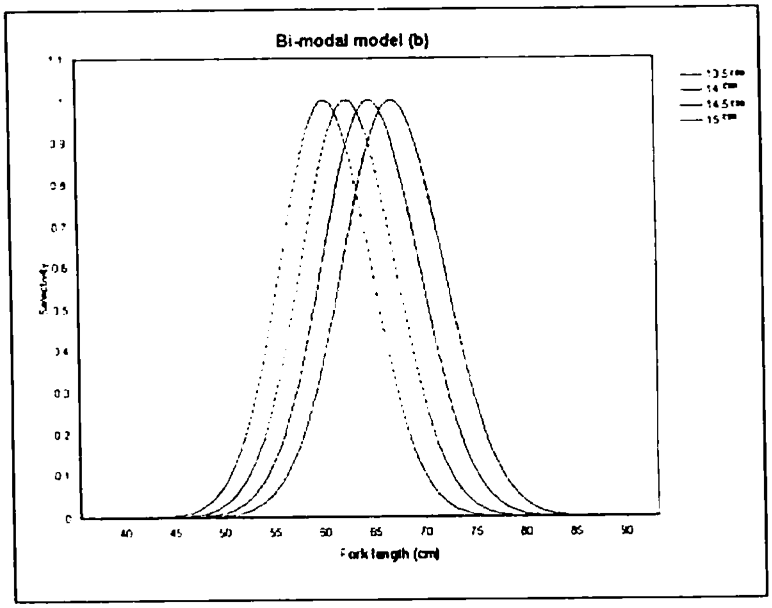


Fig. 39.10

(585.7) under the assumption of fishing power is proportional to mesh size and log-normal (647.55).

The deviance of all the models fitted was evaluated further since D was higher than DF, for a precision fit by referring it to a chi-square distribution. Estimated dispersion values were 4.55 for normal scale model under the assumptions, 4.95 for gamma, 5.1 for normal location and 5.63 for log-normal model. Over dispersion was indicated in all the models including better-fit normal since, dispersion parameter was higher than ' 1'. Over dispersion in turn showed lack of fit in normal scale model.

Residual plots of all models (Fig. 40) revealed the fishing powers of 14 cm 14.5 cm and 15 cm were greater than mesh size 13.5 cm except better-fit normal scale in which meshes of 13.5, 14.5 and 15 were greater than 14 indicated by predominance of positive residuals. Of these three meshes, mesh size of 14.5 cm ranked first in all the models followed by 15 cm including better fit model model. Fishing power of 13.5 cm was ranked third place in normal scale model while 14 cm in other models. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models. It was not true in the better-fit normal scale model since, fishing power of 14.5 was higher in the assumption of equal fishing power than the assumption of fishing power proportional to mesh size. Residual plots of normal scale model showed that mesh size 13.5 cm captured only smaller length group fishes (36.5 – 58.5 cm) , mesh size 14 cm captured only middle and larger length group fishes, various groups were caught from the mesh size of 14.5 cm and mesh size 15 cm captured very smaller and little larger groups. However, other all residual plots appeared similar in all the models.

Model length and spread of the selection curves of different models for the different mesh sizes were presented in the Table 31. Modal length and spread of the selection curves were increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they varied between assumptions of equal fishing power and fishing power is proportional to mesh size. Estimated modal length and spread of the better fit model were 59.3cm to 65.9 cm and 5.54 to 6.15 for the

Fig. 40 **Residuals plots of selectivity curves of various models for different mesh sizes and fishing powers for *Caranx ignobilis* (Area of the circle is proportional to square of the residual)**

a : Equal fishing power

b : Fishing power α mesh size

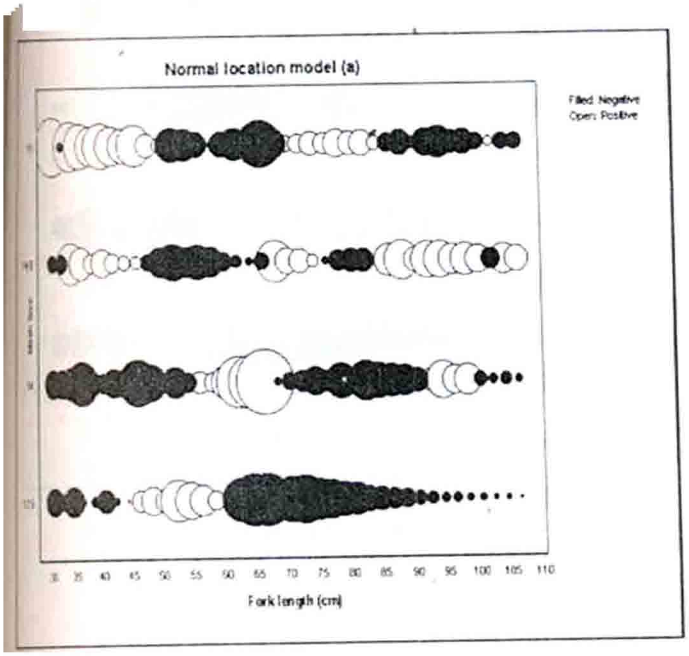


Fig. 40.1

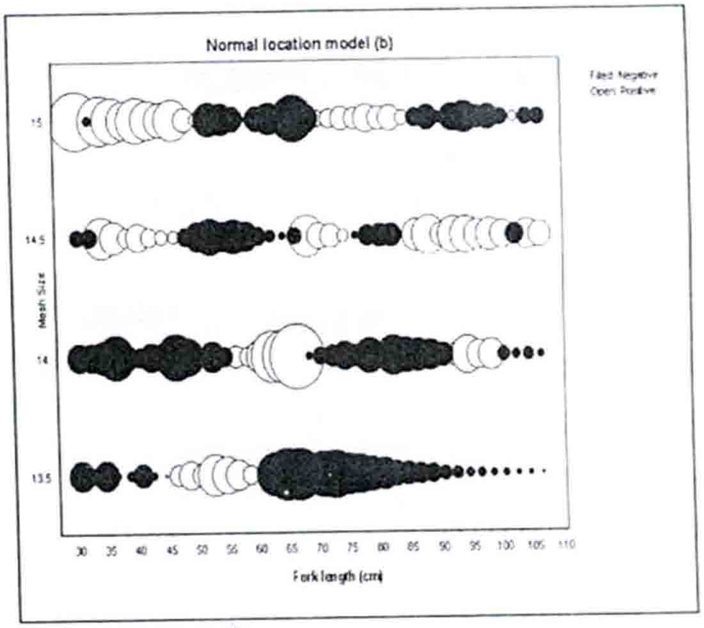


Fig. 40.2

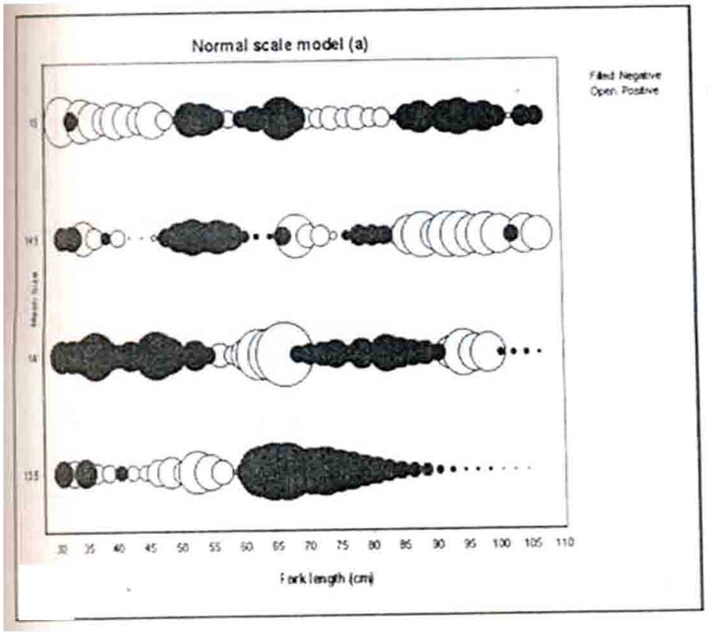


Fig. 40.3

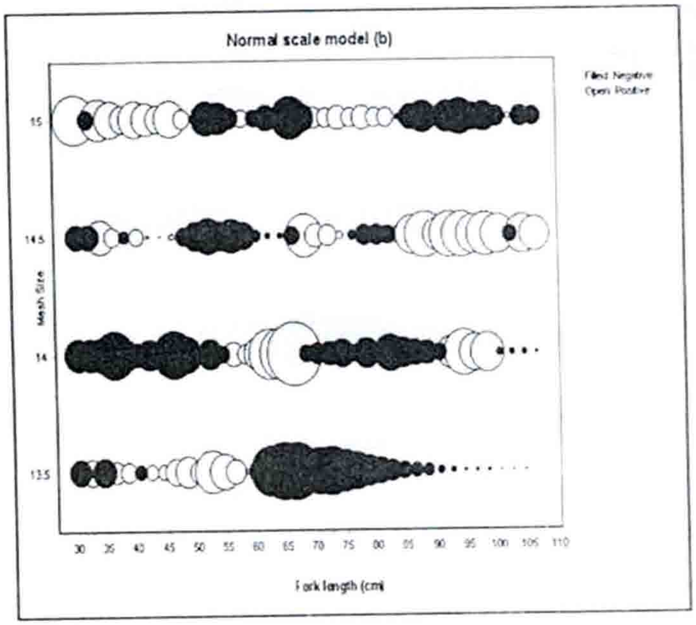


Fig. 40.4

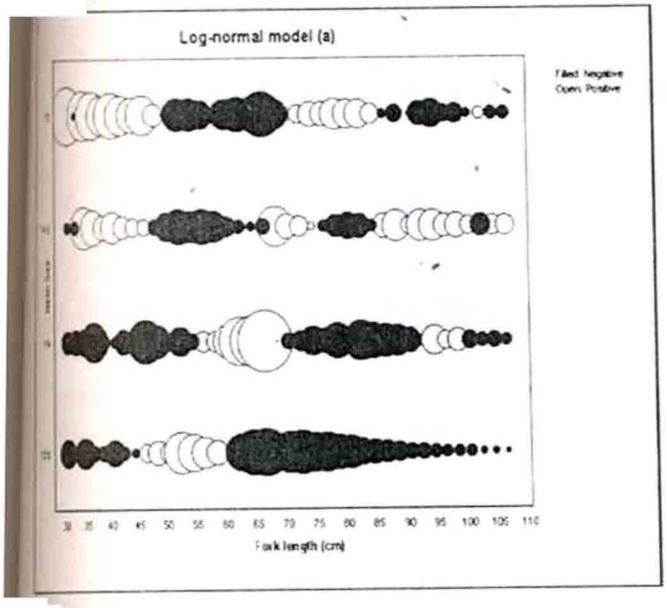


Fig. 40.5

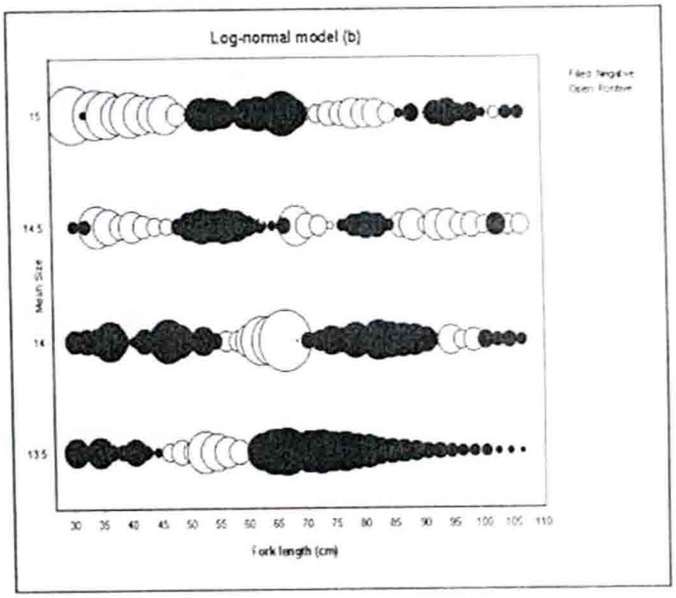


Fig. 40.6

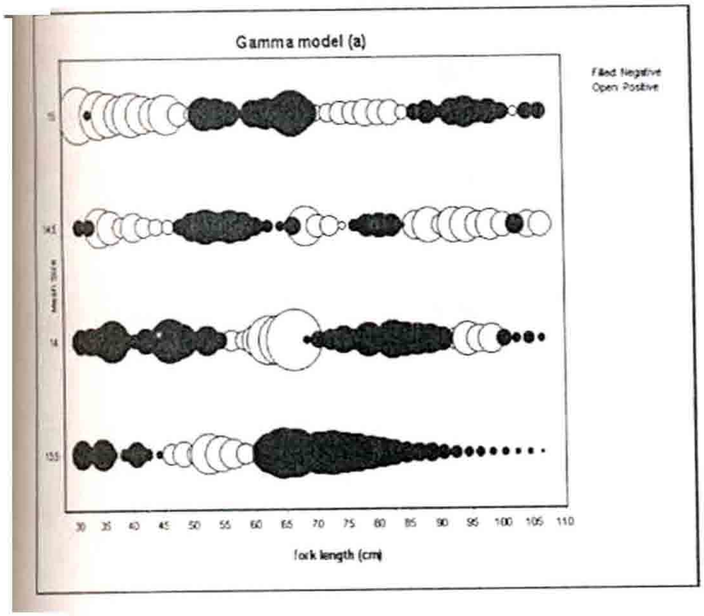


Fig. 40.7

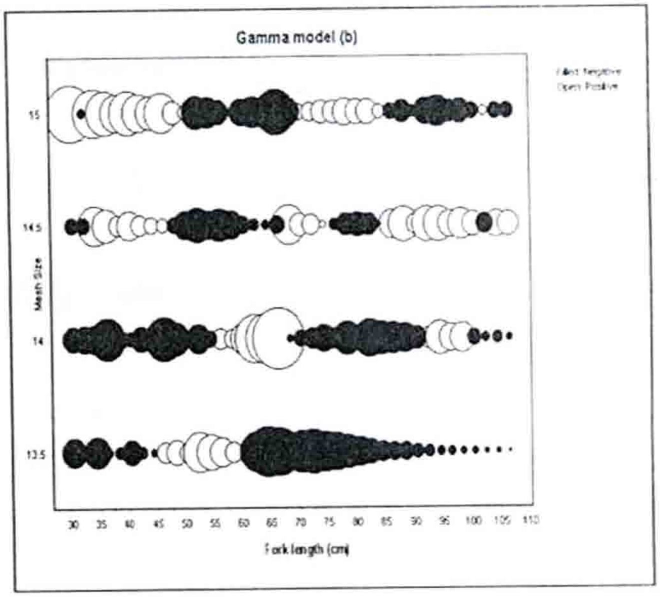


Fig. 40.8

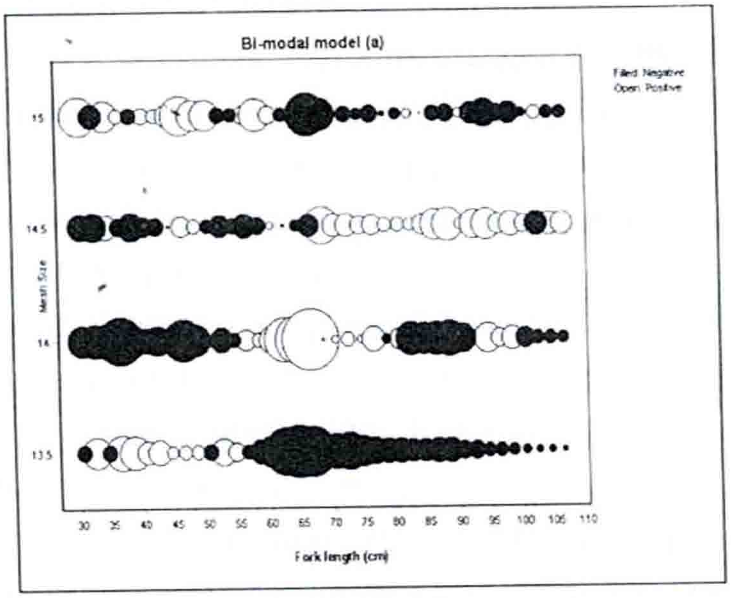


Fig. 40.9

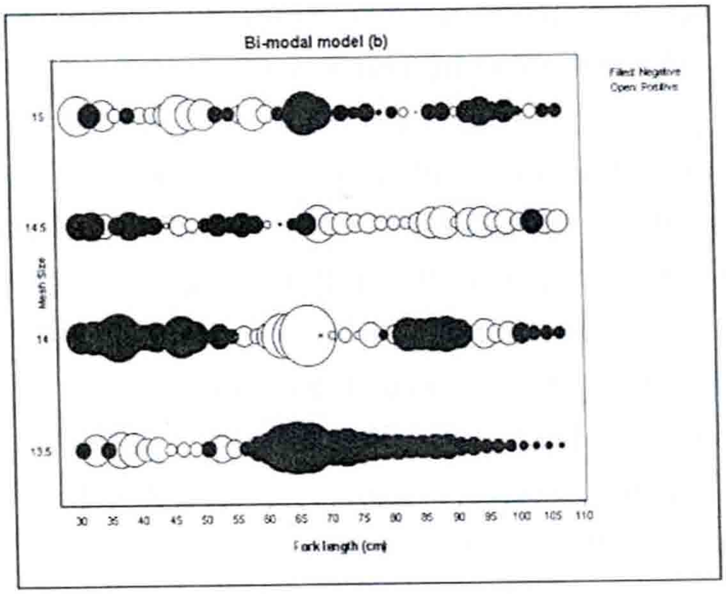


Fig. 40.10

equal fishing power and 59.8 cm to 66.5 cm and 5.51 to 6.12 for the fishing power is proportional to mesh size.

4.7.1.4.1 Refitting of Models

Uni-modal normal scale was extended to bi-modal or bi-normal model since systematic and large sized residuals present in the residual plots. Bi-modal selectivity curves and their parameters were estimated under both the assumption of equal fishing power and fishing power proportional to mesh size (Table. 30). DF for the bi-modal was 112.

Model deviance of bi-modal model was reduced to 366.1 and 366.31 for the assumption of equal fishing power and fishing power proportional to mesh size respectively. Estimated dispersion parameter of bi-modal curve was 3.27 for equal fishing power and fishing power proportional to mesh size. It revealed over dispersion of the model and moreover, it was lower than value of uni-modal normal scale fit dispersion parameter (4.55), gamma (4.95), normal location (5.1) and log-normal (5.63). Significant difference was observed between deviances of bi-modal (366.1) and normal scale model (522.79). Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to mesh size were 58.9 cm - 65.4 cm with the spread range of 7.86 - 8.66 cm and 60 - 66.7 cm with the spread of 7.79 - 8.66 respectively.

Residual plots of bi-modal function under both the assumption were presented in Fig. 40.9 and 40.10. Plots explained that the mesh sizes of 14, 14.5 and 15 cm were greater than modeled with the presence of more positive residuals. A residual plot of bi-modal was different from uni-modal normal scale. In this model, the mesh size 14.5 cm ranked first as existed in the normal scale model but the next effective mesh size was 14 cm followed by 15 cm. It was reverse in the normal scale model. There was little difference was shown in the bi-normal model with normal scale model in terms of size groups caught. In the mesh size 14 cm, many larger fishes were caught, fishing power of mesh 14.5 cm was high on very larger length group fishes while effect of fishing power by the mesh size 15 cm was only on smaller groups. Further, a drastic reduction was observed in the deviance of bi-modal than the uni-modal normal scale model selection.

4.7.1.5 *Caranx papuensis*

Over all total catch of *Caranx papuensis* obtained from four mesh sizes was 1473 numbers. Of which, 286 specimens were caught from mesh size 13.5 cm, 418 from 14 cm, 375 from 14.5 cm and 394 from 15 cm (Table. 18).

Uni-normal curves such as Normal location, Normal scale, Log-normal and Gamma fitted to the selectivity data (Table. 8) were presented in Fig. 41. Total degrees of freedom (DF) for uni-modal curves were 109 and selectivity parameters, standard deviation (SD), model deviance (D) and other selectivity statistics viz., modal length and spread of selection curve are presented in the Table 30 & 31.

Selection curves of all normal curves were symmetrical in shape and almost similar in all the models without skew ness. After evaluating of goodness of fit of all models using model deviance (D), selection curves of all the models, the entire selection curve gave good fit. However, log-normal model yielded better fit than other models having a small model deviance (525.56) in both the assumption of equal fishing power and fishing power is proportional to mesh size. There was no significant difference between models ($P>0.005$) except with normal scale ($P<0.005$). Other better fits followed by log-normal model based on deviance value were gamma (527.17), normal location (540.89) under the assumption of fishing power proportional to mesh size, and normal scale (561.60) under equal fishing power.

The deviance of models fitted was evaluated through dispersion parameter further for a precision fit by referring it to a chi-square distribution. Estimated dispersion values were 4.82 for log-normal, 4.84 for gamma model, 4.96 for normal location with respect to fishing power is proportional to mesh size and 5.15 for normal scale model for both the assumptions. Over dispersion was observed in all the models including better-fit log-normal model since estimated dispersion parameter was higher than '1'. Over dispersion in turn showed lack of fit in better-fit log-normal model.

Fig. 41 Selectivity curves of various models for different mesh sizes and fishing powers for *Caranx papuensis*

a : Equal fishing power

b : Fishing power α mesh size

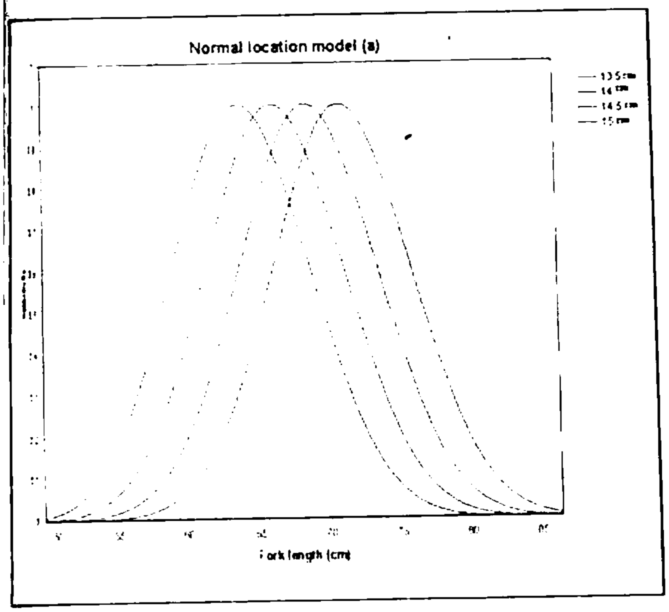


Fig. 41.1

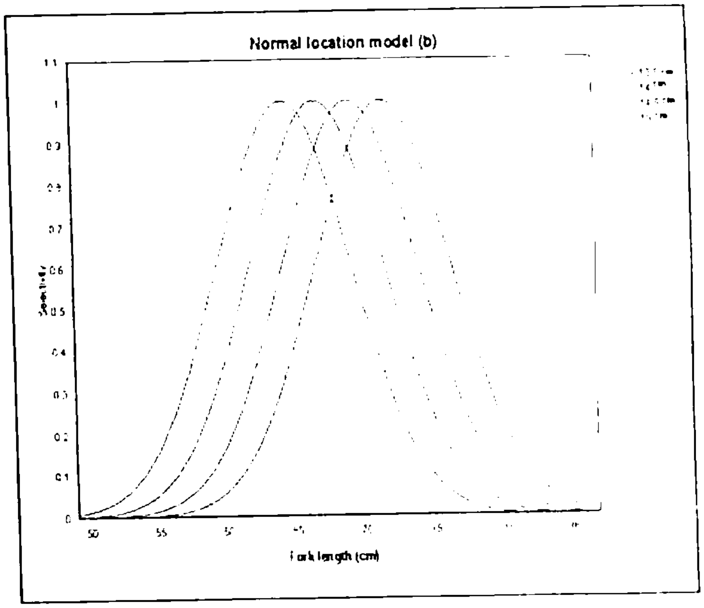


Fig. 41.2

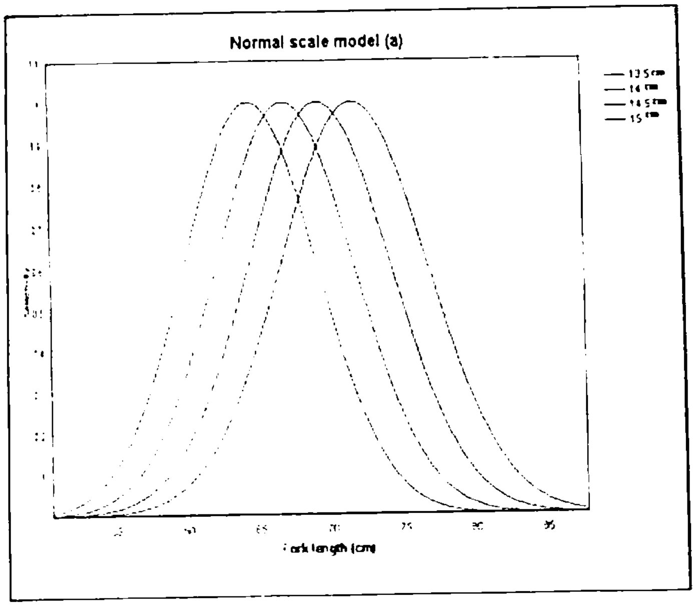


Fig. 41.3

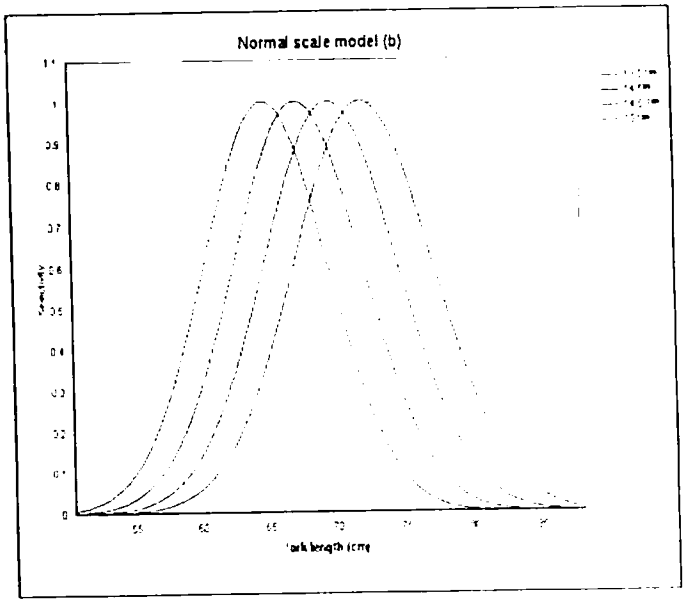


Fig. 41.4

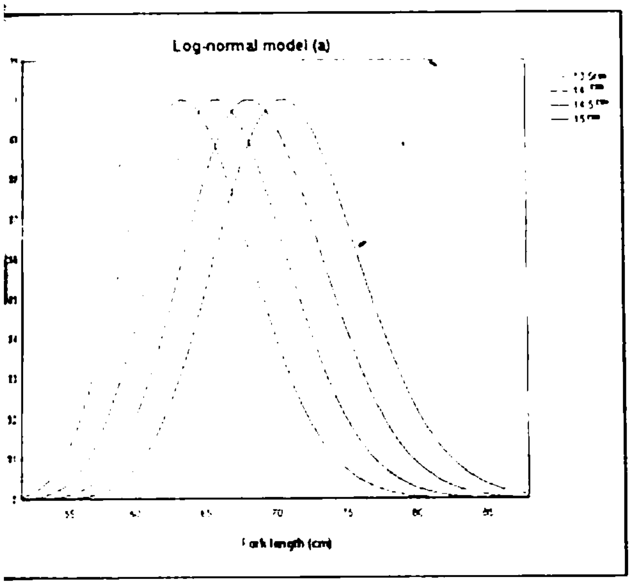


Fig. 41.5

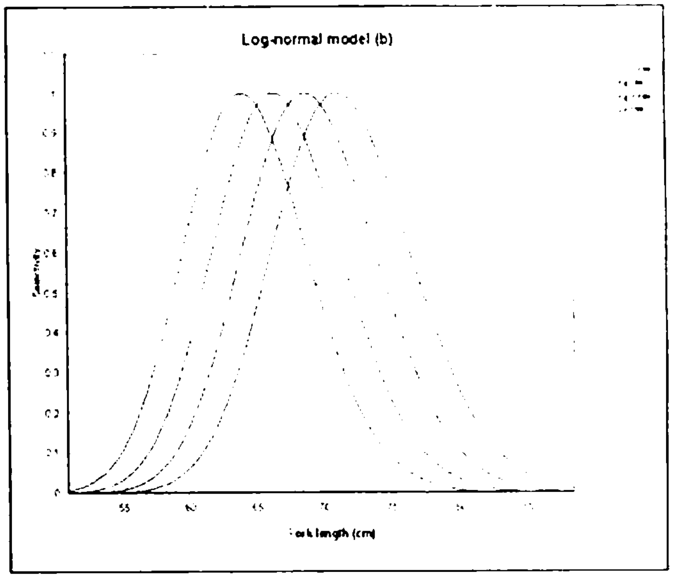


Fig. 41.6

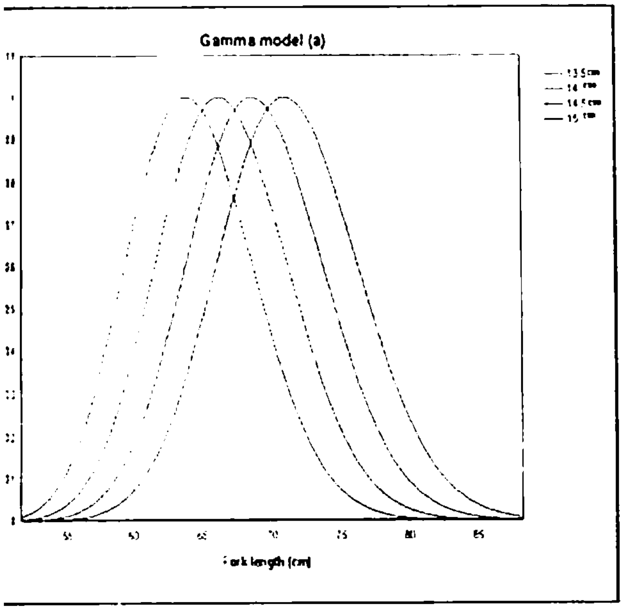


Fig. 41.7

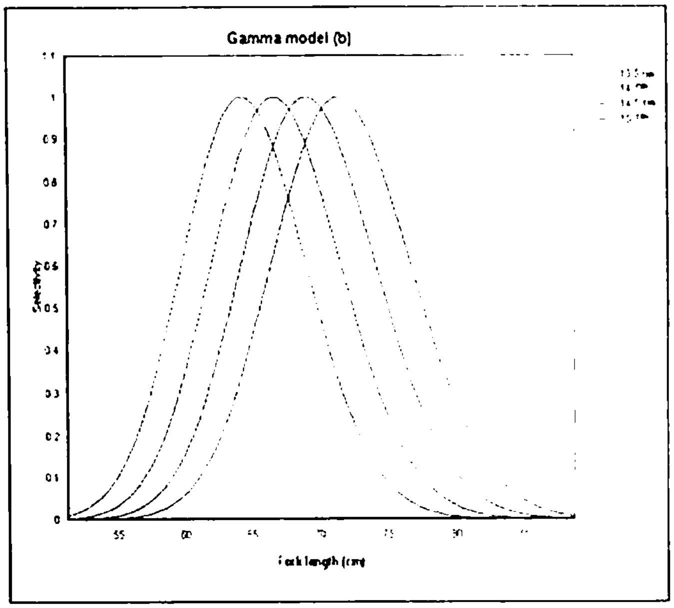


Fig. 41.8

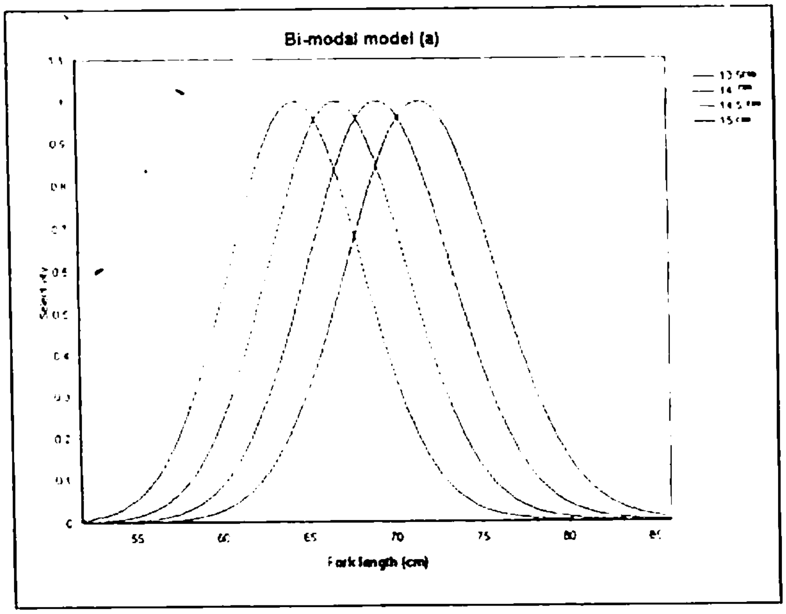


Fig. 41.9

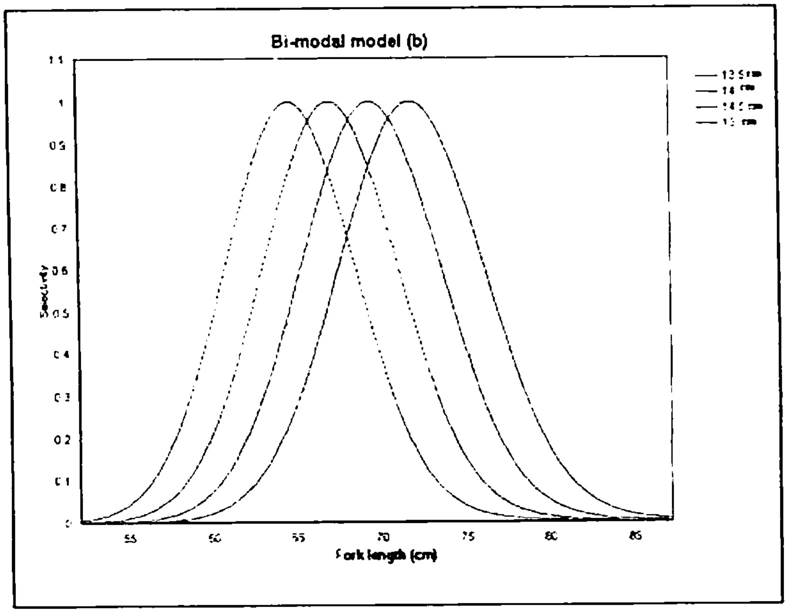


Fig. 41.10

Residual plots of all the models (Fig. 42) were evaluated and they revealed the fishing powers of 14 cm and 14.5 cm were greater than modeled due to predominance of positive residuals. Of these meshes, mesh size of 14.5 cm ranked first in all the models followed by 14 cm. Fishing powers were almost equal in both the normal location and normal scale model by the presence of equal number of positive residuals in respective mesh sizes except in the mesh size 13.5 cm. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models. It became true in the better-fit lognormal model also. Mesh sizes of 13.5 and 15 had equal fishing power in the gamma and normal location model. Residual plots showed that smaller and middle length class group of fish were caught from mesh size of 14 cm (40.5 - 70.5 cm) and 14.5 cm captured larger fishes (72.5 - 102.5 cm) and overlapping of catch were also observed in these mesh sizes.

Model length and spread of the selection curves of different models for the different mesh sizes were presented in the Table 31. Modal length and spread of the selection curves were increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they varied between assumptions of equal fishing power and fishing power is proportional to mesh size. Estimated modal length and spread of the better fit model were 63.6 cm - 70.6 cm and 4.61 - 5.12 for the equal fishing power and 63.9 cm - 71 cm and 4.63 - 5.15 for the fishing power is proportional to mesh size.

4.7.1.5.1 Refitting of Models

Residual plot of better-fit log-normal model showed lack of fit by the presence of large sized both positive and negative residuals and systematic occurrence of residuals instead of random order especially in the mesh sizes of 13.5 cm and 14 cm. Thus the uni-modal log-normal was extended to bi-modal or bi-normal model since, value of all the residuals was not less than 2. Bi-modal selectivity curves and their parameters were estimated under both the assumption of equal fishing power and fishing power proportional to mesh size (Table. 30). DF for the bi-modal was 106.

Fig. 42 Residuals plots of selectivity curves of various models for different mesh sizes and fishing powers for *Caranx papuensis* (Area of the circle is proportional to squar of the residual)

a : Equal fishing power

b : Fishing power α mesh size

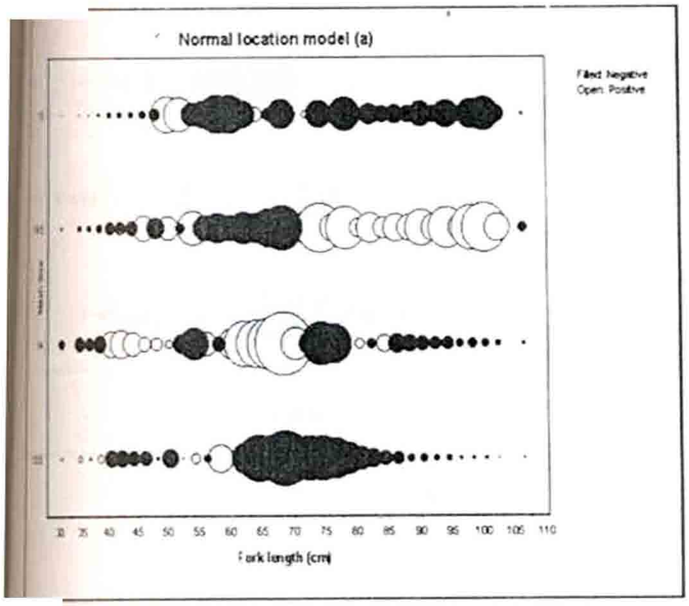


Fig. 42.1

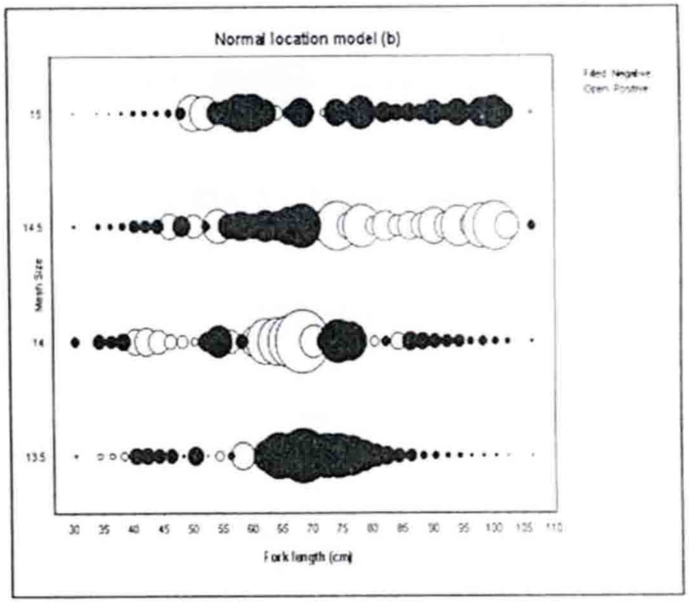


Fig. 42.2

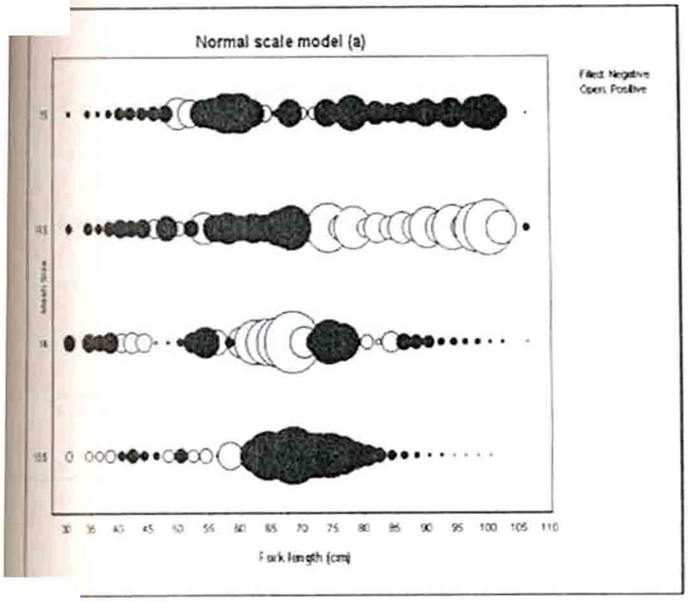


Fig. 42.3

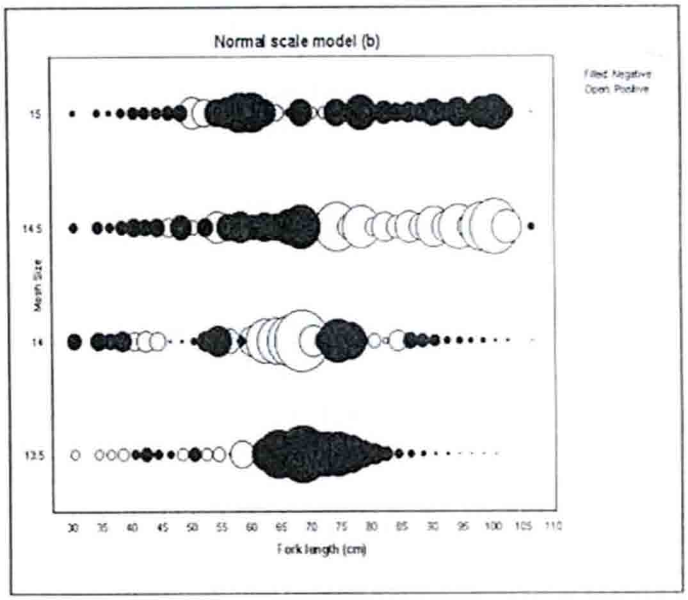


Fig. 42.4

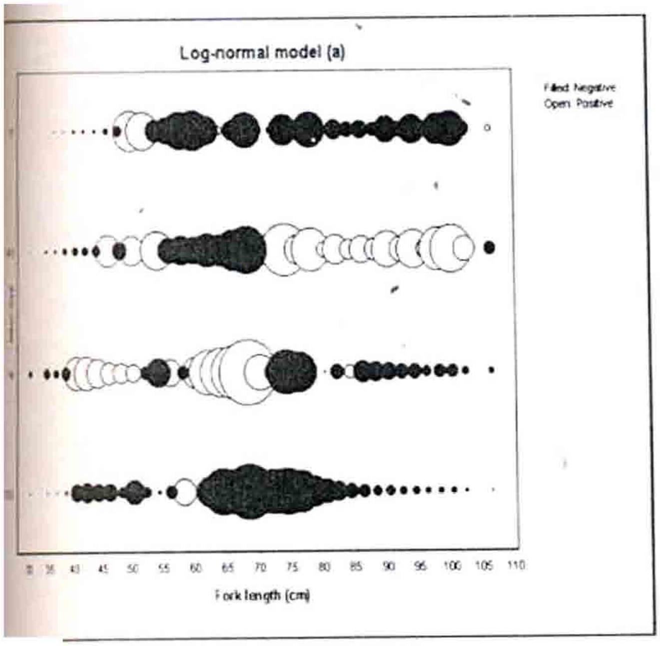


Fig. 42.5

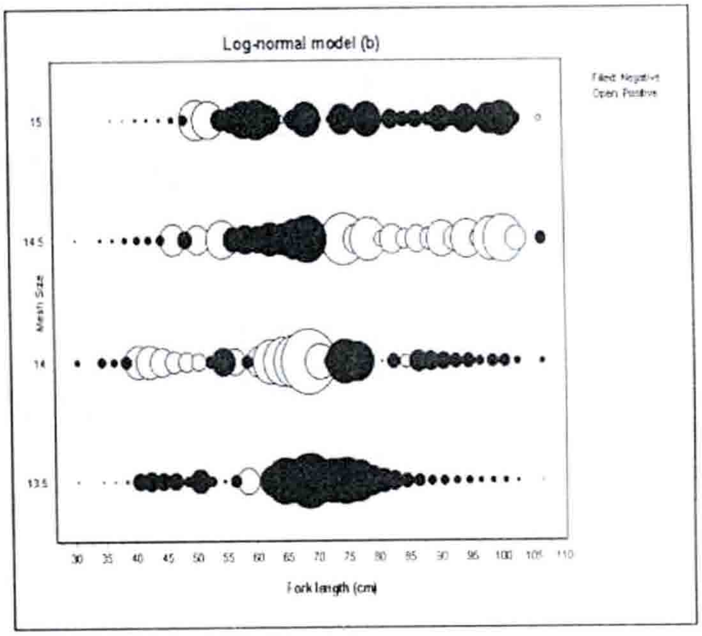


Fig. 42.6

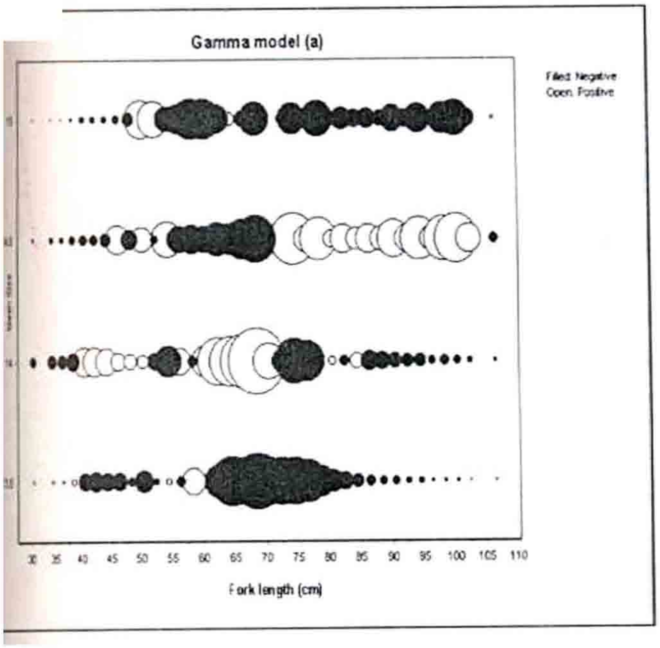


Fig. 42.7

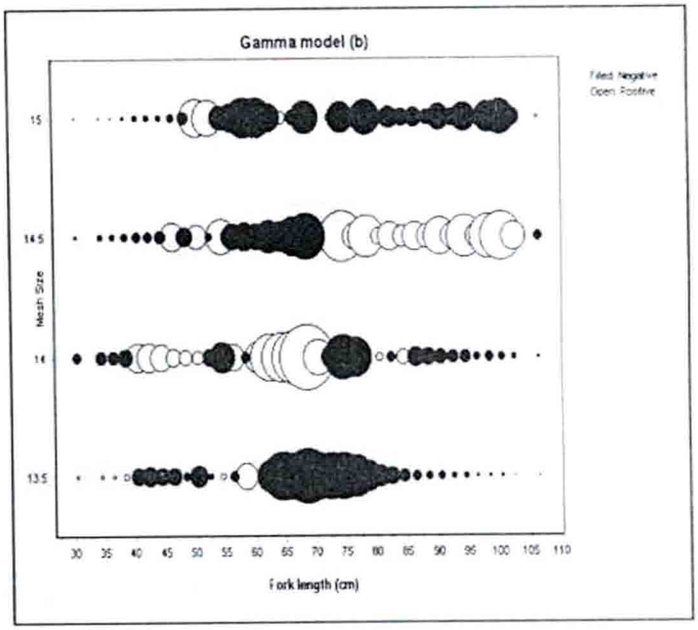


Fig. 42.8

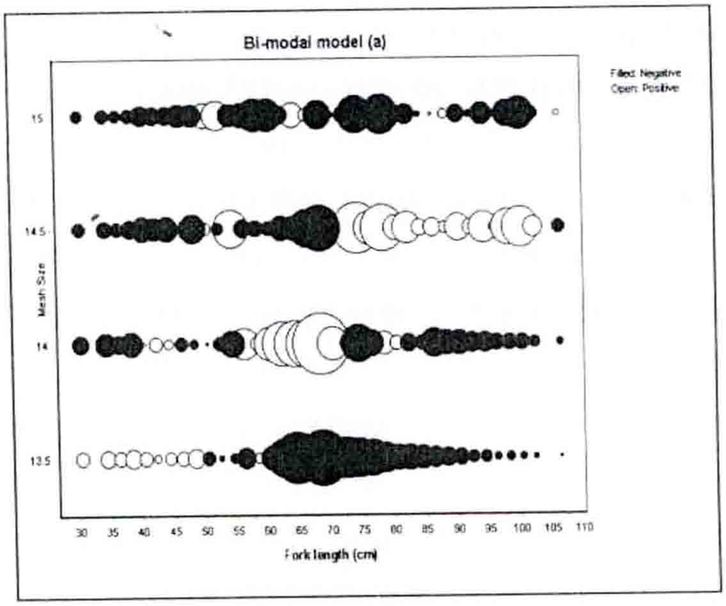


Fig. 42.9

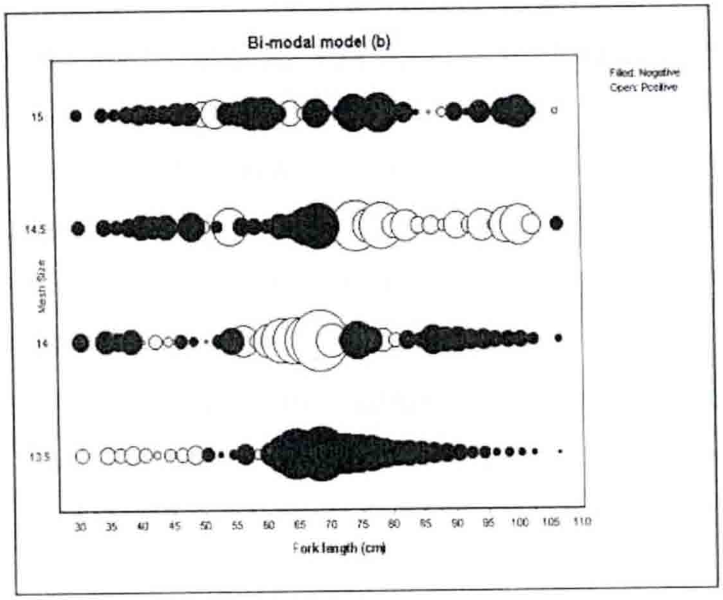


Fig. 42.10

Model deviance of bi-modal model was slightly reduced to 461.41 from 525.56of log-normal model for the assumption of equal fishing power despite the deviance was 461.6 for the assumption of fishing power is proportional to mesh size. In order to find out goodness of fit of the bi-modal curve, dispersion parameter was also estimated. It was 4.35 and 4.34 for both the assumptions of equal fishing power and fishing power proportional to mesh size respectively. It revealed over dispersion of the model and other dispersion parameters of uni-modal were log-normal (4.82), gamma (4.84), normal location (4.96) under fishing power proportional to mesh size and normal scale (5.15). Further there was significant difference ($P<0.005$) between deviances of bi-modal (461.41) and log-normal model (525.56).

Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to mesh size were 64.4 cm to 71.5 cm with the spread range of 3.84 to 4.26 and 64.6 to 71.8 cm with the spread of 3.83 to 4.26 respectively.

Residual plots of bi-modal function under both the assumption were presented in Fig. 42.9 and 42.10. Plots explained that the mesh sizes of 13.5, 14, and 14.5 cm were greater than modeled with the presence of more positive residuals. Residual plots of both uni-modal log-normal and bi-modal varied little. In this model, the effective mesh size was ranked as existed in the uni-modal log-normal model viz., 14.5, 14 and13.5. Of these meshes, 14.5 cm caught larger fish (72.5 to 102.5) and middle length groups (56.5 to 80.5) were caught by 14 cm mesh and very small fish from mesh 13.5 cm. There little difference was shown in this model with log-normal model in terms of size groups caught. A huge reduction was observed in the deviance of bi-modal than the uni-modal log-normal model selection.

4.7.1.6 *Caranx sexfasciatus*

Over all total catch of *Caranx sexfasciatus* obtained from four mesh sizes was 1205 numbers. Of which, 410 specimens were caught from mesh size 13.5 cm, 301 from 14 cm, 324 from 14.5 cm and 170 from 15 cm (Table. 18).

43 Selectivity curves of various models for different mesh sizes and fishing powers for *Caranx sexfasciatus*

a : Equal fishing power

b : Fishing power α mesh size

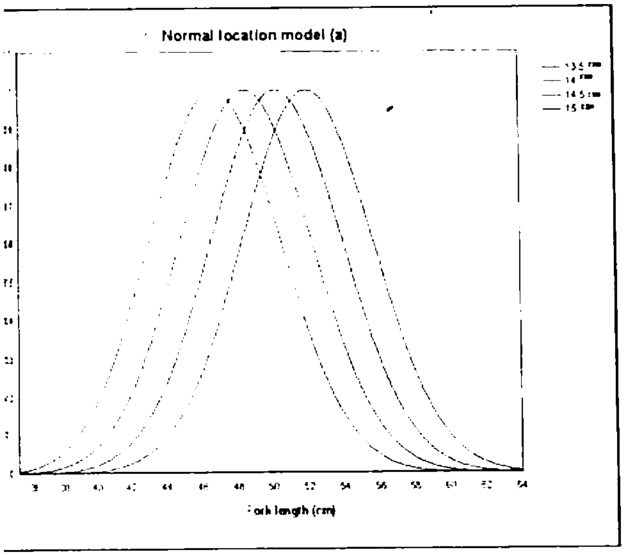


Fig. 43.1

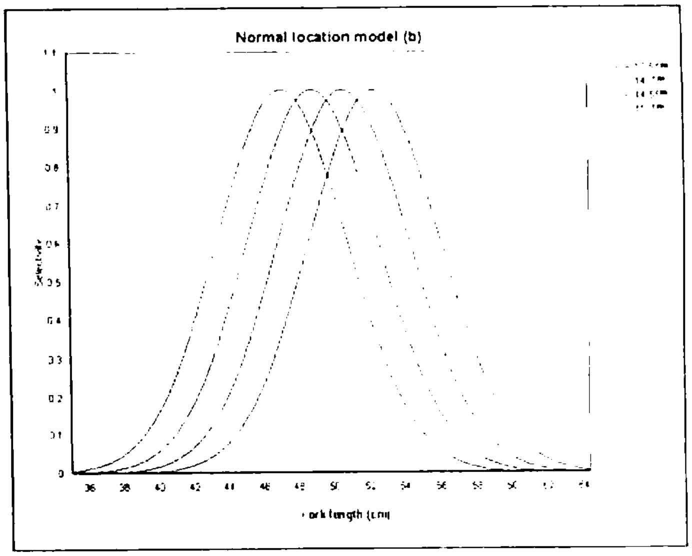


Fig. 43.2

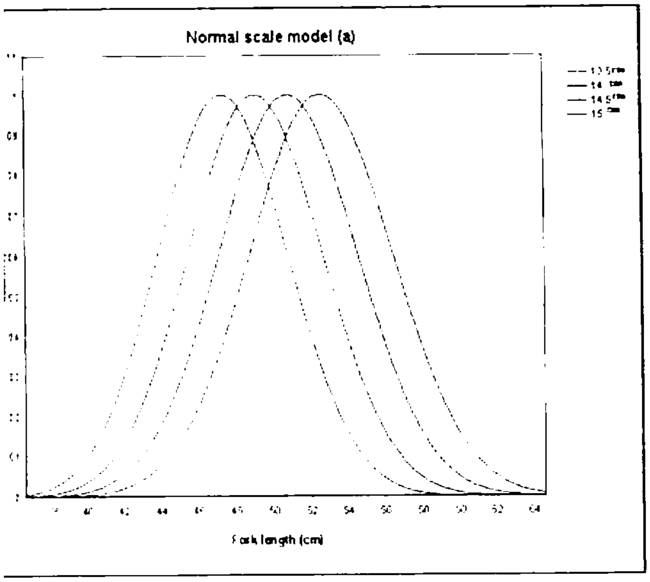


Fig. 43.3

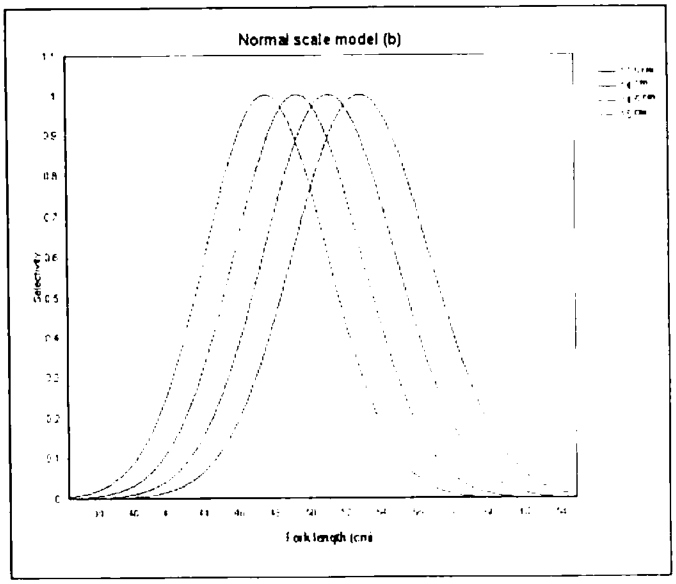


Fig. 43.4

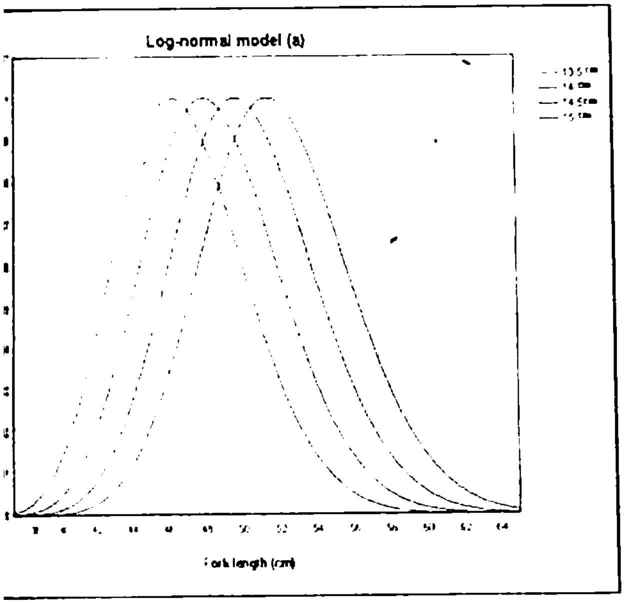


Fig. 43.5

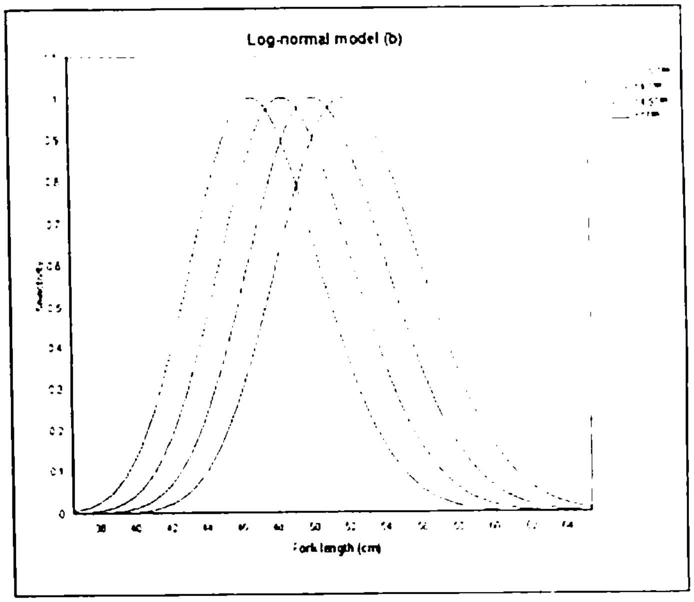


Fig. 43.6

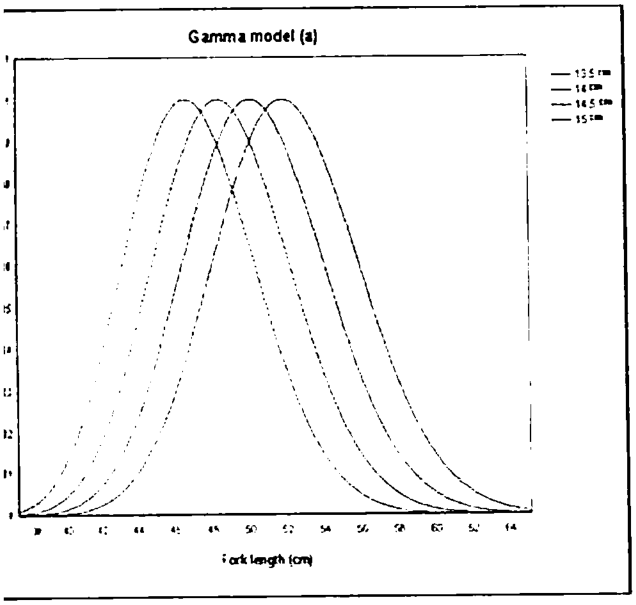


Fig. 43.7

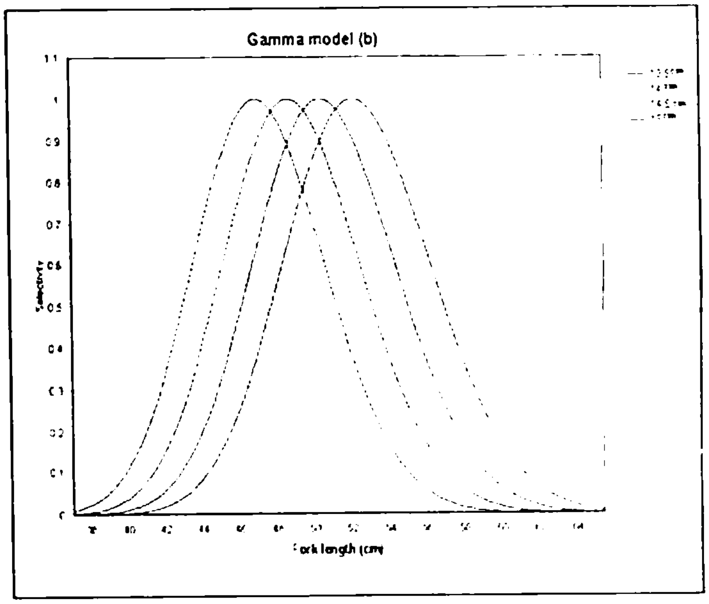


Fig. 43.8

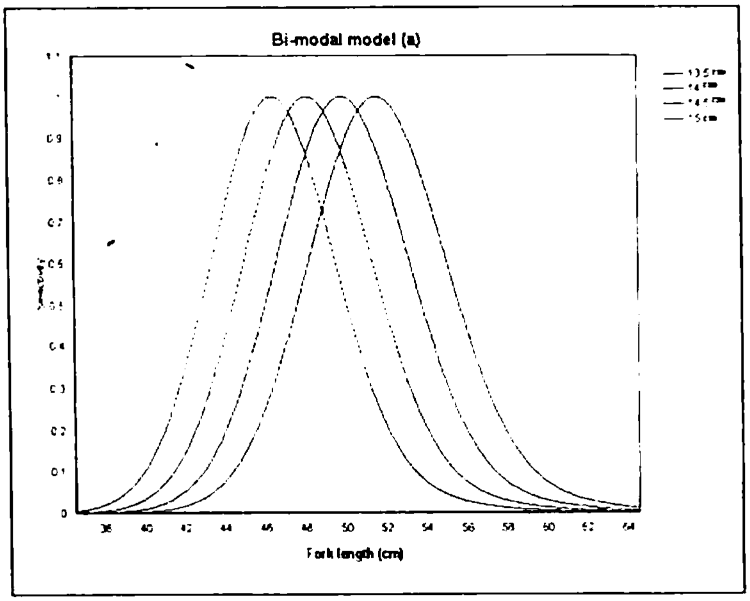


Fig. 43.9

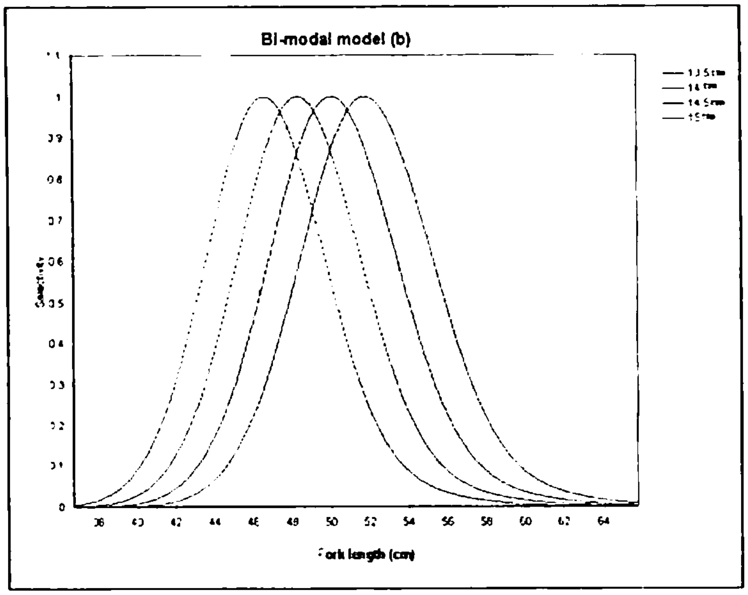


Fig. 43.10

All uni-normal selection curves were fitted to the data (Table. 9) and are presented in Fig. 43. Total degrees of freedom (DF) for uni-modal curves were 61. Estimated standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve are presented in the Table 30 & 31.

Selection curves of all normal curves were symmetrical in shape and almost similar in all the models without skew ness. Model deviance of each model was validated to find out best fit of the model. After analyzing the deviance and selection curves of all the models, all the selection curves were found good fit. However, log-normal model yielded better fit than other models having a small model deviance (344.73) in both the assumption of equal fishing power and fishing power is proportional to mesh size. There was no significant difference between models ($P>0.005$) except with normal scale ($P<0.005$). Other better fits followed by log-normal model based on deviance value were normal location (344.8) under the assumption of fishing power proportional to mesh size, gamma (350.66), and normal scale (380.51) under equal fishing power

The deviance of all the models fitted was evaluated further using dispersion parameter. Estimated dispersion values were 5.65 for log-normal, 5.65 and 5.66 for normal location with respect to fishing power is proportional to mesh size and equal fishing power, 5.75 for gamma model, and 6.24 for normal scale model for both the assumptions. It obviously indicated over dispersion was observed in all the models including better-fit log-normal model. Over dispersion in turn showed lack of fit in log-normal model.

Evaluated residual plots of the all models for the species *Caranx sexfasciatus* (Fig.44) under both the assumptions of equal fishing power and fishing power proportional to mesh size (Mcullagh and Nelder, 1989) revealed the fishing powers of 13.5cm 14 cm and 14.5 cm were greater than mesh size 15 cm due to predominance of positive residuals. Of these three meshes, mesh size of 14.5 cm ranked first in all the models followed by 14 cm and 13.5 cm. Fishing powers were almost equal in both normal scale and gamma model by the presence of equal number of positive residuals in respective mesh sizes. Similarly fishing power of normal location was similar

Fig. 44 Residuals plots of selectivity curves of various models for different mesh sizes and fishing powers for *Caranx sexfasciatus* (Area of the square is proportional to square of the residual)

a : Equal fishing power

b : Fishing power α mesh size

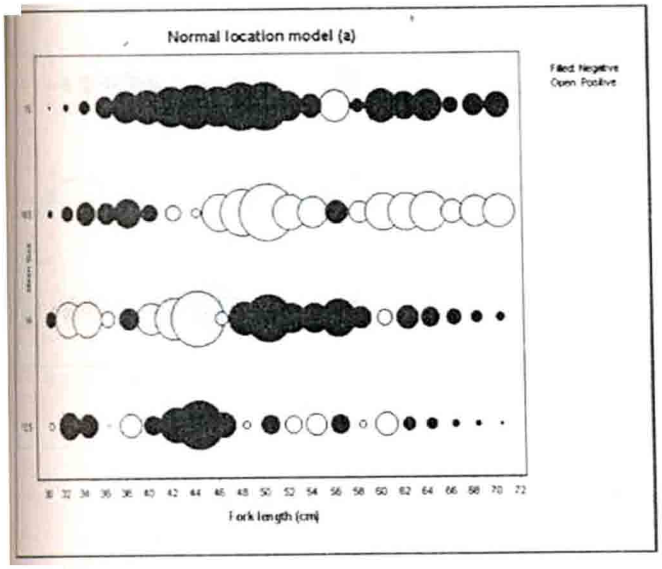


Fig. 44.1

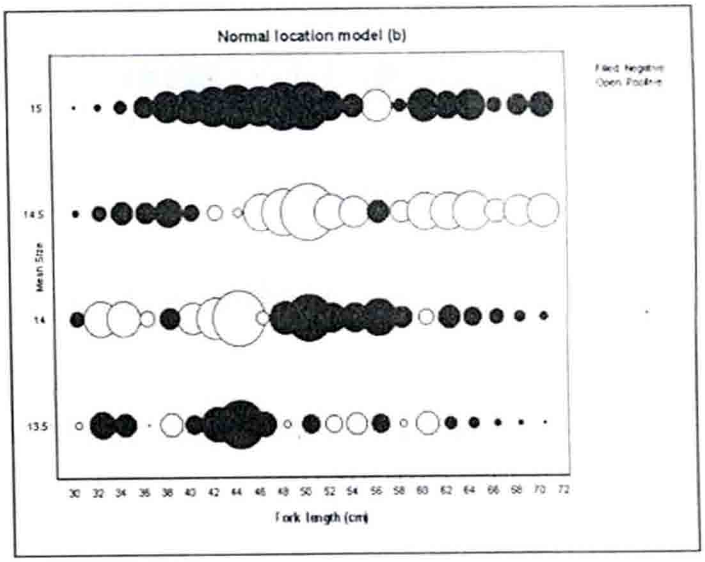


Fig. 44.2

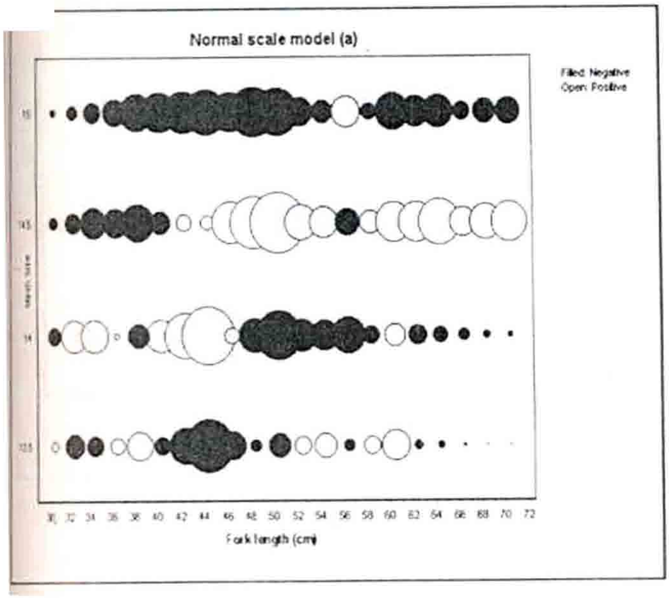


Fig. 44.3

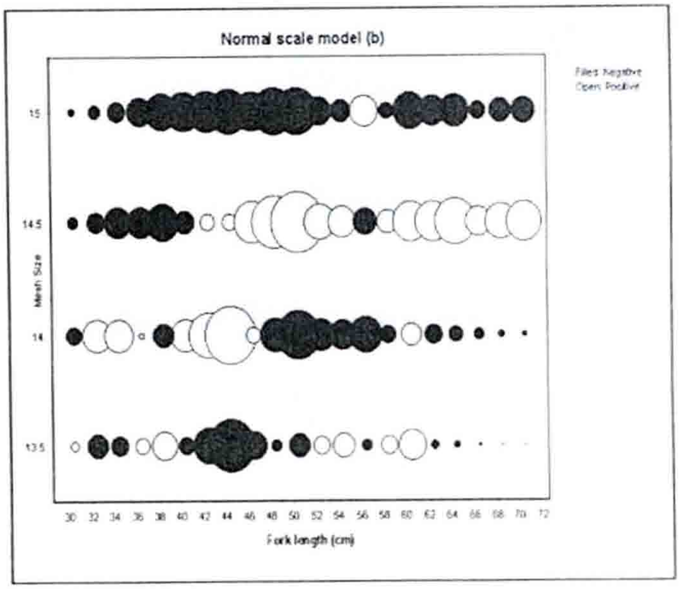


Fig. 44.4

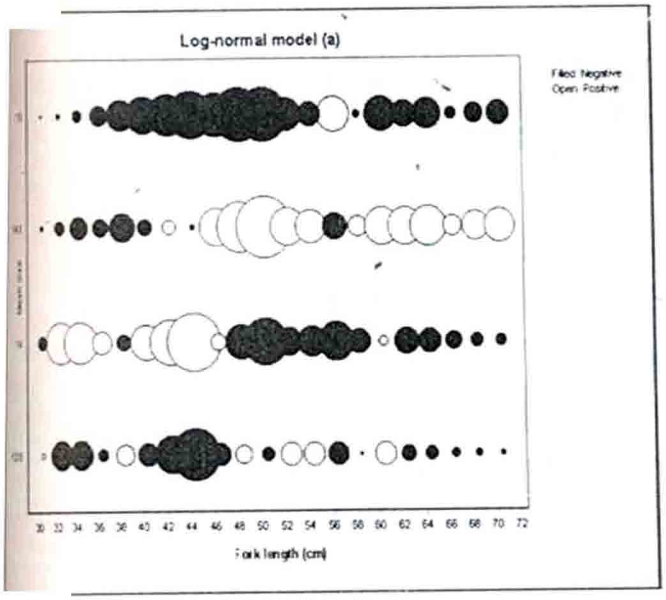


Fig. 44.5

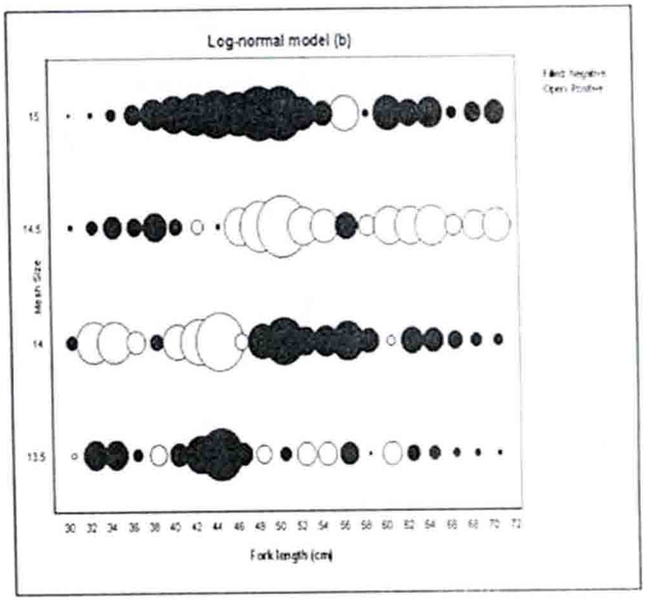


Fig. 44.6

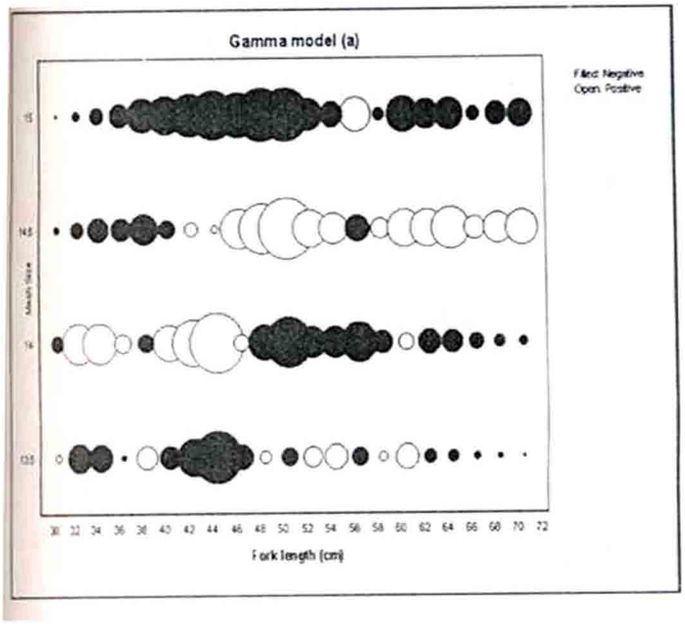


Fig. 44.7

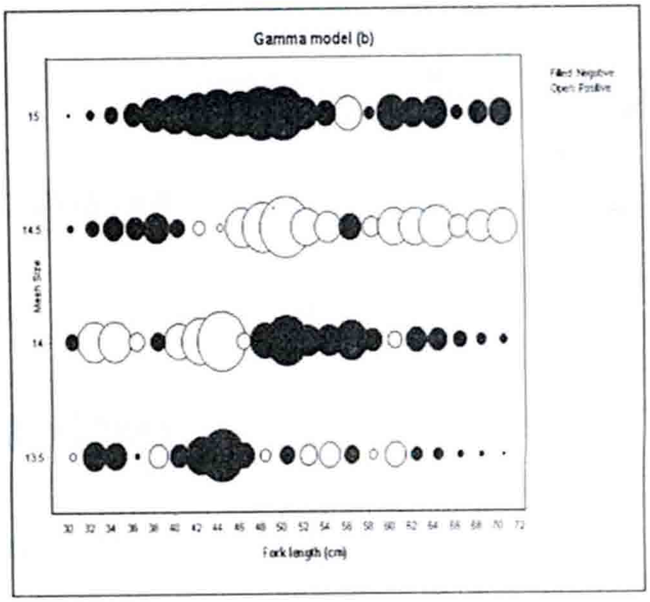


Fig. 44.8

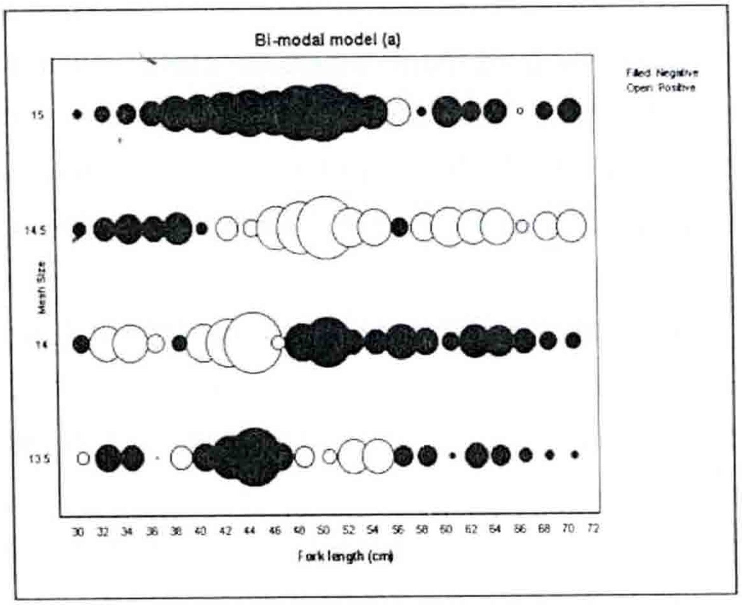


Fig. 44.9

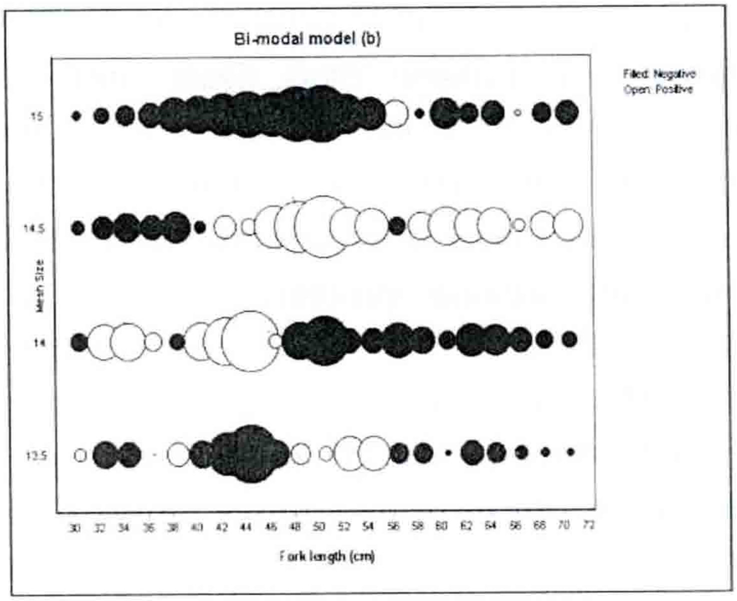


Fig. 44.10

with normal scale and gamma except in the mesh size 13.5 cm. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models. It became true in the better-fit lognormal model also.

Residual plots showed that smaller length class group of fish were caught from mesh size of 14 cm (32.5 to 46.5 cm) and 14.5 cm captured wider range of smaller and larger fishes (42.5 to 70.5 cm) and overlapping of catch were also observed in these mesh sizes. Mesh size of 13.5 captured all size groups of fish.

Model length and spread of the selection curves of different models for the different mesh sizes were presented in the Table 31. Modal length and spread of the selection curves were increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they varied between assumptions of equal fishing power and fishing power is proportional to mesh size. Estimated modal length and spread of the better fit model were 46.4 cm to 51.5 cm and 3.58 to 3.97 for the equal fishing power and 46.7 cm to 51.8 cm and 3.6 to 4.0 for the fishing power is proportional to mesh size.

4.7.1.6.1 Refitting of Models

Residual plot of better-fit log-normal model showed lack of fit by the presence of large sized both positive and negative residuals and systematic occurrence of residuals instead of random order especially in the mesh sizes of 14.5 cm and 14 cm. Thus the uni-modal log-normal was extended to bi-modal or bi-normal model since, value of all the residuals was not less than 2. Bi-modal selectivity curves and their parameters were estimated under both the assumption of equal fishing power and fishing power proportional to mesh size (Table. 30). DF for the bi-modal was 58.

Model deviance of bi-modal model was slightly reduced to 335.02 from 344.73 of log-normal model for the assumption of equal fishing power despite the deviance was 335.06 for the assumption of fishing power is proportional to mesh size. In order to find out goodness of fit of the bi-modal curve, dispersion parameter was also estimated. It was 5.78 for both the assumptions of equal fishing power and fishing power proportional to mesh size. It revealed over dispersion of the model and higher than all uni-models including better-fit log-normal model (5.65) except normal scale (6.24). Other dispersion parameters of uni-modal were normal location (5.65) and gamma (5.75). Further there was significant difference ($P<0.005$) between deviances of bi-modal (355.02) and log-normal model (344.73).

Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to mesh size were 46.4 - 51.5 cm with the spread range of 3.01 - 3.34 and 46.5 - 51.7 cm with the spread of 3.0 - 3.34 respectively. There was no much difference between modal length and spread between equal fishing power and fishing power proportional to mesh size. Modal length between bi-modal and uni-modal log-normal for each mesh size was same and spread for bi-normal was little lower than the log-normal model.

Residual plots of bi-modal function under both the assumption were presented in Fig. 44.9 &44.10. Plots explained that the mesh sizes of 13.5, 14, and 14.5 cm were greater than modeled with the presence of more positive residuals. Residual plots of both bi-modal and uni-modal log-normal model were almost same. In this model, the effective mesh size was ranked as existed in the uni-modal log-normal model viz., 14.5, 14 and13.5. Of these meshes, latter two meshes fished equally there was no difference between bi-modal and log-normal model in terms of size groups caught though a little reduction was observed in the deviance of bi-modal from the uni-modal log-normal model selection.

4.7.1.7 *Caranx tille*

Over all total catch of *Caranx tille* obtained from four mesh sizes was 1571 numbers. Of which, 375 specimens were caught from mesh size 13.5 cm, 425 from 14 cm, 419 from 14.5 cm and 352 from 15 cm (Table 18).

Selection curves of uni-normal models such as Normal location, Normal scale, Log-normal and Gamma fitted to the data (Table. 10) are presented in Fig. 45. Total degrees of freedom (DF) for uni-modal curves was 91 and estimated standard deviation (SD), model deviance (D), other parameters and other selectivity statistics viz., modal length and spread of selection curve are presented in the Table 30 & 31.

g.45 Selectivity curves of various models for different mesh sizes and fishing powers for *Caranx tille*

a : Equal fishing power

b : Fishing power α mesh size

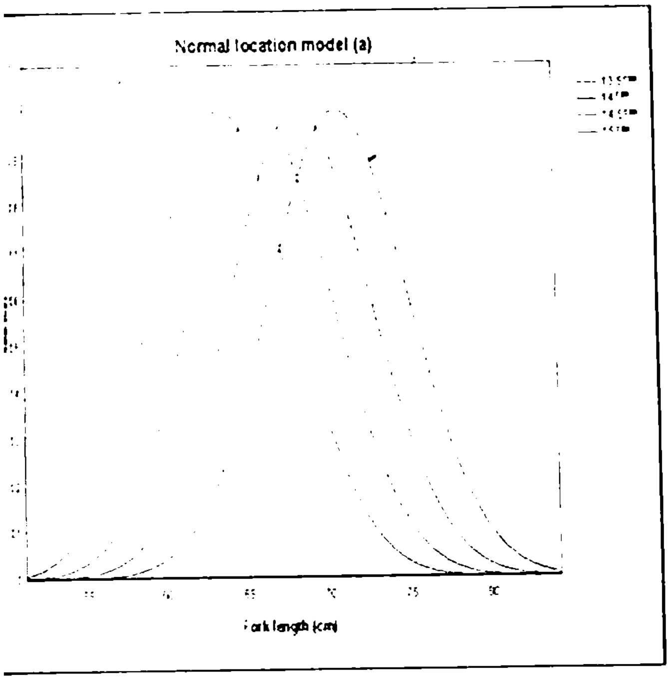


Fig. 45.1

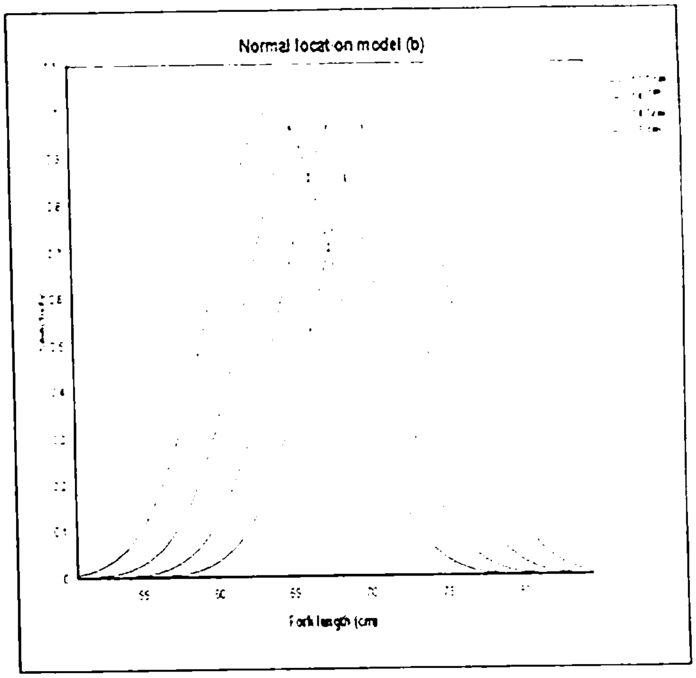


Fig. 45.2

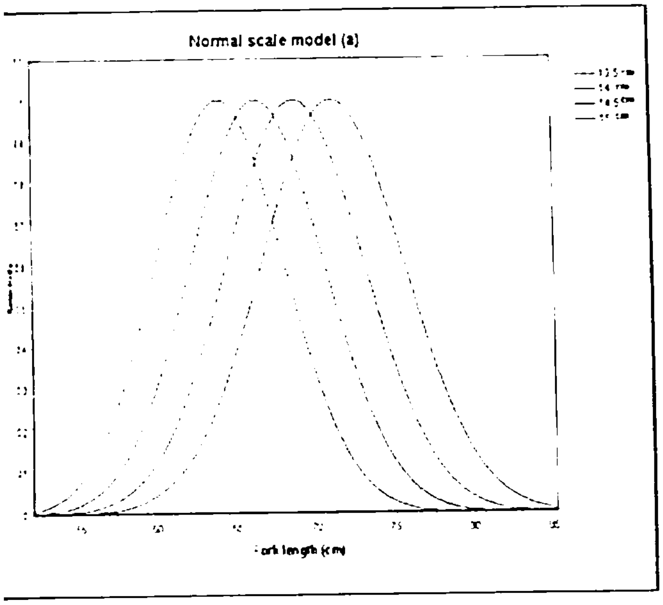


Fig. 45.3

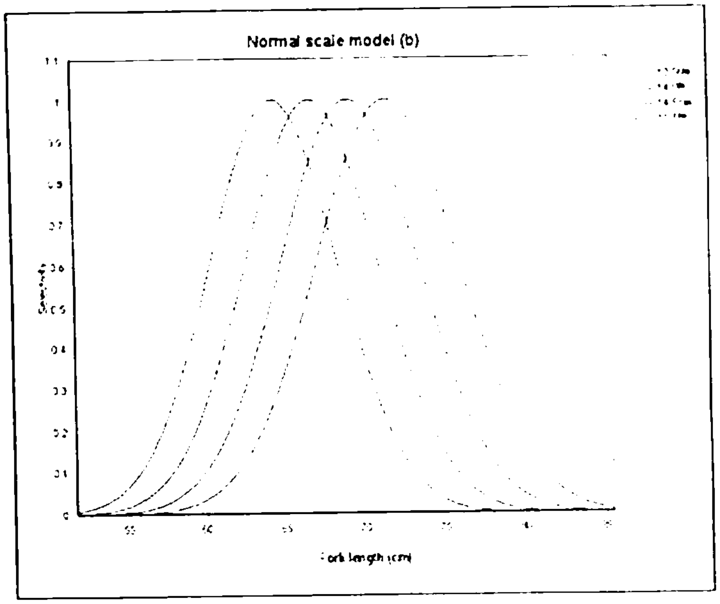


Fig. 45.4

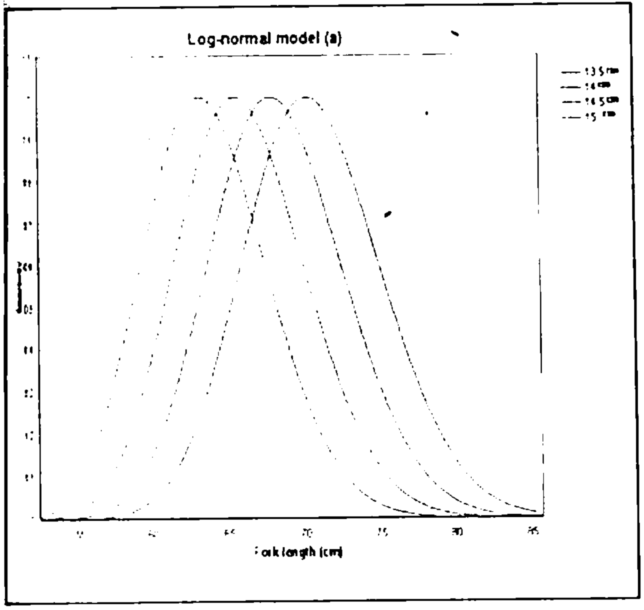


Fig. 45.5

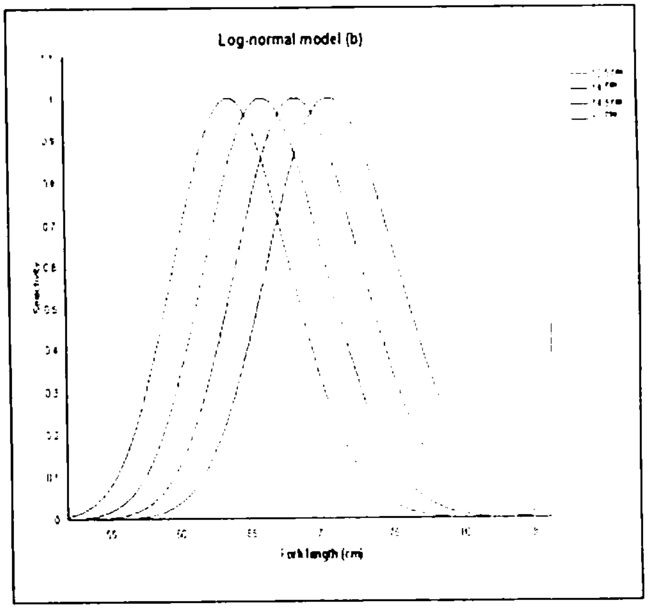


Fig. 45.6

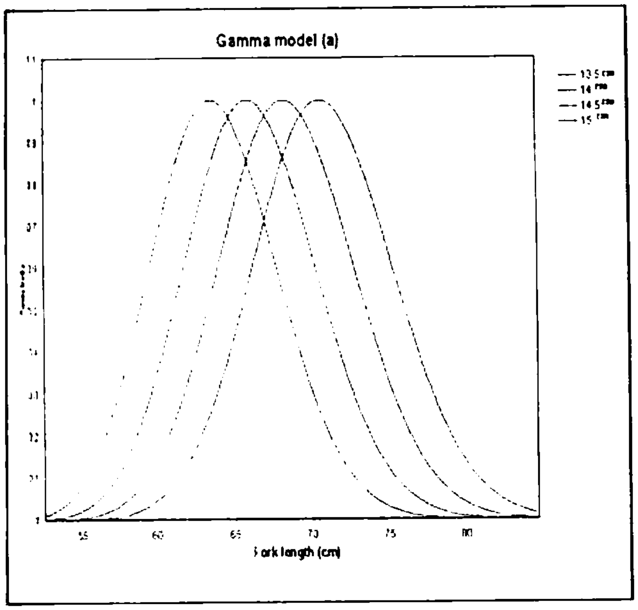


Fig. 45.7

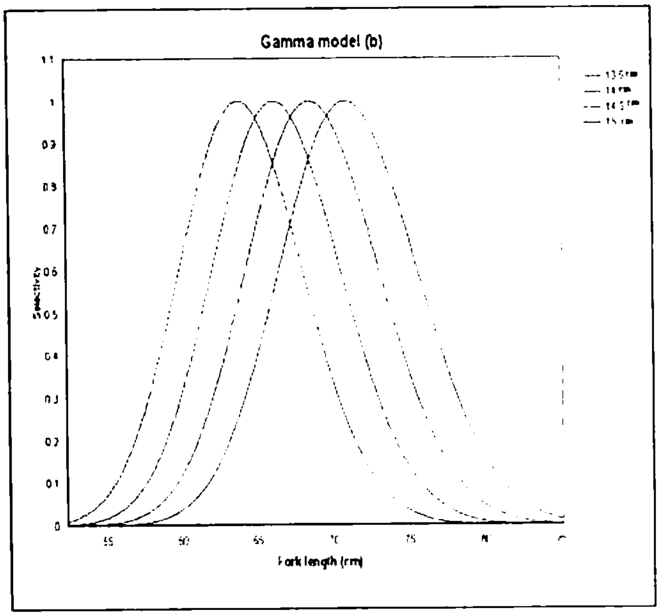


Fig. 45.8

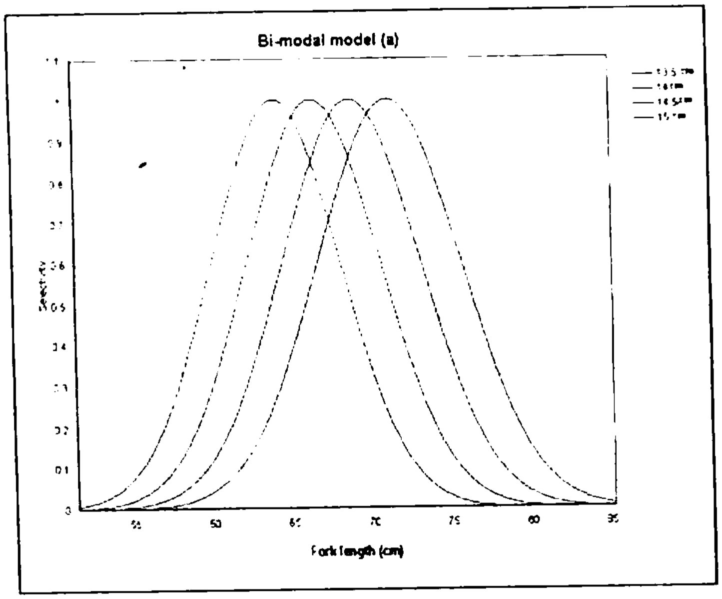


Fig. 45.9

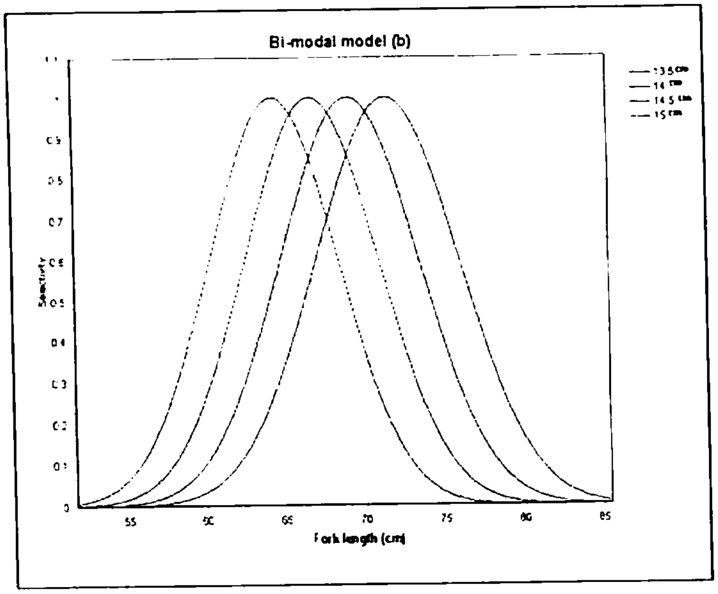


Fig. 45.10

After fitting the various uni-modal curves, goodness of fit was validated using the important statistic tool, called model deviance (D). Selection curves of all normal curves were symmetrical in shape and almost similar in all the models without skew ness. After analyzing the deviance and selection curves of all the models, it was found that all the selection curves gave good fit. However, log-normal model yielded better fit than other models having a small model deviance (458.56) in both the assumption of equal fishing power and fishing power is proportional to mesh size. There was no significant difference between models ($P>0.005$) except with normal scale ($P<0.005$). Other better fits followed by log-normal model based on deviance value were normal location (466.6 &466.75) under the assumption of fishing power proportional to mesh size and equal fishing power respectively, gamma (469.95), and normal scale (510.58 & 510.8) under equal fishing power and fishing power proportional to mesh size respectively.

The deviance of models fitted was evaluated further through dispersion parameter. Estimated dispersion values were 5.04 for log-normal, 5.14 & 5.13 for normal location with respect to constant fishing power and fishing power is proportional to mesh size respectively 5.16 for gamma model, and 5.61 for normal scale model for both the assumptions. Estimated dispersion parameter was greater than one in all the models. It obviously indicated over dispersion in all the models including better-fit log-normal model. Over dispersion in turn showed lack of fit in log-normal model.

Residual plots (Fig. 46) of all models tested revealed the fishing powers of 14 cm and 14.5 cm were greater than modeled with the occurrence of predominance of positive residuals. Of these meshes, mesh size of 14 cm ranked first in all the models followed by 14.5 and 13.5 cm except the log-normal model where fishing power was equal in both 13.5 and 15 cm. Fishing powers were almost equal in both the normal location and gamma model by the presence of equal number of positive residuals in respective mesh sizes except in the mesh size 13.5 cm. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models. It was seen true in the better-fit lognormal model also. Residual plots were almost similar in all the models. Plots showed capture of middle-

. 46 Residuals plots of selectivity curves of various models for different mesh sizes and fishing powers for *Caranx tille* (Area of the circle is proportional to square area of the residual)

a : Equal fishing power

b : Fishing power α mesh size

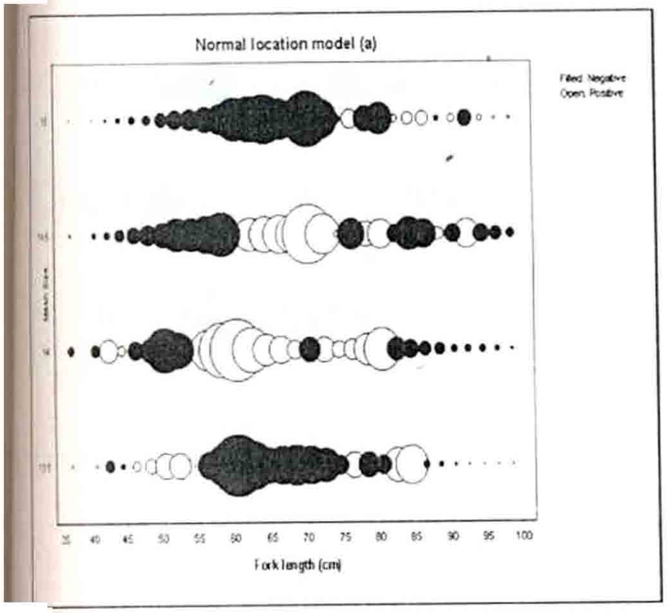


Fig. 46.1

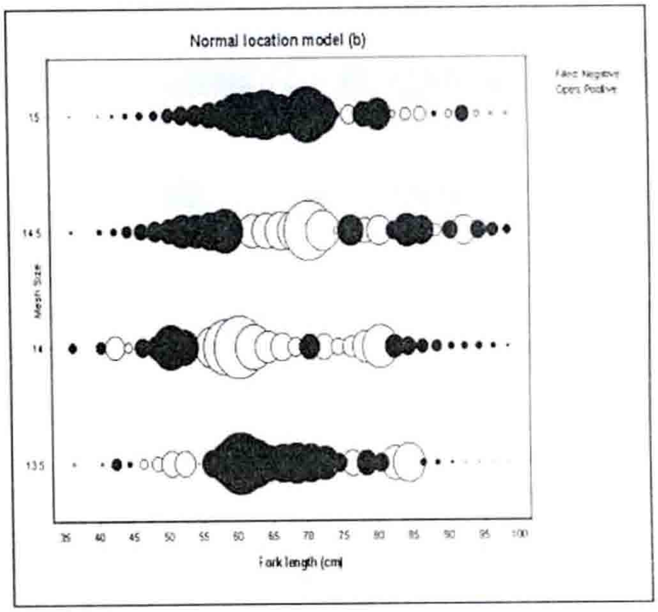


Fig. 46.2

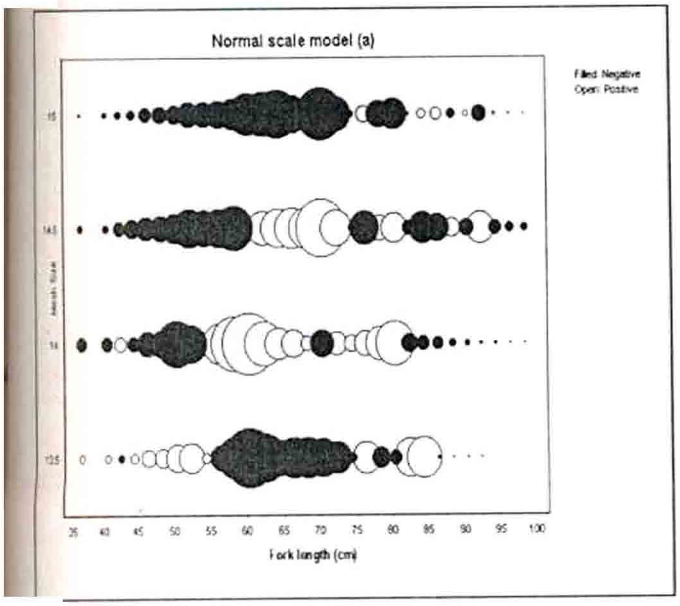


Fig. 46.3

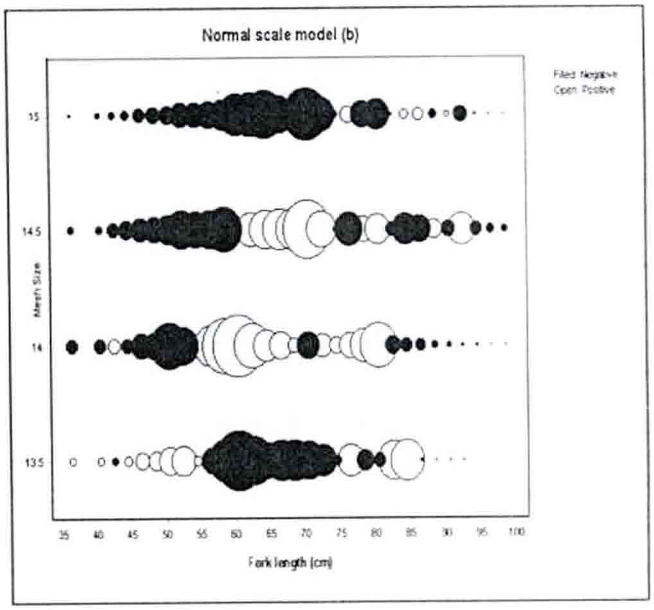


Fig. 46.4

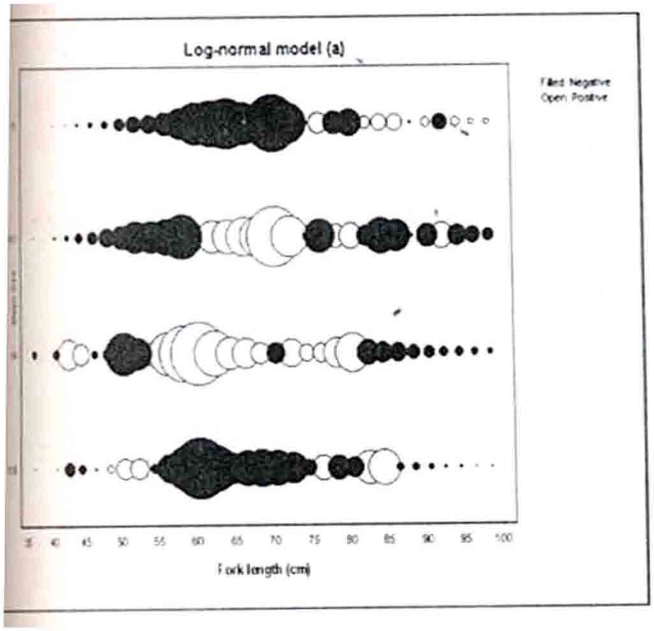


Fig. 46.5

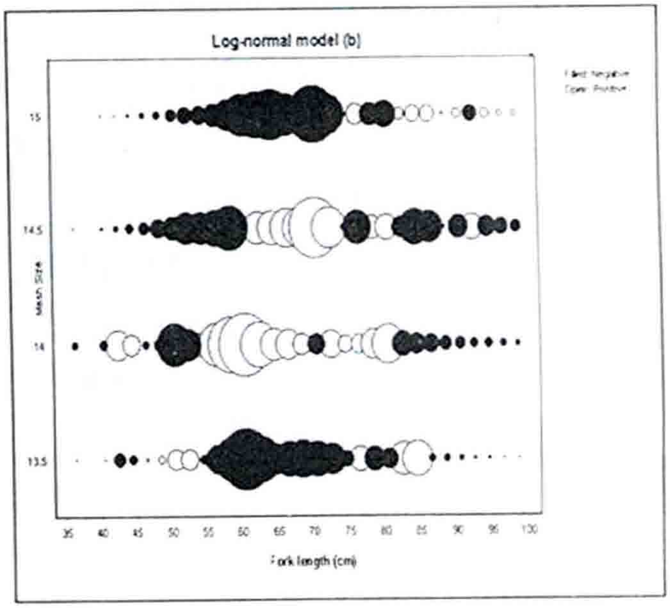


Fig. 46.6

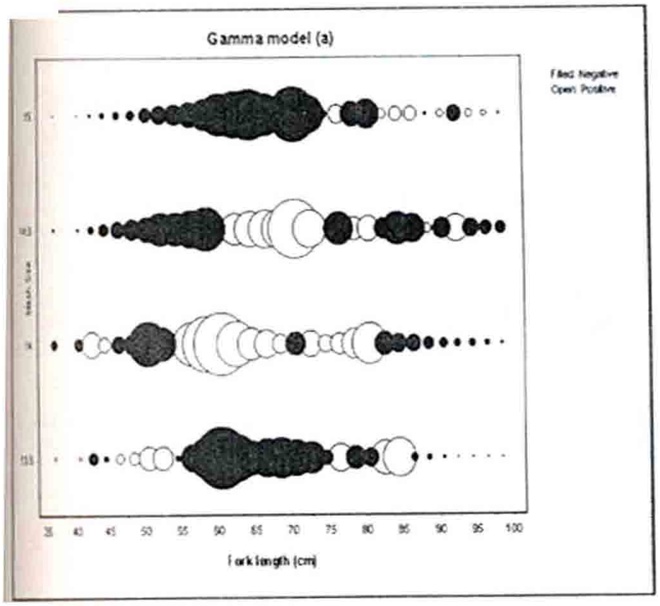


Fig. 46.7

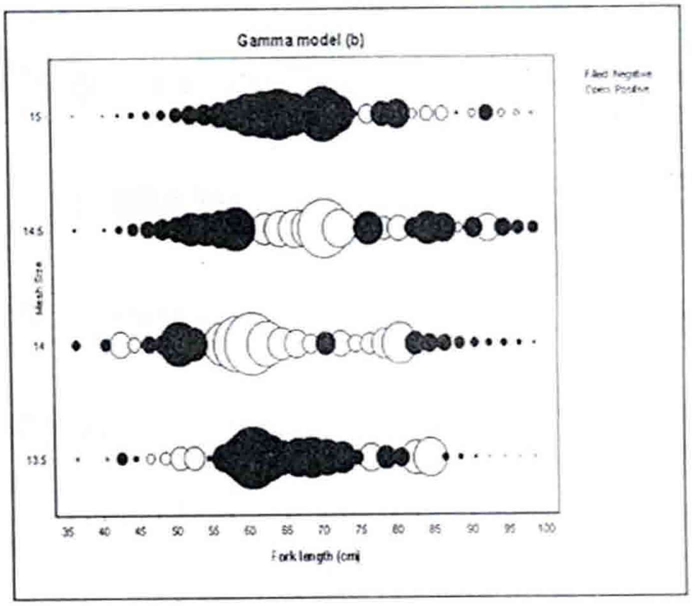


Fig. 46.8

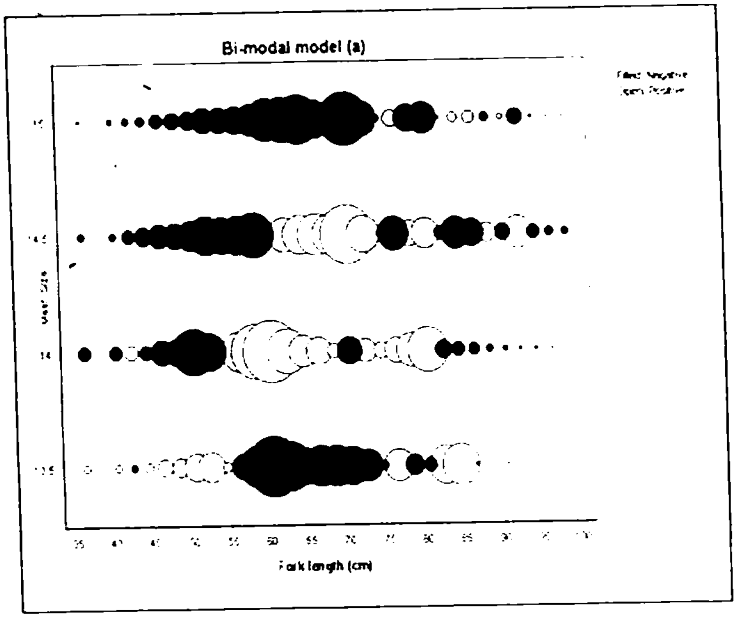


Fig. 46.9

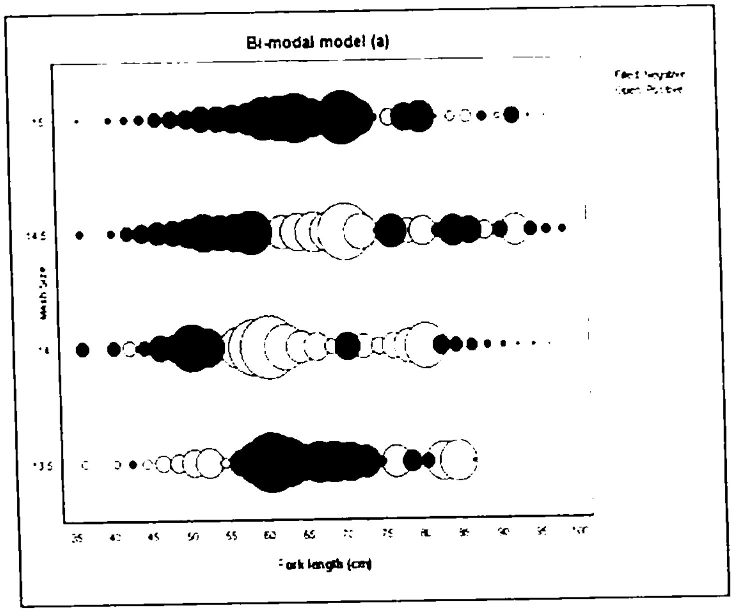


Fig. 46.10

sized length group (54.5 - 80.5 cm) from the mesh size of 14 cm and this mesh size overlapped with the mesh of 14.5 by capturing the same size group fish (60.5-80.5 cm). However, mesh 15 cm captured larger fishes (82.5 - 98.5 cm).

Model length and spread of the selection curves of different models for the different mesh sizes were presented in the Table 31. Modal length and spread of the selection curves were increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they varied between assumptions of equal fishing power and fishing power is proportional to mesh size. Estimated modal length and spread of the better fit model were 63.3 - 70.3 cm and 4.09 - 4.55 for the equal fishing power and 63.6 - 70.6 cm and 4.11 - 4.56 for the fishing power is proportional to mesh size.

4. 7.1.7.1 Refitting of Models

Residual plot of better-fit log-normal model showed lack of fit by the presence of large sized both positive and negative residuals and systematic occurrence of residuals instead of random order especially in the mesh sizes of 13.5 cm and 14 cm. Thus the uni-modal log-normal was extended to bi-modal since, value of all the residuals was not less than 2. Estimated bi-modal parameters under both the assumption of equal fishing power and fishing power proportional to mesh size are presented in Table 30. DF for the bi-modal was 88.

Model deviance of bi-modal model was higher (510.58) than better-fit uni-modal log-normal model (458.56) for the assumption of fishing power is proportional to mesh size. Hence, it was inferred that bi-modal curve was not best-fit model and it is not necessary to go for further analysis.

4.7.1.8 *Scomberoides commersonnianus*

Over all total catch of *Scomberioides commersonnianus* obtained from four mesh sizes was 1351 numbers. Of which, 297 specimens were caught from mesh size 13.5 cm, 440 from 14 cm, 336 from 14.5 cm and 278 from 15 cm (Table 18).

Fig. 47 Selectivity curves of various models for different mesh sizes and fishing powers for *Scomberoides commersonnianus*

a : Equal fishing power

b : Fishing power α mesh size

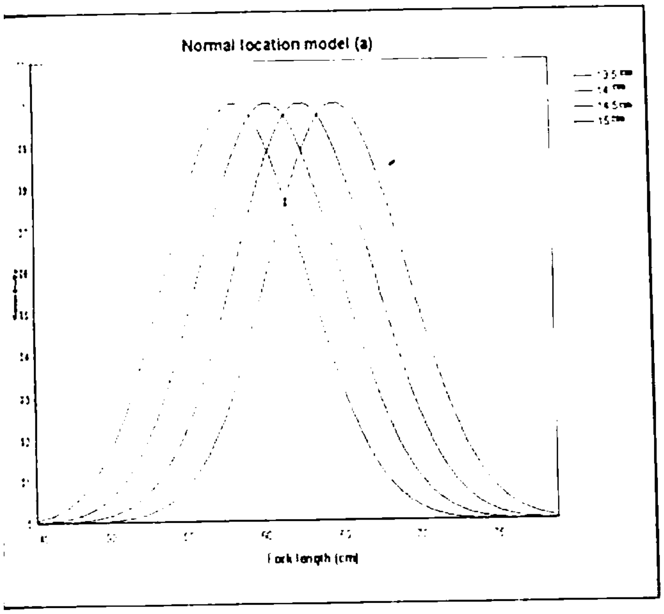


Fig. 47.1

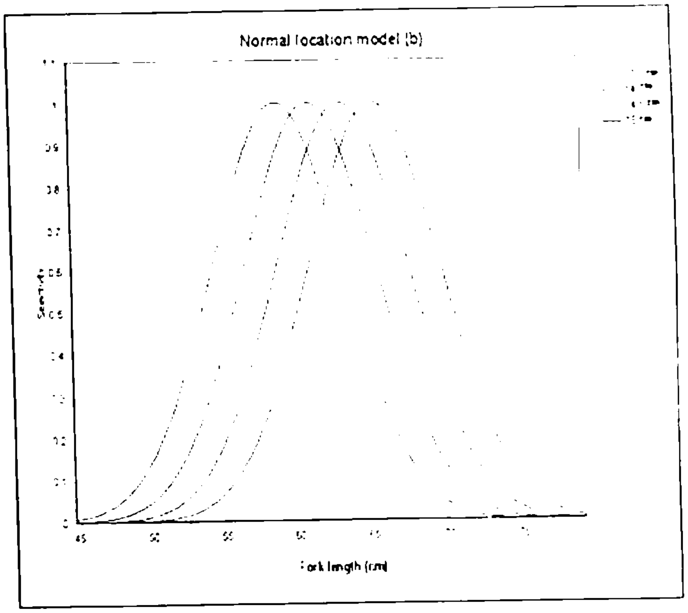


Fig. 47.2

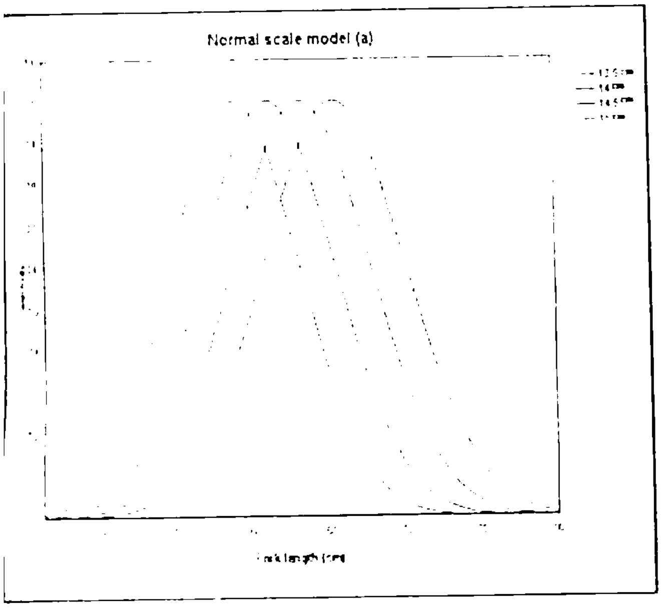


Fig. 47.3

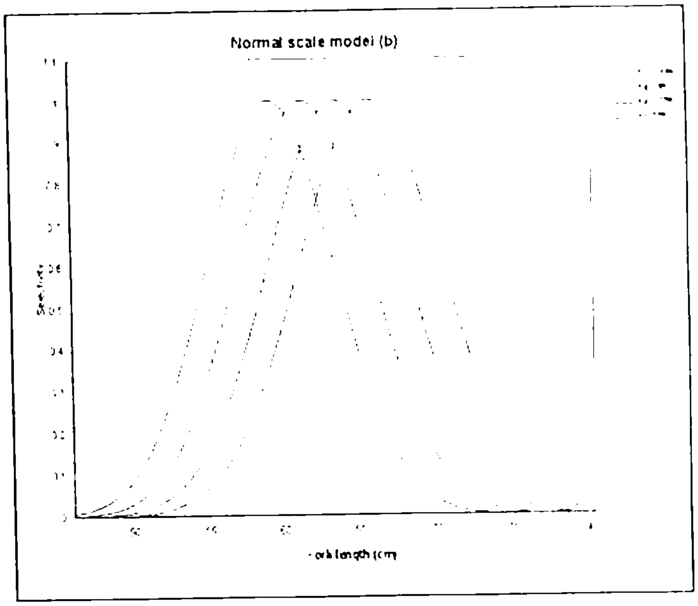


Fig. 47.4

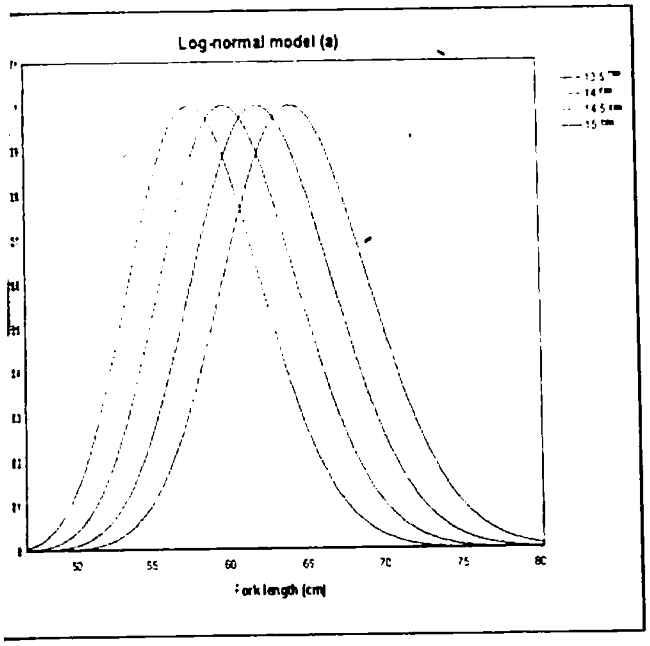


Fig. 47.5

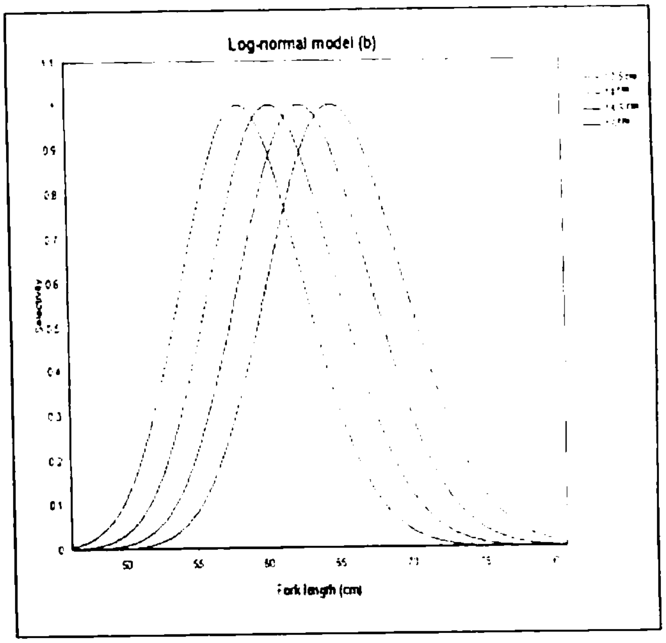


Fig. 47.6

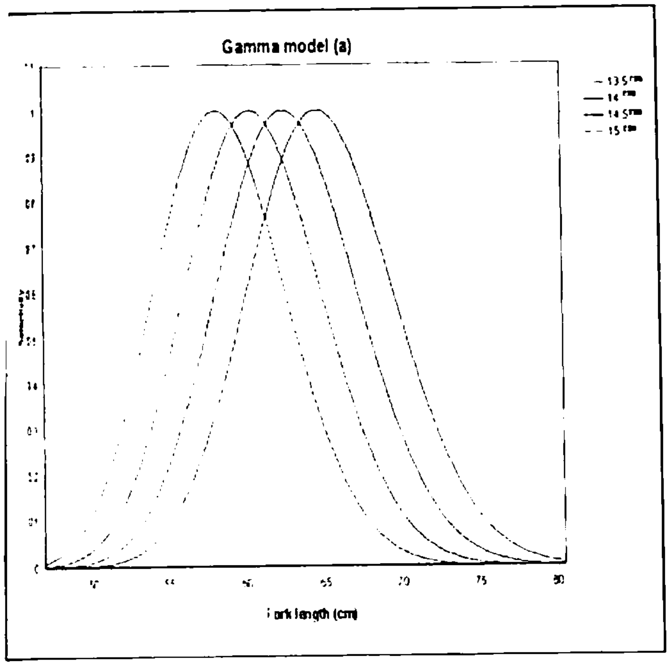


Fig. 47.7

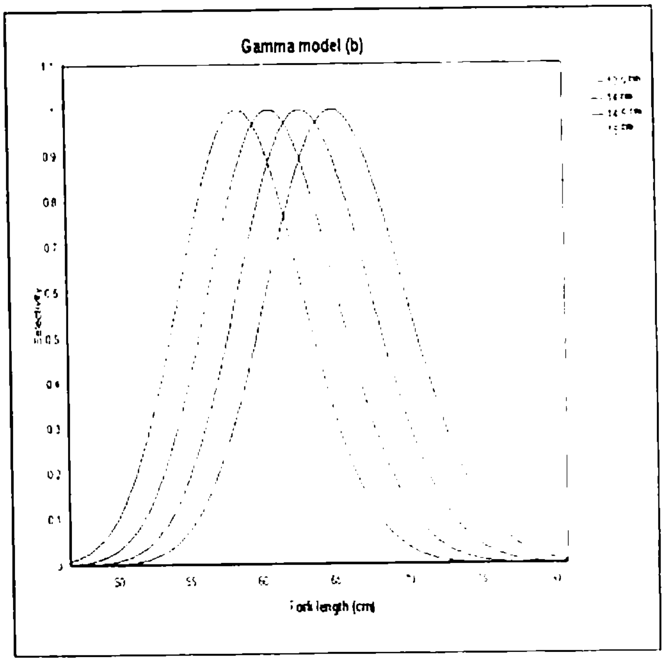


Fig. 47.8

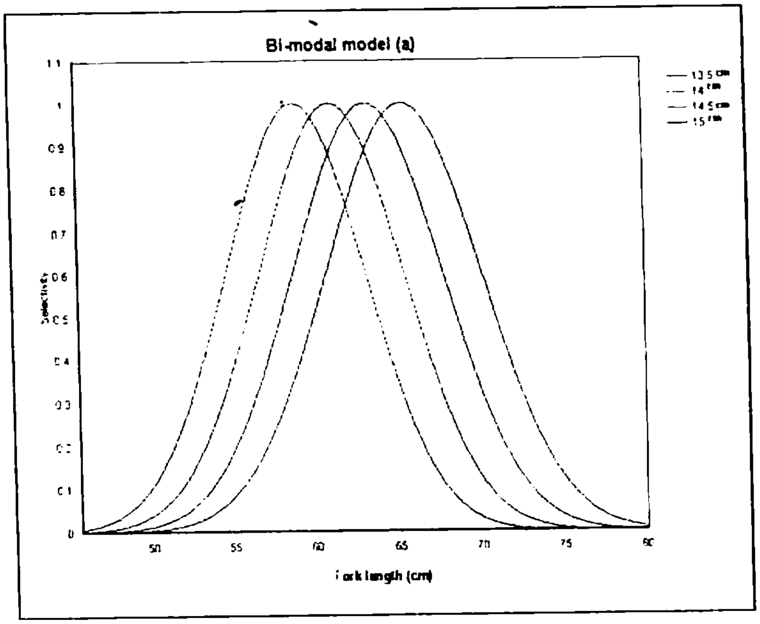


Fig. 47.9

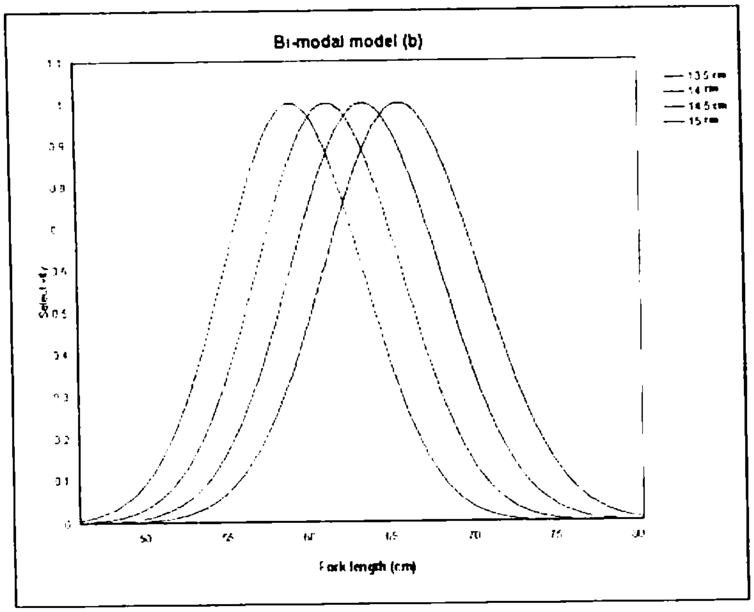


Fig. 47.10

Four families of uni-normal selection curves such as Normal location, Normal scale, Log-normal and Gamma fitted to the data (Table. 11) are presented in Fig. 47. Total degrees of freedom (DF) for uni-modal curves was 94, and other selectivity estimates including standard deviation (SD), model deviance (D), and modal length and spread of selection curve are presented in the Table.30 & 31.

Selection curves of all normal curves were symmetrical in shape and almost similar in all the models without skew ness. Model deviance of each model was observed to find out best fit of the model. While analyzing the deviance and selection curves of all the models, all the selection curves gave good fit. However, log-normal model yielded better fit than other models having a small model deviance (531.33) in both the assumption of equal fishing power and fishing power is proportional to mesh size. There was no significant difference between models except with normal scale ($P<0.01$). Other better fits followed by log-normal model based on deviance value were gamma (543.09), normal location (548.11 & 549.22) under the assumption of fishing power proportional to mesh size and equal fishing power respectively. and normal scale (590.09 & 590.42) under equal fishing power and fishing power proportional to mesh size respectively.

The deviance of models fitted was evaluated further through dispersion parameter for a precision fit by referring it to a chi-square distribution since deviance was greater than degrees of freedom. Estimated dispersion values were 5.65 for log-normal, 5.78 for gamma model, 5.83 & 5.84 for normal location with respect to fishing power is proportional to mesh size and constant fishing power respectively and 6.28 for normal scale model for both the assumptions. Estimated dispersion parameter was greater than one in all the models. It obviously indicated over dispersion in all the models including better-fit log-normal model. Over dispersion in turn showed lack of fit in log-normal model.

Residual plots of all the models are presented in Fig. 48. and they revealed the fishing powers of 14 cm and 14.5 cm were greater than modeled with the occurrence of predominance of positive residuals. Of these meshes, mesh size of 14 cm ranked first in all the models followed by 14.5 cm

g. 48 **Residuals plots of selectivity curves of various models for different mesh sizes and fishing powers for *Scomberoides commersonnianus* *(Area of the square is proportional to square of the residual)***

a : Equal fishing power

b : Fishing power α mesh size

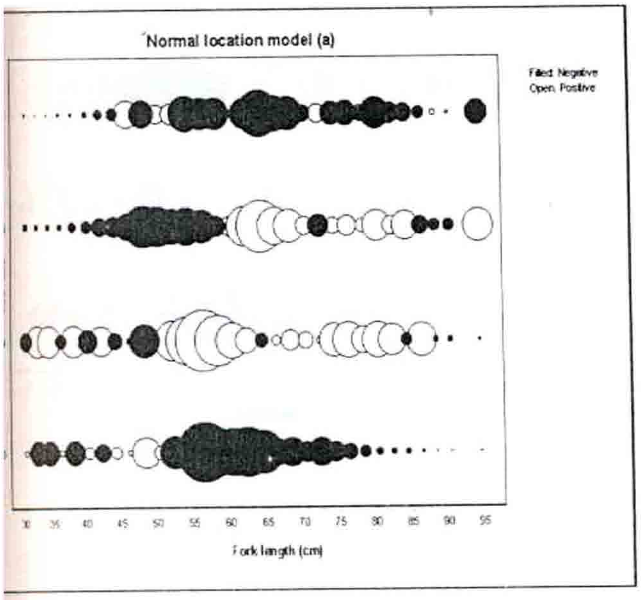


Fig. 48.1

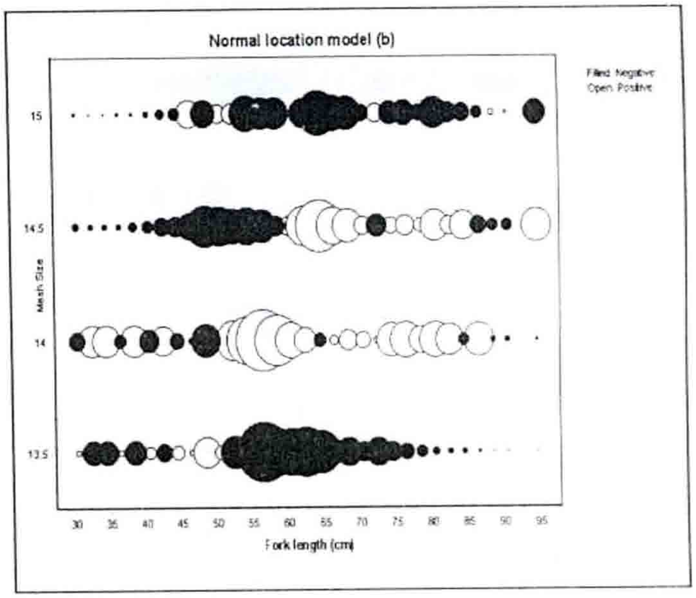


Fig. 48.2

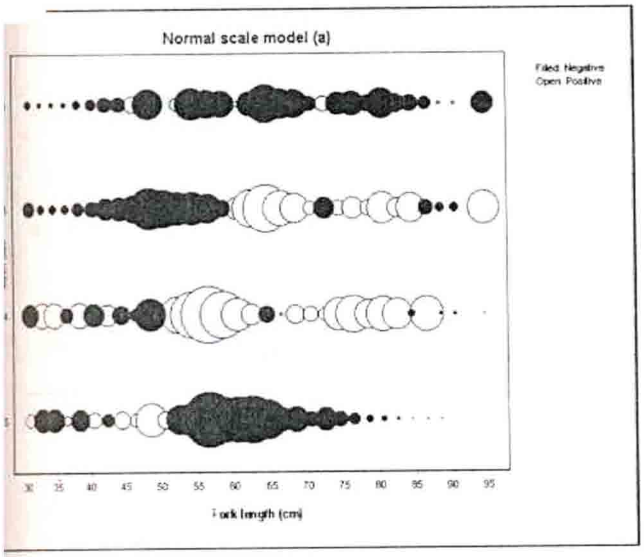


Fig. 48.3

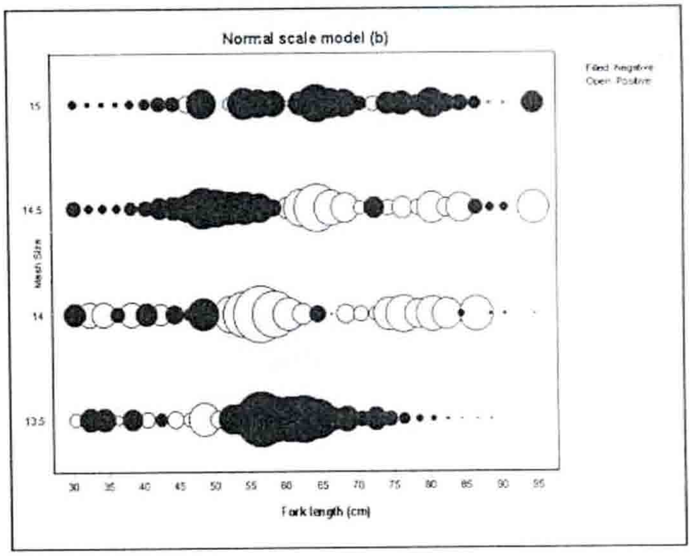


Fig. 48.4

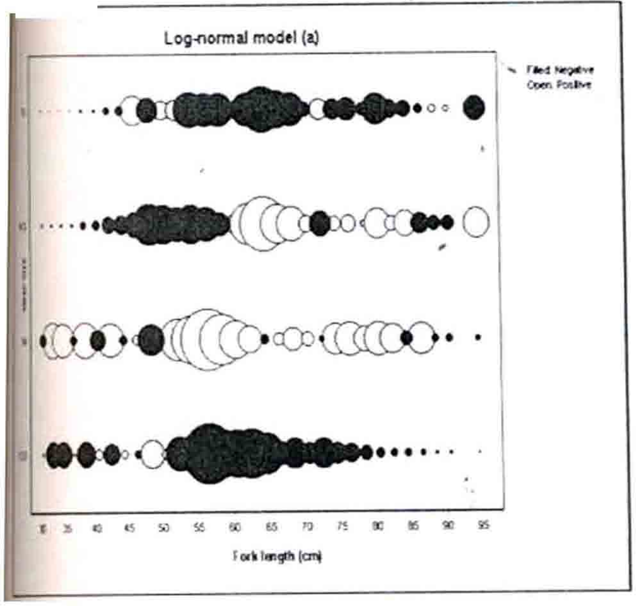


Fig. 48.5

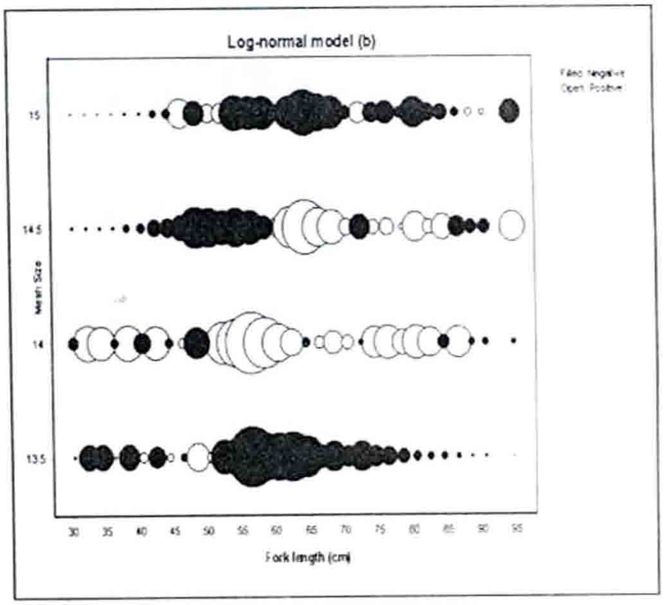


Fig. 48.6

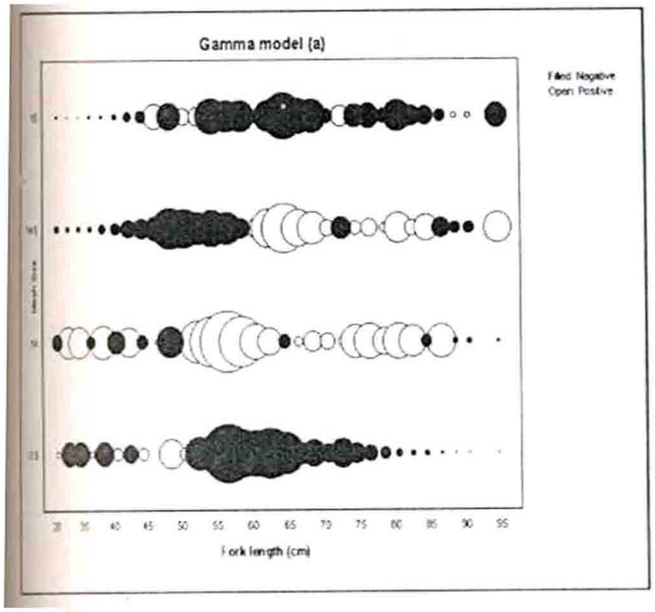


Fig. 48.7

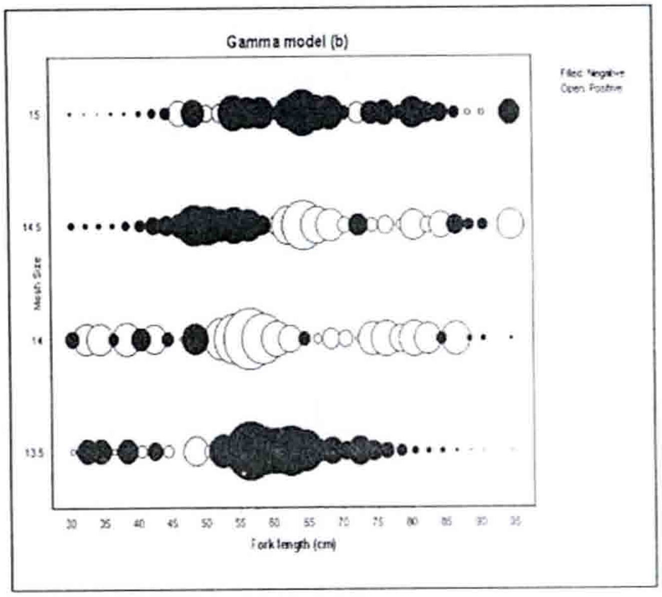


Fig. 48.8

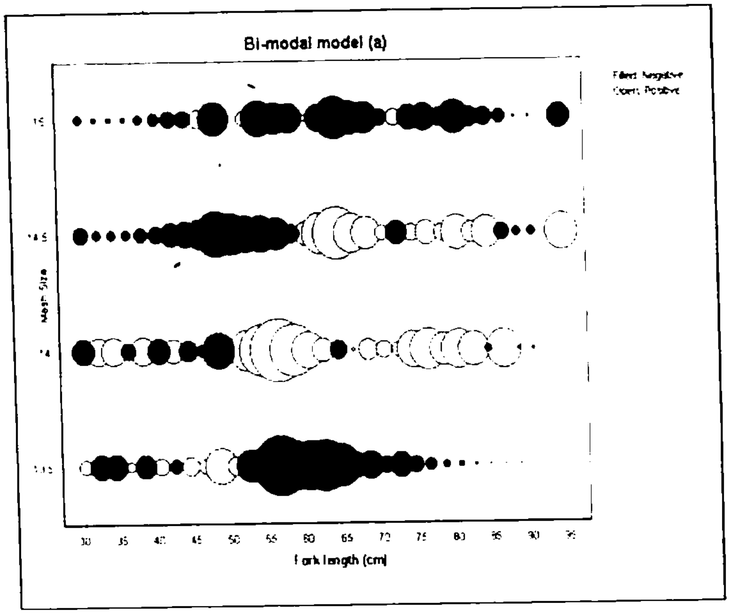


Fig. 48.9

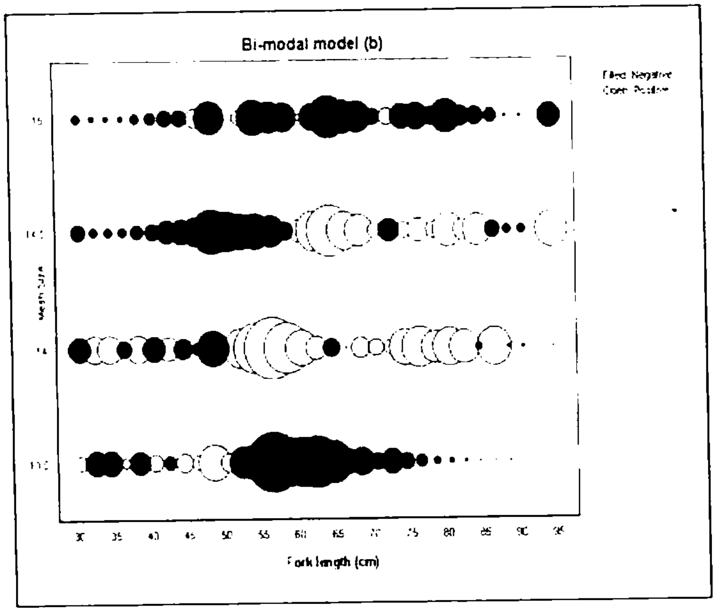


Fig. 48.10

and 13.5. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models. It is seen in the better-fit lognormal model also. Mesh sizes of 13.5 and 15 had equal fishing power in the better-fit log-normal model though fishing power was very poor in these meshes. Residual plots showed that almost all length group of fish were caught from mesh size of 14 cm (30.5 - 86.5 cm) and 14.5 cm captured larger fishes (60.5 - 84.5 cm) and overlapping of catch were also observed in these mesh sizes.

Model length and spread of the selection curves of different models for the different mesh sizes were presented in the Table 31. Modal length and spread of the selection curves were increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they were varied between assumptions of equal fishing power and fishing power is proportional to mesh size. Estimated modal length and spread of the better fit model were 57.9 cm - 64.3 cm and 4.24 - 4.71 for the equal fishing power and 58.2 cm - 64.7 cm and 4.26 - 4.73 for the fishing power is proportional to mesh size.

4. 7.1.8.1 Refitting of Models

Residual plot of better-fit log-normal model showed lack of fit. Hence, the uni-modal log-normal was extended to bi-modal model since value of all the residuals was not less than 2. Estimates of bi-modal selectivity curves and their parameters under both the assumption of equal fishing power and fishing power proportional to mesh size are presented in Table 30. DF for the bi-modal was 91.

Model deviance of bi-modal model was higher (590.09) than better-fit uni-modal log-normal model (531.33) and dispersion (6.48) of this model was also higher than log-normal. It clearly indicated that bi-modal curve was not best-fit model and hence it is not necessary to go for further analysis. Further there was significant difference ($P<0.01$) between deviances of bi-modal (590.09) and log-normal model (531.33) for the degrees of freedom given by the difference between number of parameters. Residual plot of bi-modal function under both the assumption were presented in Fig. 48.9 &

48.10 and were similar with normal location, normal scale. Fishing power was also similar with log-normal model and in capturing size group of fish.

4.7.1.9 *Scomberoides lysan*

Over all total catch of *Scomberoides lysan* obtained from four mesh sizes was 1672 numbers. Of which, 450 specimens were caught from mesh size 13.5 cm, 406 from 14 cm, 327 from 14.5 cm and 483 from 15 cm (Table. 18).

Four families of uni-nomal selection curves fitted to the data (Table. 12) are presented in Fig. 49. Total degrees of freedom (DF) for uni-modal curves was 70. Estimated standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve are presented in the Table 30 & 31.

After fitting the various uni-modal curves, goodness of fit was validated using the important statistic tool, called model deviance (D). Selection curves of all normal curves were symmetrical in shape and almost similar in all the models without skew ness. Model deviance of each model was observed to find out best fit of the model. After evaluation of the deviance and selection curves of all the models, all the selection curves gave good fit. However, log-normal model yielded better fit than other models having a small model deviance (362.85) in both the assumption of equal fishing power and fishing power is proportional to mesh size. There was significant difference between models ($P<0.05$) except with gamma model ($P>0.05$). Other better fits followed by log-normal model based on deviance value were gamma (387.05), normal location (400.55 & 400.68) under the assumption of equal fishing power and fishing power proportional to mesh size respectively, and normal scale (455.55 and 455.95) under equal fishing power and fishing power proportional to mesh size respectively.

The deviance of models fitted was evaluated further using dispersion parameter. Estimated dispersion values were 5.18 for log-normal, 5.53 for gamma model, 5.7 and 5.72 for normal location with respect to constant fishing power and fishing power is proportional to mesh size respectively, and 6.51 for normal scale model. Over dispersion was indicated

g. 49 Selectivity curves of various models for different mesh sizes and fishing powers *Scomberoides lysan*

a : Equal fishing power

b : Fishing power α mesh size

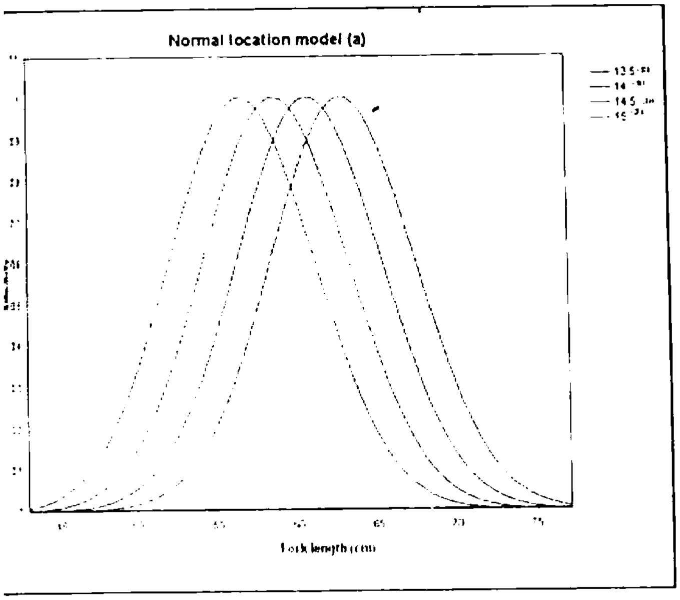


Fig. 49.1

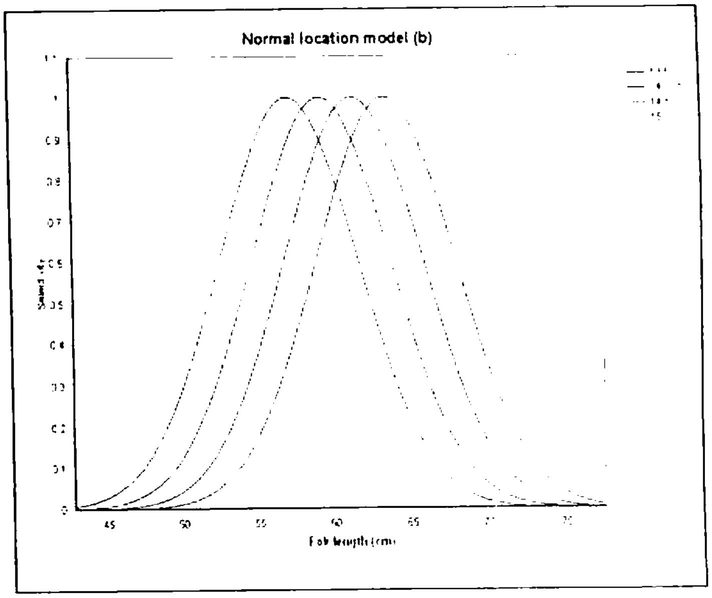


Fig. 49.2

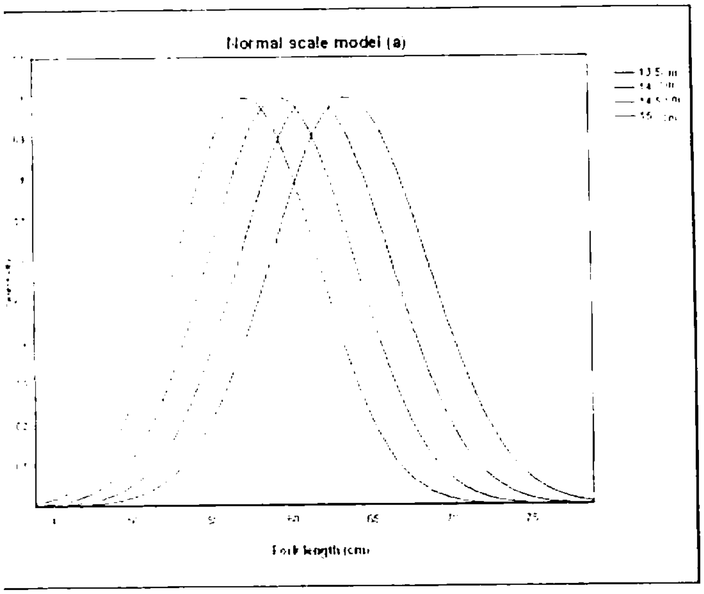


Fig. 49.3

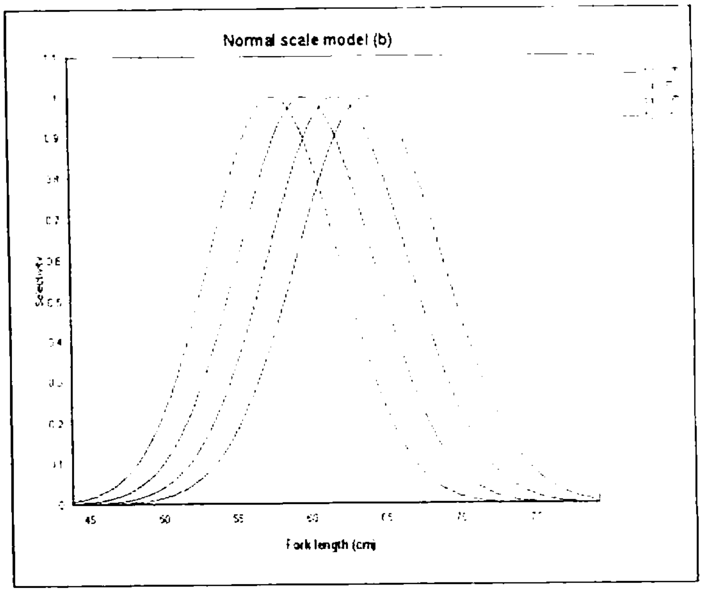


Fig. 49.4

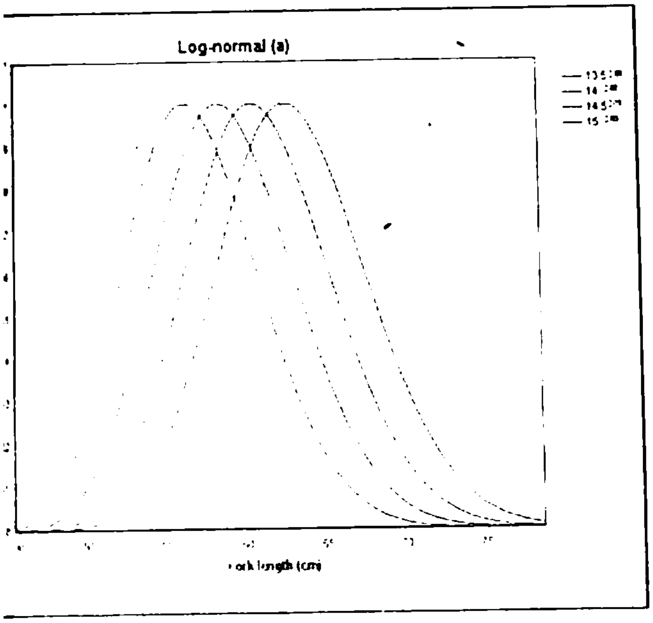


Fig. 49.5

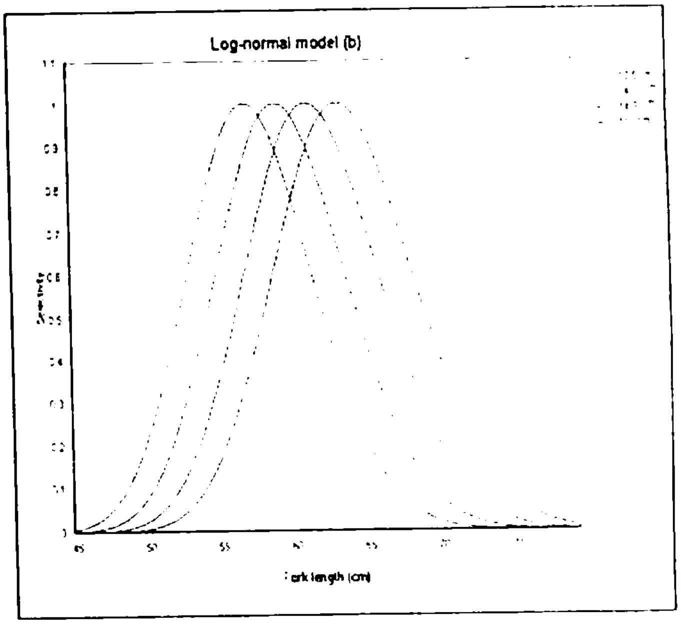


Fig. 49.6

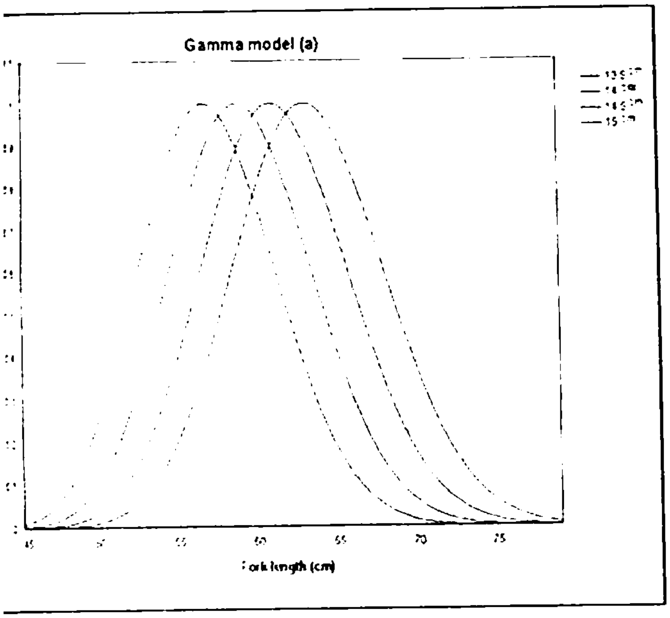


Fig. 49.7

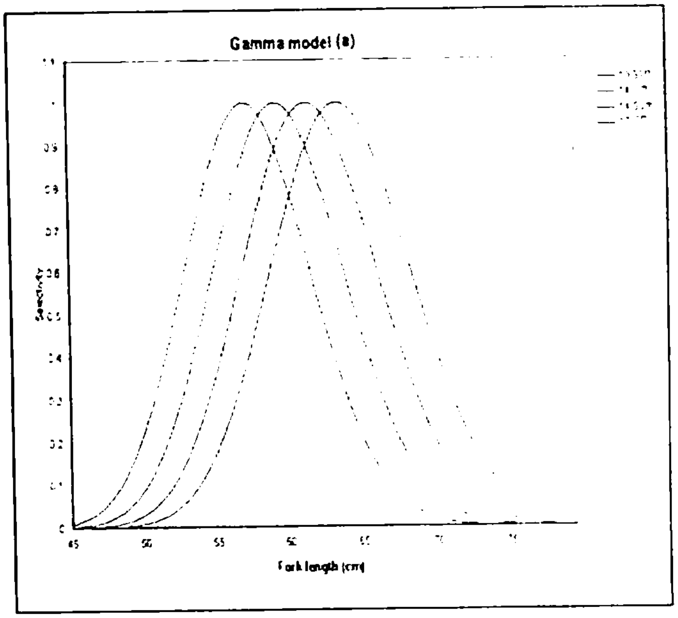


Fig. 49.8

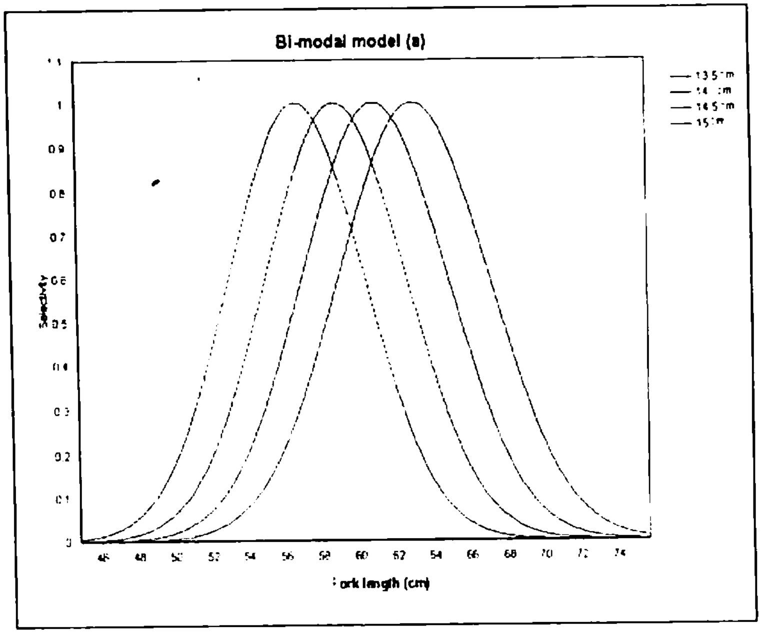


Fig. 49.9

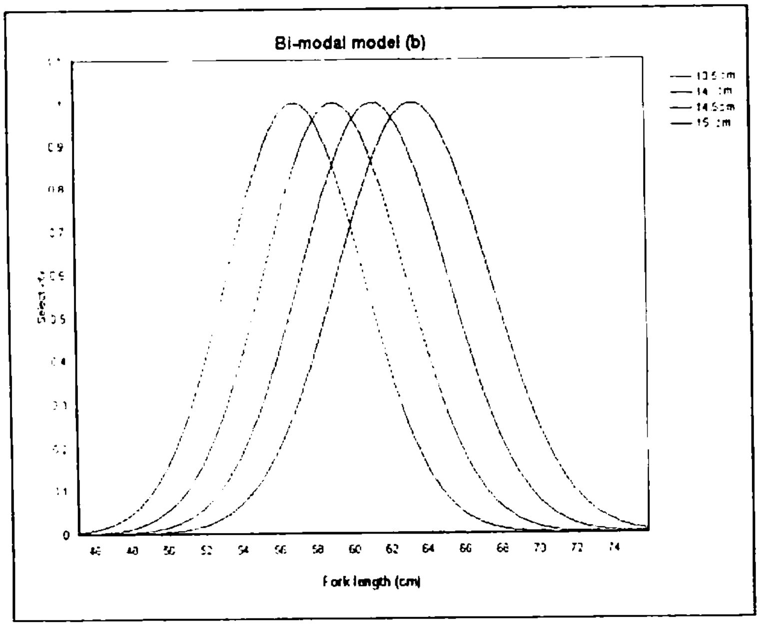


Fig. 49.10

ig. 50 Residual plots of selectivity curves for various models for different mesh sizes and fishing powers *for Scomberoides lysan* (Area of the circle ~~mesh sizes and~~ proportional to square of the residual)

a : Equal fishing power

b : Fishing power α mesh size

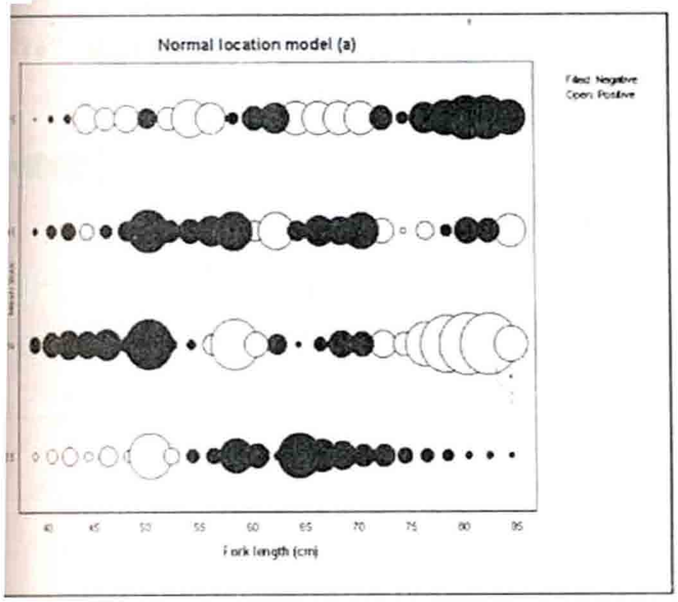


Fig. 50.1

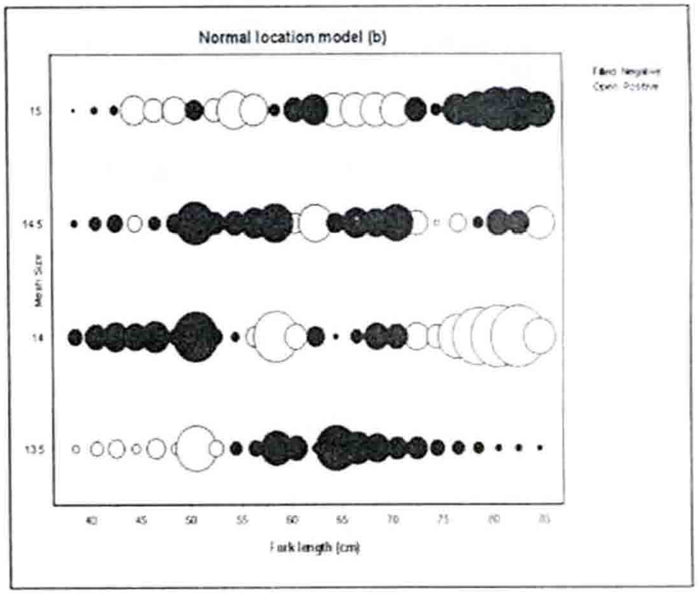


Fig. 50.2

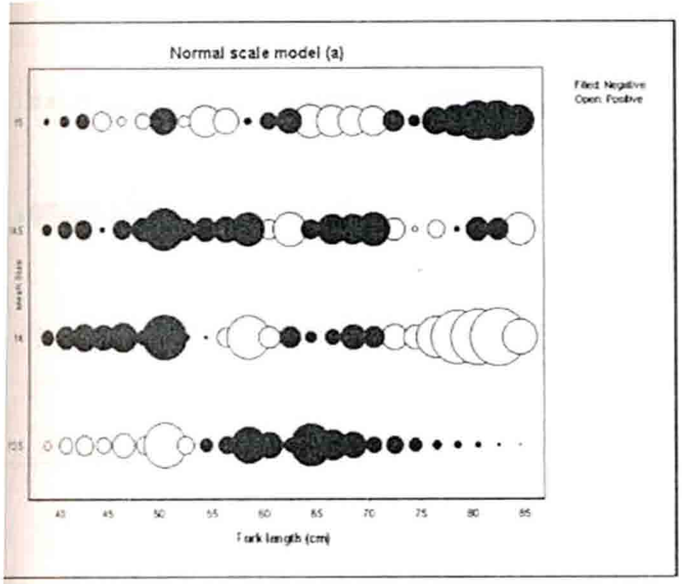


Fig. 50.3

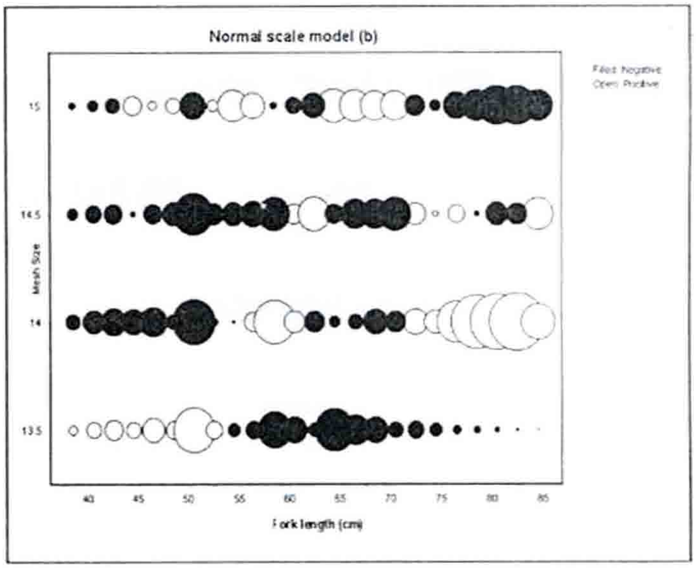


Fig. 50.4

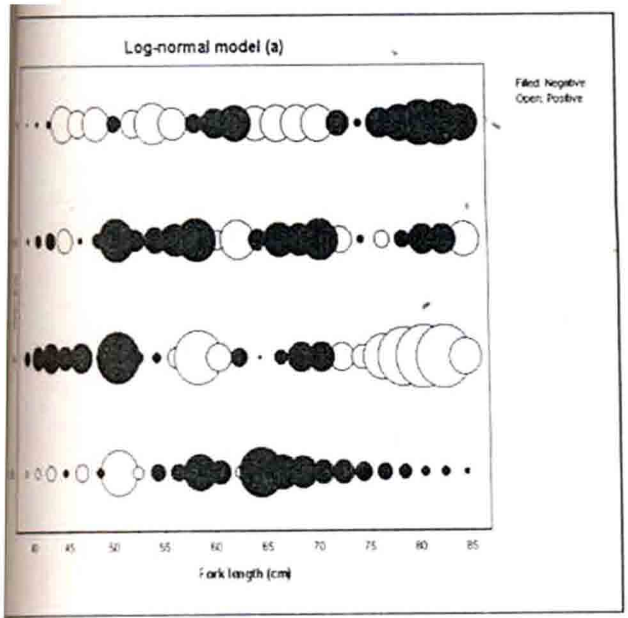


Fig. 50.5

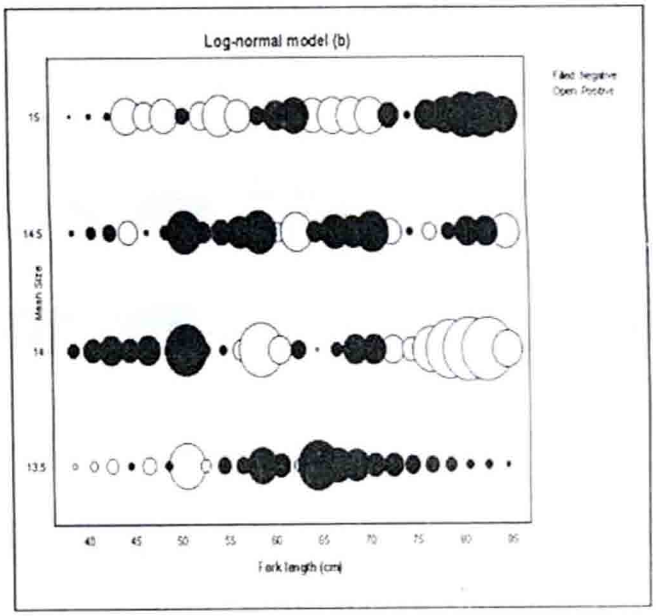


Fig. 50.6

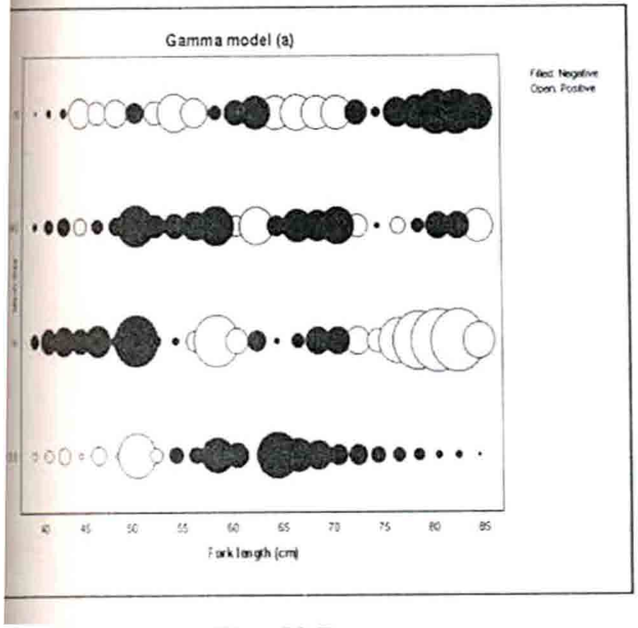


Fig. 50.7

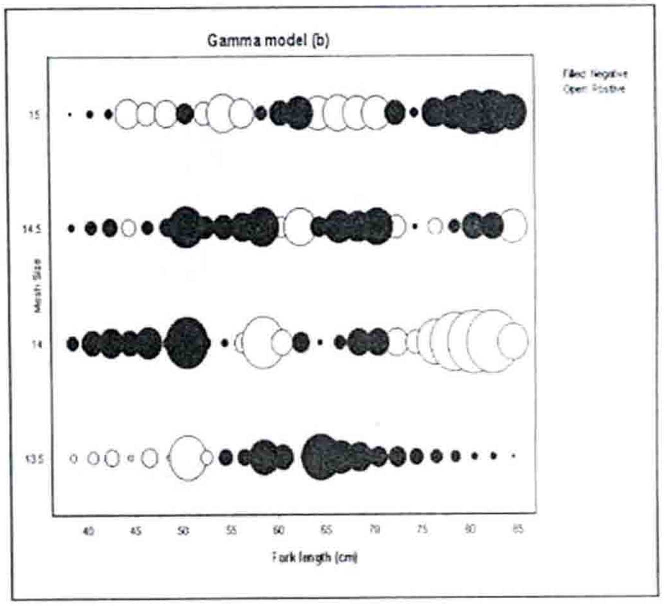


Fig. 50.8

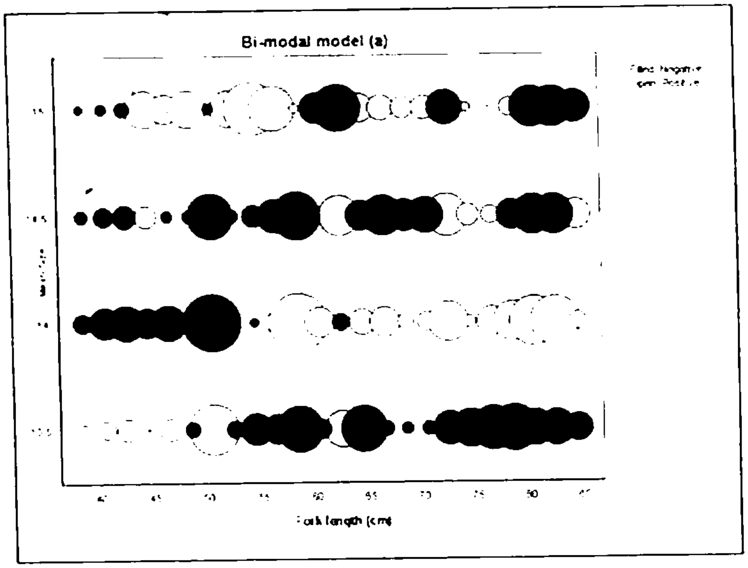


Fig. 50.9

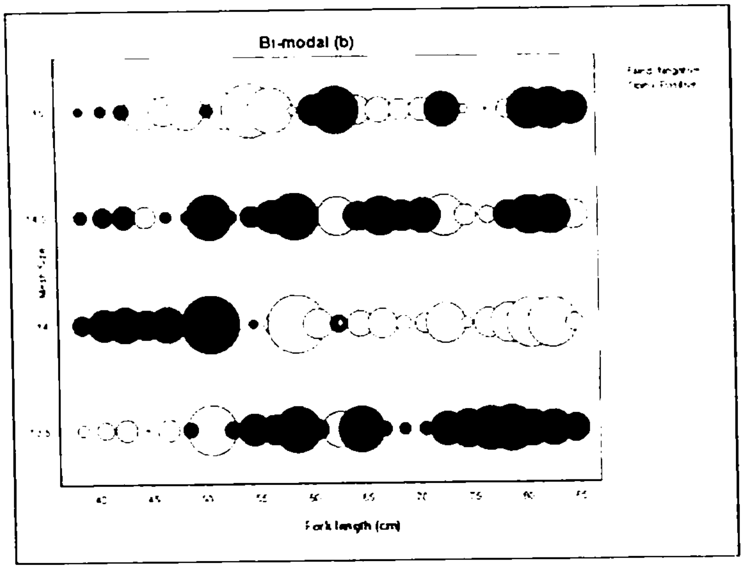


Fig. 50.10

in all the models including better-fit log-normal model and it in turn showed lack of good fit in log-normal model.

Analysis of deviance residuals (Mcullagh and Nelder, 1989) of the all models for the species *S. lysan* were plotted (Fig. 50) under both the assumptions of equal fishing power and fishing power proportional to mesh size. Residual plots revealed the fishing powers of 14 cm and 15 cm were greater than mesh size 14.5 cm by the predominance of positive residuals and fishing power of mesh sizes of 14 and 15 cm were equal in normal scale, normal location and gamma model. Mesh size of 13.5 cm ranked second in all models except log-normal where 15 cm was ranked second and 13.5 cm ranked in third place. However, mesh size 14.5 cm was in third place in all the models except log-normal model.

Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models including better-fit lognormal model. Residual plots showed that mesh size of 14 cm captured middle and large group of fish (56.5 to 84.5) and smaller and middle length group of fish were caught (44.5 to 70.5) by 15 cm mesh size. Mesh sizes of 14.5 and 13.5 cm caught various size classes.

Model length and spread of the selection curves of different models for the different mesh sizes were presented in the Table 31. Modal length and spread of the selection curves were increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they varied between assumptions of equal fishing power and fishing power is proportional to mesh size. Estimated modal length and spread of the better-fit model were 56.5 to 62.8 cm and 4.24 to 4.71 for the equal fishing power and 56.8 to 63.1 cm and 4.26 to 4.73 for the fishing power is proportional to mesh size.

4.7.1.9.1 Refitting of Models

Uni-modal log-normal was refitted to bi-modal or bi-normal model since it showed poor fit, having large size of residuals. Bi-modal selectivity curves and their parameters were estimated under both the assumption of equal fishing power and fishing power proportional to mesh size and presented in Table 30. DF for the bi-modal was 67.

Model deviance of bi-modal model was greatly reduced to 223.67 for the assumption equal fishing power and 223.69 for fishing power proportional to mesh size despite the deviance of uni-modal log-normal model was 362.85. In order to find out goodness of fit of the bi-modal curve, dispersion parameter was` also estimated. It was 3.34 for both equal fishing power and fishing power proportional to mesh size as well. It revealed over dispersion of the model and lesser than dispersion parameter of uni-modal log-normal fit (5.18) and other dispersion ratio for remaining uni-models was, gamma (5.53), and normal location (5.7) and normal scale (6.51). Further there was significant difference ($P<0.01$) between deviances of bi-modal (223.67) and log-normal model (362.85). Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to mesh size were 56.7 - 63 cm with the spread range of 3.64 - 4.04 and 57 - 63.3 cm with the spread of 3.63 to 4.03 respectively.

Residual plots of bi-modal function under both the assumption were presented in Fig. 50.9 &50.10. Plots explained that the mesh sizes of 14, and 15 cm were greater than modeled with the presence of more positive residuals. Residual plots of both uni-modal log-normal and bi-modal differed greatly from log-normal. In this model the mesh size of 14 cm ranked first followed by 15 cm as existed in the log-normal model while other two mesh sizes had equal fishing power. There was little difference was shown with log-normal model in terms of size groups caught. Fishing power of mesh size 14 cm concentrated on wide range of larger length class (56.5 to 84.5 cm) compared to 15 cm where small and medium sized fish (44.5 to 78.5 cm) were captured. Fishing power was minimum for 13.5 and 14.5 cm and effected on small and bigger fishes respectively. However, a great reduction observed in the deviance of bi-modal than the uni-modal log-normal model selection.

4.7.1.10 *Scomberoides tala*

Over all total catch of *Scomberoides tala* obtained from four mesh sizes was 1113 numbers. Of which, 417 specimens were caught from mesh size 13.5 cm, 176 from 14 cm, 242 from 14.5 cm and 278 from 15 cm (Table. 18).

51 Selectivity curves of various models for different mesh sizes and fishing powers for *Scomberoides tala*

a : Equal fishing power

b : Fishing power α mesh size

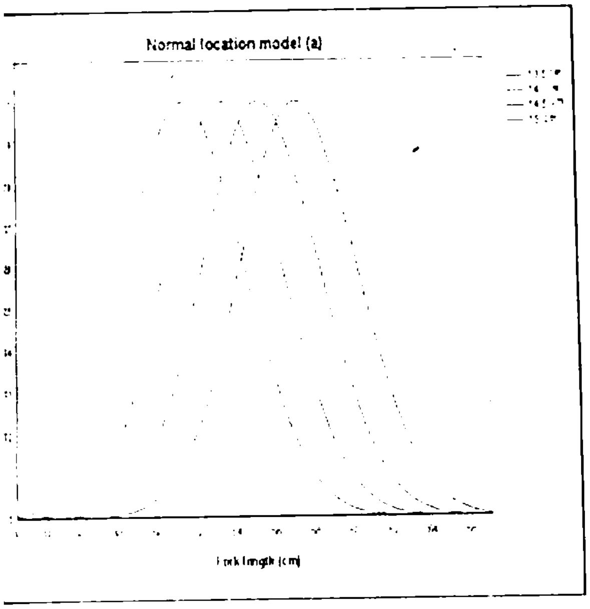


Fig. 51.1

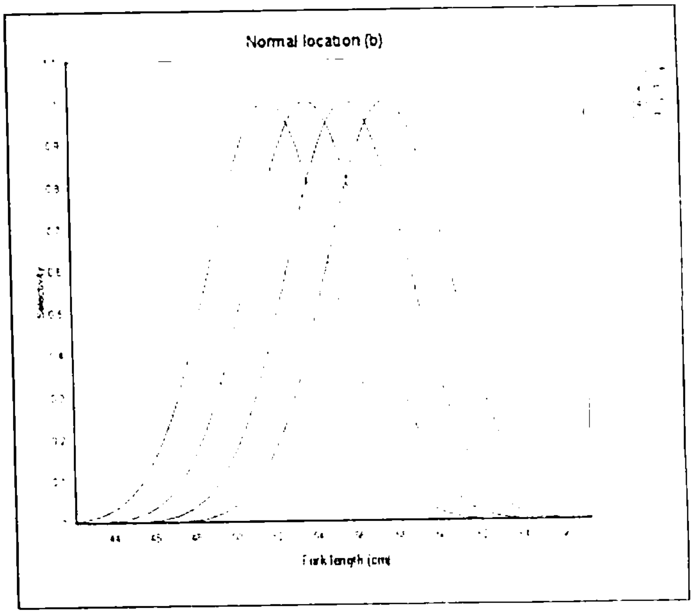


Fig. 51.2

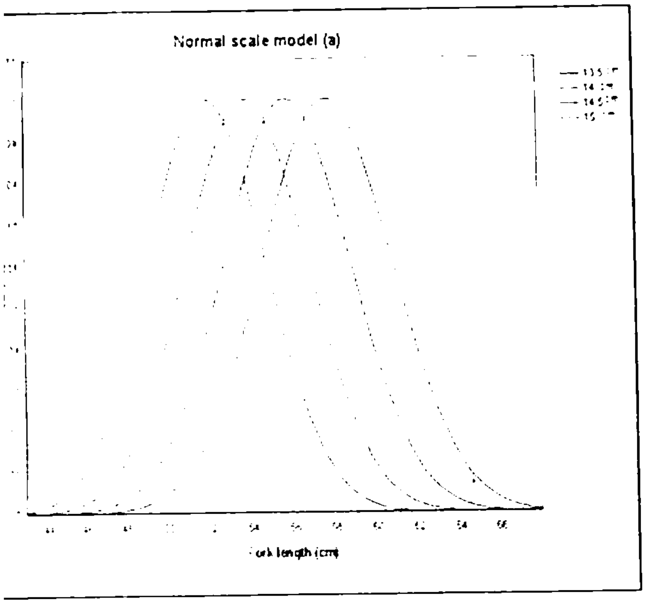


Fig. 51.3

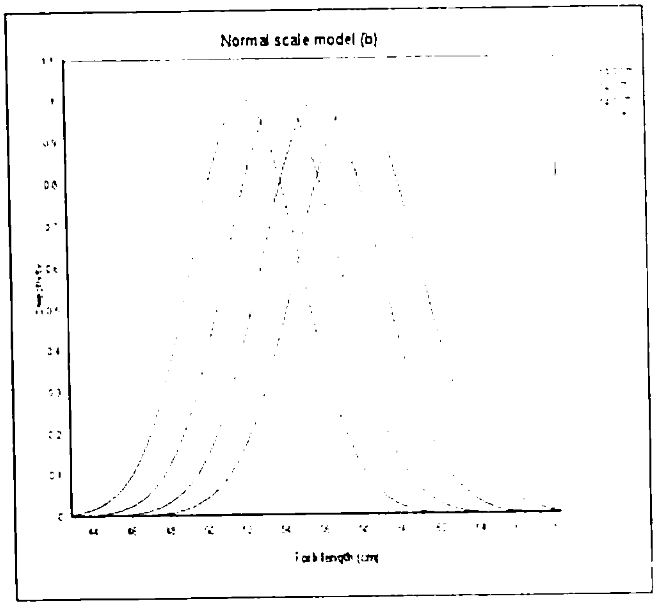


Fig. 51.4

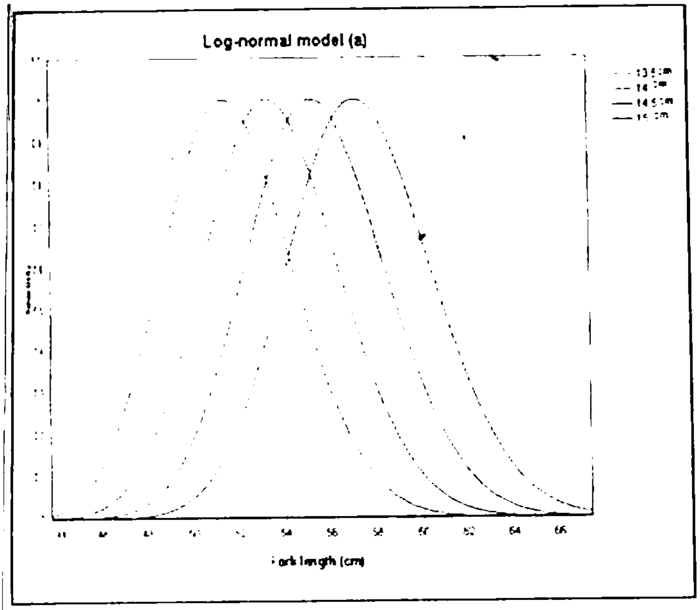


Fig. 51.5

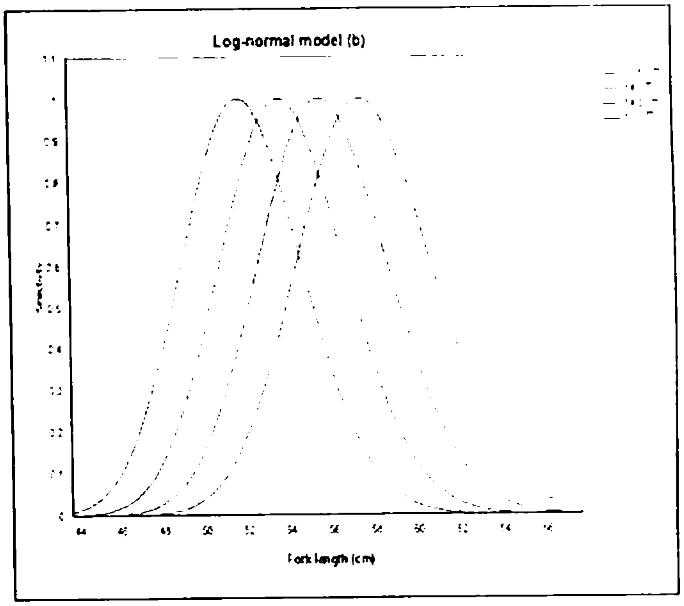


Fig. 51.6

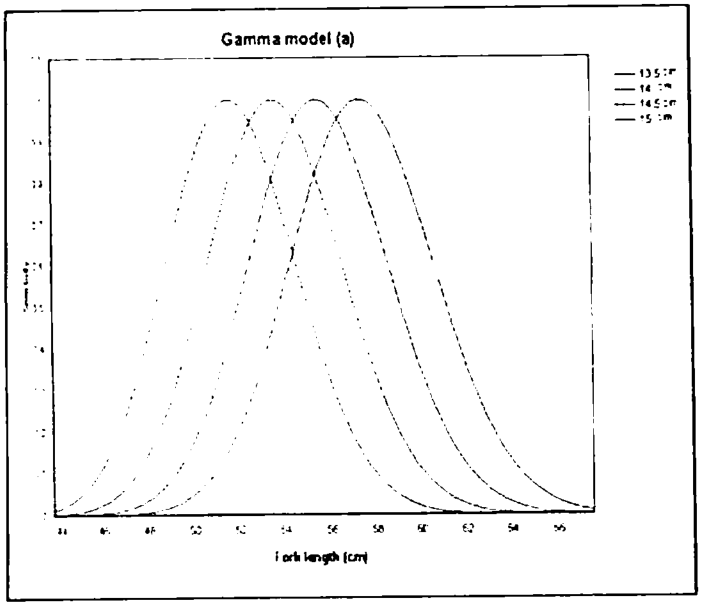


Fig. 51.7

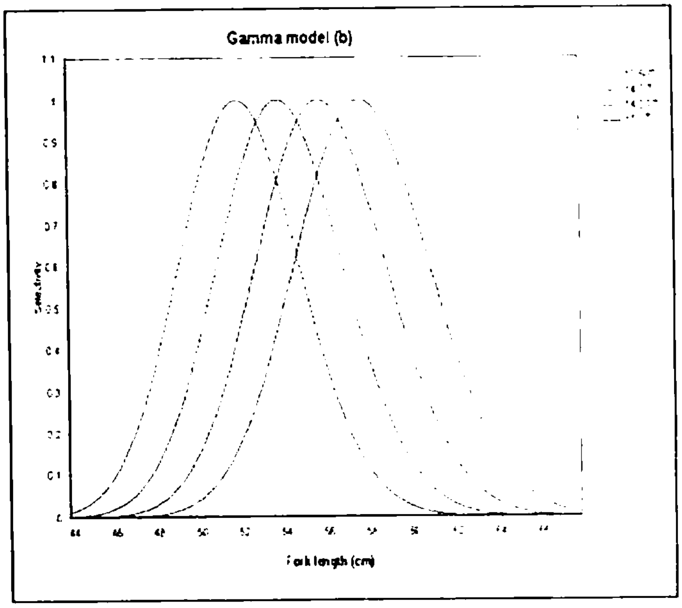


Fig. 51.8

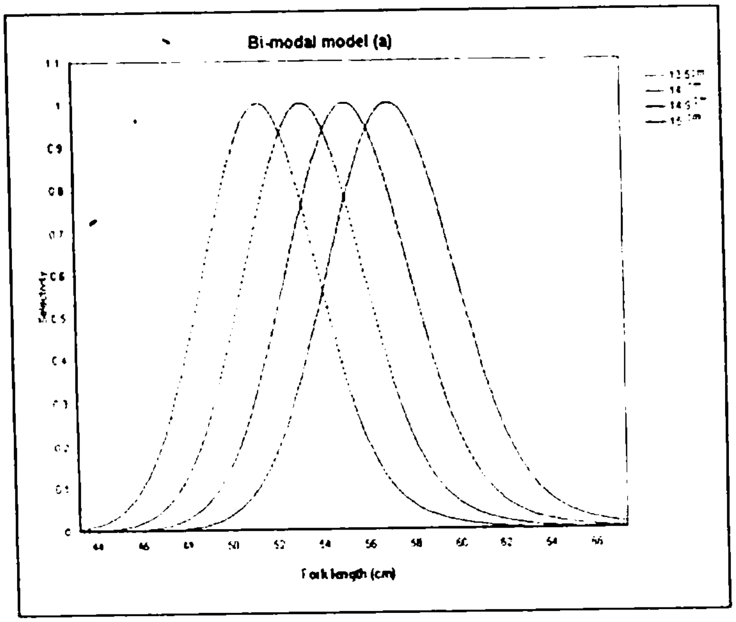


Fig. 51.9

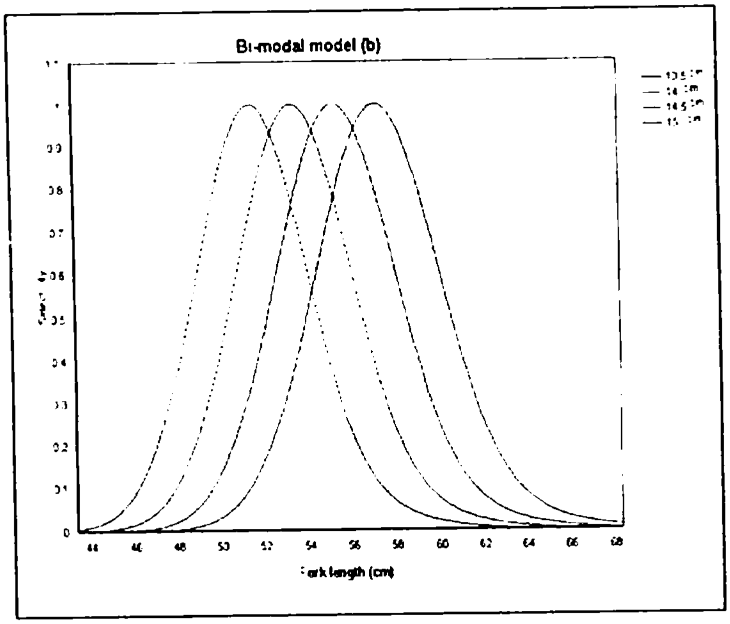


Fig. 51.10

Selection curves belong to uni-normal model fitted to the data (Table. 11) and are presented in Fig. 51. Total degrees of freedom (DF) for uni-modal curves was 61 and standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve were estimated and presented in the Table 30 & 31. Goodness of fit of all fitted models was validated using statistical tool called model deviance (D). Selection curves of all normal curves were symmetrical in shape and almost similar in all the models without skew ness.

Model deviance of each model revealed that selection curves of all the models gave good fit. Nonetheless, log-normal model yielded better fit than other models having a small model deviance (212.02) in both the assumption of equal fishing power and fishing power is proportional to mesh size. There was no significant difference between models ($P>0.05$) except with normal scale ($P<0.01$). Other better fits followed by log-normal model based on deviance value were gamma (225.54), normal location (227.78) under the assumption of fishing power proportional to mesh size, and normal scale (261.4) under equal fishing power

In all the model analysis, deviance was greater than degrees of freedom (61). Hence, the deviance of models fitted was evaluated further for a precision fit by referring it to a chi-square distribution using dispersion parameter. Estimated dispersion values were 3.48 for log-normal, 3.7 for gamma model, 3.73 for normal location with respect to equal fishing power and fishing power is proportional to mesh size and 4.29 for normal scale model for both the assumptions. Estimated dispersion parameter was greater than one in all the models. It obviously indicated over dispersion in all the models including better-fit log-normal model. Over dispersion in turn showed lack of fit in log-normal model.

Residual plots (Fig. 52) of all models revealed the fishing powers of 13.5cm 14.5 cm and 15 cm were greater than mesh size 14 cm by the predominance of positive residuals. Of these three meshes, mesh size of 13.5 cm ranked first in all the models followed by 14.5 cm and 15 cm. Fishing powers were equal in both the log-normal and gamma model by the presence of equal number of positive residuals in respective mesh sizes. Deviance

ig. 52 Residual plots of Selectivity curves of various models for different mesh sizes and fishing powers for *Scomberoides tala* (Area of the circle is proportional to square of the residual)

a : Equal fishing power

b : Fishing power α mesh size

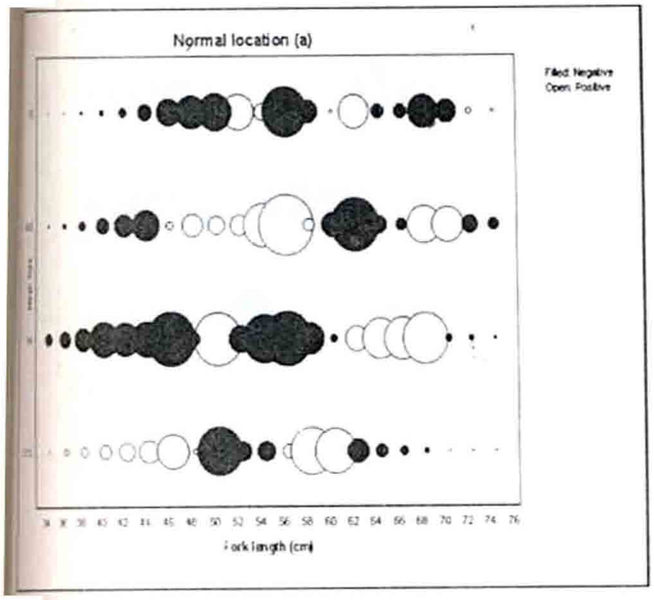


Fig. 52.1

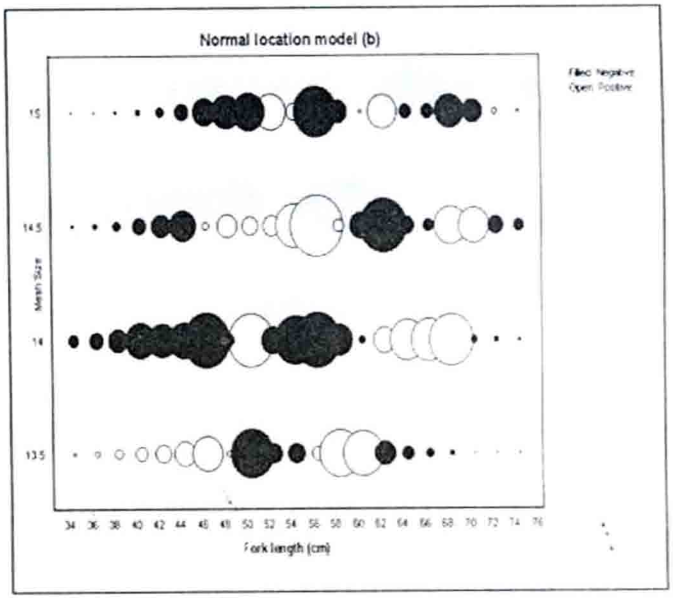


Fig. 52.2

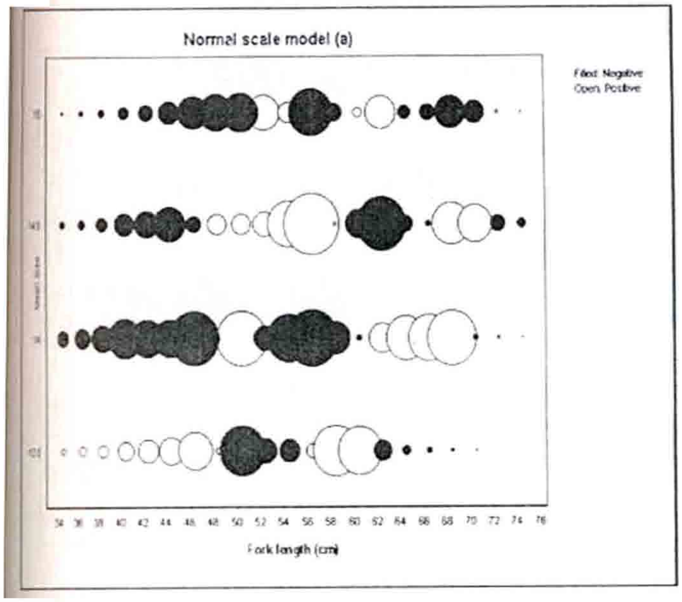


Fig. 52.3

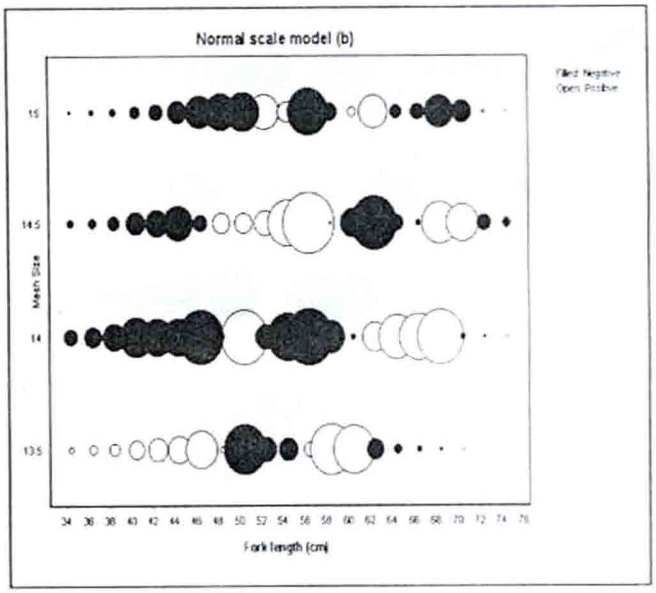


Fig. 52.4

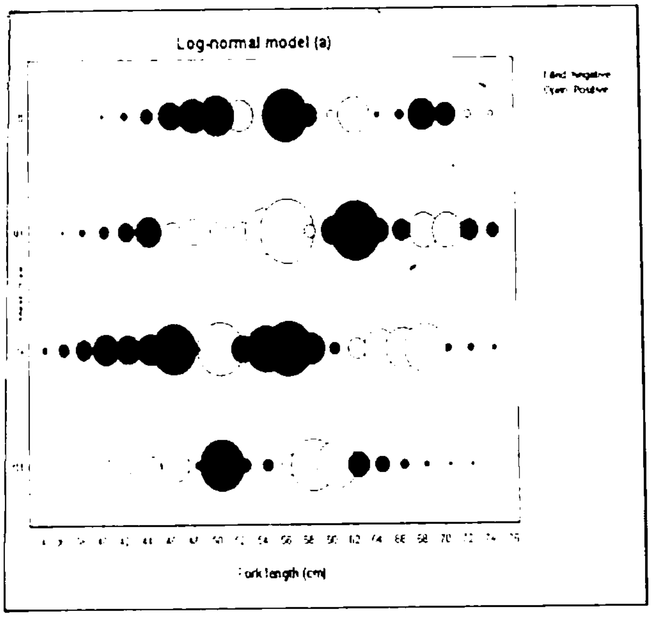


Fig. 52.5

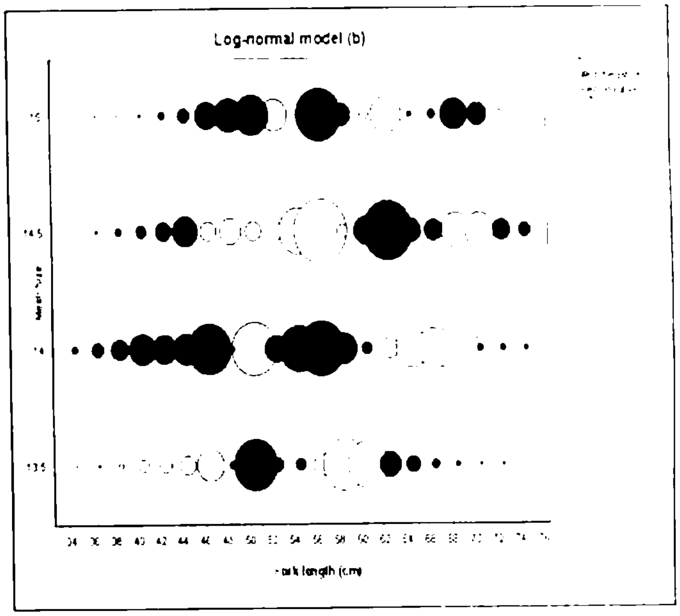


Fig. 52.6

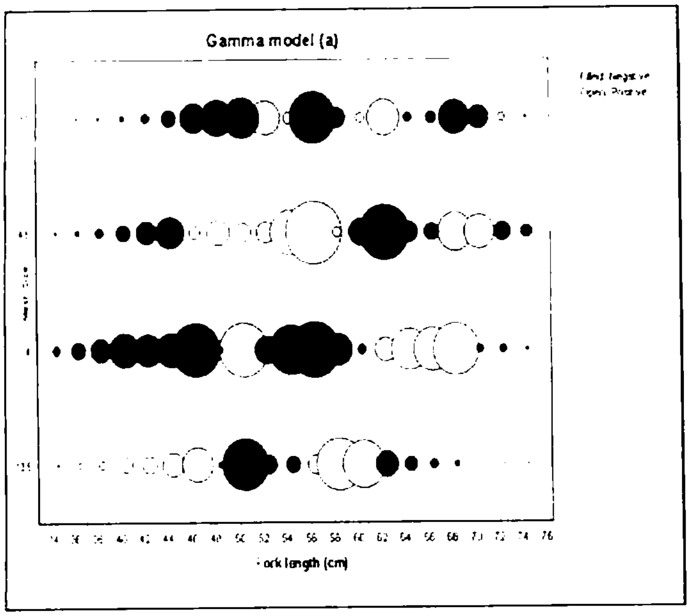


Fig. 52.7

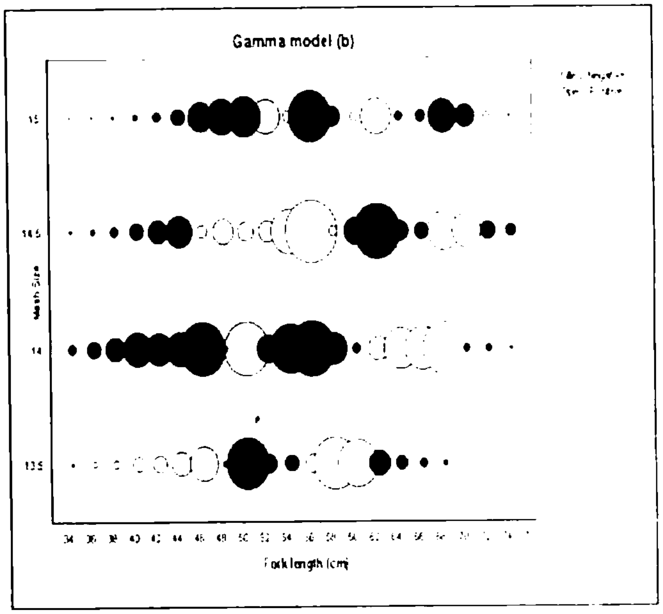


Fig. 52.8

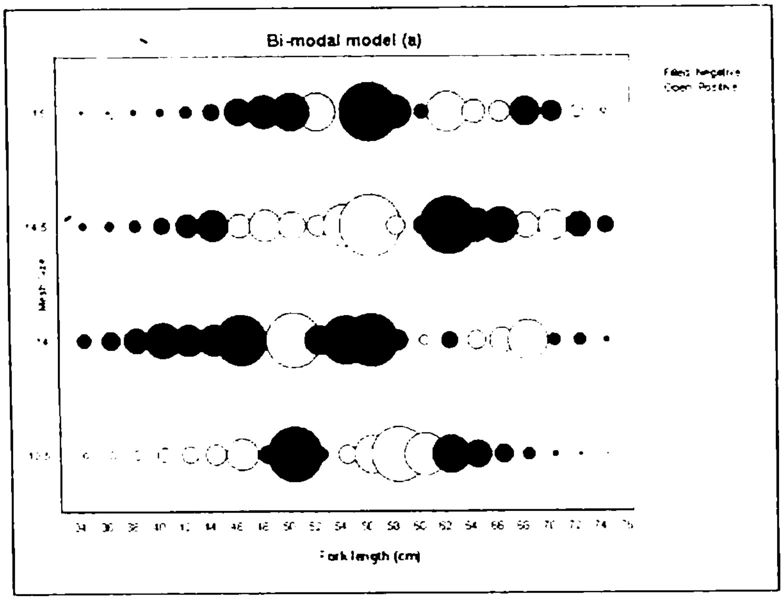


Fig. 52.9

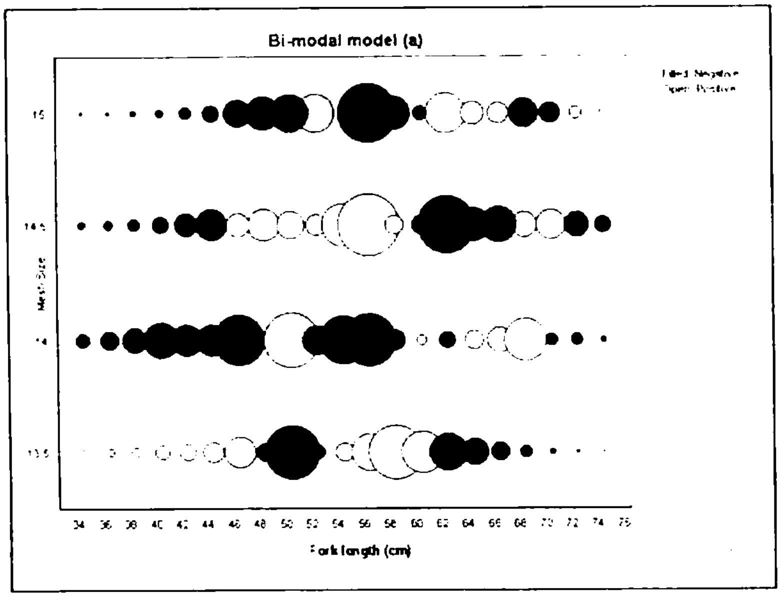


Fig. 52.10

residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models including better-fit lognormal model.

Mesh sizes of 13.5, 14 cm and 15 had equal fishing power in the normal scale and normal location model. Fishing power of 14 and 15 cm was equal in all the four models while fishing power of the above meshes including 14.5 cm were equal in normal location, log-normal and gamma model. Residual plots showed that smaller and middle length class group of fish were caught from mesh size of 13.5 cm (34.5 - 60.5 cm) and 15 cm captured middle length group with little larger fishes (46.5 - 70.5 cm). Fishing power of 13.5 and 15 cm was very poor.

Model length and spread of the selection curves of different models for the different mesh sizes were presented in the Table 31. Modal length and spread of the selection curves were increased with mesh sizes in all the models except normal location model where spread is fixed over the mesh size. However they varied between assumptions of equal fishing power and fishing power is proportional to mesh size. Estimated modal length and spread of the better fit model were 51.5 - 57.2 cm and 2.83 - 3.15 for the equal fishing power and 51.6 - 57.4 cm and 2.84 - 3.16 for the fishing power is proportional to mesh size.

4.7.1.10.1 Refitting of Models

Residual plot of better-fit log-normal model showed lack of fit by the presence of large sized both positive and negative residuals and systematic occurrence of residuals instead of random order especially in the mesh sizes of 13.5 cm and 14.5 cm. Thus the uni-modal log-normal was extended to bi-modal model. Estimated bi-modal selectivity curves under both the assumption of equal fishing power and fishing power proportional to mesh size and their parameters are presented in Table. 30. DF for the bi-modal was 58.

Model deviance of bi-modal model was slightly reduced to 207.07 from 212.02 of log-normal model for the assumption of equal fishing power despite the deviance was 207.11 for the assumption of fishing power is proportional to mesh size. In order to find out goodness of fit of the bi-modal curve, dispersion parameter was also estimated. It was 3.57 for both the assumptions of equal fishing power and fishing power proportional to mesh size. It revealed over dispersion of the model and higher than better-fit uni-modal log-normal (3.48). Other dispersion parameters of uni-modal were gamma (3.7), normal location (3.73) and normal scale (4.29). Further there was no significant difference between deviances of bi-modal (207.07) and log-normal model (212.02).

Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to mesh size were 51.3 cm - 57 cm with the spread range of 2.47 - 2.75 and 51.4 - 57.2 cm with the spread of 2.47 - 2.75 respectively. Modal length and spread between two assumptions did not vary much and lower than log-normal model. Residual plots of bi-modal function under both the assumption were presented in Fig. 52.9 & 52.10. Plots explained that the mesh sizes of 13.5 and 14.5 cm were greater than modeled with the presence of more positive residuals. Fishing power of 14 and 15 cm were equal by the presence of equal number of positive residuals.

Residual plots of both uni-modal log-normal and bi-modal varied little. In this model, the effective mesh size was ranked as existed in the uni-modal log-normal model viz., 13.5 & 14.5. Of these meshes, 14.5 cm caught little larger fish (46.5 to 70.5), middle length groups (48.5 to 62.5) were caught by 14 cm mesh and very small fish from mesh 13.5 cm. There little difference was shown in this model with log-normal model in terms of size groups caught and slight reduction was observed in the deviance of bi-modal from the uni-modal log-normal model selection.

4.7.2 Fitting of Various Models for Drift Hand Line and Hook Selectivity Data for Various Species

Selectivity data collected from drift hand lines for four species were estimated using GILLNET software and the results of individual species were given as follows;

Table. 32 SELECT model parameter estimates for hook selectivity for various carangid species

S.No.	Species	Model		Degrees of freedom	Equal fishing power			Fishing power α mesh size		
					Parameters	SD	Model deviance	Parameters	SD	Model deviance
1	*Carangoides fulvoguttatus*	Normal location	Fixed spread	43	(k,s) = (6.6174, 16.9819)	0.1109, 1.0354	120.95	(k,s) = (7.1212, 18.0939)	0.1412, 1.2169	136.98
		Normal scale	spread α mj	43	(k1,k2) = (7.3237, 1.7123)	0.1043, 0.0886	100.17	(k1,k2) = (7.7117, 1.6594)	0.1070, 0.0805	100.28
		Lognormal	spread α mj	43	(m,s) = (3.9345, 0.2656)	0.0209, 0.0145	105.88	(m,s) = (4.0050, 0.2656)	0.0247, 0.0148	105.88
		Gamma	spread α mj	43	(k,a) = (0.4615, 16.3798)	0.0500, 1.5830	102.42	(k,a) = (0.4615, 17.3798)	0.0501, 1.6314	102.42
		Bimodal	spread α mj	40	(a1,b1) = (7.1629, 1.5925)	0.1166, 0.0957	96.12	(a1,b1) = (7.5047, 1.5468)	0.1255, 0.0883	96.07
					(a2,b2) = (9.7338, 0.1636)	0.0518, 0.1117	96.12	(a2,b2) = (9.7370, 0.1639)	0.0444, 0.1080	96.07
					w = 1.0479	2.2065	96.12	w = 1.4046	2.8624	96.07
2	*Caranx heberi*	Normal location	Fixed spread	49	(k,s) = (6.1149, 14.4052)	0.0822, 0.6474	134.7	(k,s) = (8.4680, 14.8971)	0.0888, 0.6984	149.52
		Normal scale	spread α mj	49	(k1,k2) = (6.7328, 1.5791)	0.0922, 0.0734	150.14	(k1,k2) = (7.0942, 1.5318)	0.0920, 0.0661	151.34
		Lognormal	spread α mj	49	(m,s) = (3.8284, 0.2443)	0.0155, 0.0108	135.58	(m,s) = (3.8881, 0.2443)	0.0170, 0.0108	135.58
		Gamma	spread α mj	49	(k,a) = (0.3798, 18.0569)	0.0341, 1.4901	137.55	(k,a) = (0.3798, 19.0569)	0.0335, 1.5124	137.55
		Bimodal	spread α mj	46	(a1,b1) = (5.5276, 0.8313)	0.2597, 0.2947	134.74	(a1,b1) = (7.094, 1.532)	☆	151.33
					(a2,b2) = (7.4180, 1.4817)	0.7278, 0.3190	134.74	(a2,b2) = ☆	☆	151.33
					w = 1.3824	1.253	134.74	w = ☆	☆	151.33
3	*Caranx ignobilis*	Normal location	Fixed spread	49	(k,s) = (6.6306, 18.4260)	0.1466, 1.1805	84.75	(k,s) = (7.1446, 19.3434)	0.1536, 1.3124	91.92
		Normal scale	spread α mj	49	(k1,k2) = (7.3704, 1.9256)	0.1489, 0.1326	76.38	(k1,k2) = (7.8584, 1.8604)	0.1405, 0.1168	75.99
		Lognormal	spread α mj	49	(m,s) = (3.9322, 0.2795)	0.0234, 0.0187	90.48	(m,s) = (4.0103, 0.2795)	0.0260, 0.0185	90.48
		Gamma	spread α mj	49	(k,a) = (0.5347, 14.2281)	0.0711, 1.7892	84.55	(k,a) = (0.5347, 15.2281)	0.0691, 1.7934	84.55
		Bimodal	spread α mj	46	(a1,b1) = (7.37, 1.925)	0.1492, 0.1407	76.38	(a1,b1) = (4.7656, 0.5804)	0.2687, 0.2708	68.45
					(a2,b2) = ☆	☆	76.38	(a2,b2) = (8.0181, 1.5133)	0.1353, 0.1400	68.45
					w = ☆	☆	76.38	w = 4.8060	1.7526	68.45
4	*Scomberoides* commersonnianus	Normal location	Fixed spread	37	(k,s) = (6.1739, 15.4162)	0.1073, 1.0159	130.27	(k,s) = (6.5957, 16.3531)	0.1275, 1.1724	140.91
		Normal scale	spread α mj	37	(k1,k2) = (6.8901, 1.7170)	0.1204, 0.1111	134.91	(k1,k2) = (7.3040, 1.6595)	0.1202, 0.0989	135.16
		Lognormal	spread α mj	37	(m,s) = (3.8698, 0.2706)	0.0231, 0.0178	135.58	(m,s) = (3.9430, 0.2706)	0.0271, 0.0181	135.58
		Gamma	spread α mj	37	(k,a) = (0.4638, 15.3403)	0.0606, 1.8312	134.4	(k,a) = (0.4638, 16.3403)	0.0602, 1.8720	134.4
		Bimodal	spread α mj	34	(a1,b1) = (6.1581 1.1878)	0.1661, 0.1363	113.49	(a1,b1) = ☆	☆	135.16
					(a2,b2) = (8.6241 0.5668)	0.1316, 0.1053	113.49	(a2,b2) = ☆	☆	135.16
					w = 0.9662	0.1992	113.49	w = ☆	☆	135.16

☆ No value

S.No.	Species	Model	Hook size (cm)															
			No.5				No.6				No.7				No.8			
			Modal length (cm)		Spread		Modal length (cm)		Spread		Modal length (cm)		Spread		Modal length (cm)		Spread	
			a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
1	*Carangoides fulvoguttatus*	Normal location	45.1	48.6	16.98	18.09	58.2	62.6	16.98	18.09	70.3	75.6	16.98	18.09	86.6	93.2	16.98	18.09
		Normal scale	49.9	52.6	11.68	11.32	64.4	67.8	15.05	14.59	77.8	81.9	18.18	17.62	95.9	100.9	22.41	21.72
		Lognormal	47.7	51.1	14.32	15.36	61.4	65.9	18.45	19.8	74.2	79.6	22.3	23.93	91.5	98.1	27.48	29.49
		Gamma	48.4	51.5	12.34	12.74	62.4	66.4	15.91	16.42	75.4	80.3	19.22	19.83	92.9	98.9	23.69	24.45
		Bimodal	48.9	51.2	10.86	10.55	63	66	14	13.6	76.1	79.7	16.91	16.43	93.8	98.2	20.85	20.25
2	*Caranx heberi*	Normal location	41.7	44.1	14.41	14.9	53.7	56.9	14.41	14.9	64.9	68.7	14.41	14.9	80	84.7	14.41	14.9
		Normal scale	45.9	48.4	10.77	10.45	59.2	62.4	13.88	12.46	71.5	75.3	16.77	16.27	88.1	92.9	20.67	20.05
		Lognormal	43.3	46	11.75	12.47	55.8	59.3	15.14	16.08	67.5	71.6	48.3	19.42	83.2	88.3	22.55	23.94
		Gamma	44.2	46.8	10.7	11.01	56.9	60.3	13.79	14.19	68.8	72.8	16.66	17.14	84.8	81.8	20.53	21.13
		Bimodal	37.7	48.4	5.67	10.45	48.6	62.4	7.31	13.46	58.7	75.3	8.83	16.27	72.4	92.9	10.88	20.05
3	*Caranx ignobilis*	Normal location	48.2	48.7	18.43	19.34	58.3	62.8	18.43	19.34	70.4	75.9	18.43	19.34	86.8	93.5	18.43	19.34
		Normal scale	50.3	53.6	13.13	12.69	64.8	69.1	16.93	16.35	78.3	83.5	20.45	19.76	96.5	102.9	25.21	24.35
		Lognormal	47.2	51	15.12	16.35	60.8	65.8	19.49	21.07	79.4	79.4	23.55	25.46	90.6	97.9	29.02	31.38
		Gamma	48.2	51.9	13.26	13.75	62.2	66.9	17.09	17.73	75.1	80.8	20.65	21.42	92.6	99.6	25.46	26.4
		Bimodal	50.3	32.5	13.13	3.96	64.8	41.9	16.93	5.1	78.3	50.6	20.45	6.16	96.5	62.4	25.21	7.6
4	*Scomberoides* commersonnianus	Normal location	42.1	45	15.42	16.35	54.3	58	15.42	16.35	65.6	70.6	15.42	16.35	80.8	86.3	15.42	16.35
		Normal scale	47	49.8	11.71	11.32	60.6	64.2	15.09	14.59	73.2	77.6	18.23	17.62	90.2	95.6	22.47	21.72
		Lognormal	44.5	47.9	13.7	14.75	57.4	61.8	17.66	19.01	69.4	74.6	21.34	22.96	85.5	92	26.3	28.3
		Gamma	45.44	48.5	11.98	12.39	58.5	62.5	15.44	15.97	70.6	75.6	18.65	19.29	87.1	93.1	22.99	23.78
		Bimodal	42	49.8	8.1	11.32	54.1	64.2	10.44	14.59	65.4	77.6	12.61	17.62	80.6	95.6	15.55	21.72

a : Equal fishing power

b Fishing power α Mesh size

4.7.2.1 *Carangoides fulvoguttatus*

Over all total catch of *Carangoides fulvoguttatus* obtained from four hook sizes was 524 numbers. Of which, 101 specimens were caught from hook size No.5 (13.09 cm^2), 115 from No.6 (10.62 cm^2), 130 from No.7 (8.79 cm^2) and 178 from No.8 (6.82 cm^2) (Table. 19).

Four families of uni-normal selection curves such as Normal location, Normal scale, Log-normal and Gamma fitted to the selectivity data (Table. 14) are presented in Fig. 53. Total degrees of freedom (DF) for uni-modal curves were 43, Estimates of standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve are presented in the Table 32 & 33.

After fitting the various uni-modal curves, goodness of fit was validated using the important statistic tool, called model deviance (D). Selection curves of normal scale and normal location model were symmetrical in shape while the selection curves were skewed to right in all other uni-modals. Model deviance of each model revealed that selection curves of all the models gave good fit. However, normal scale model yielded better fit than other models having a small model deviance 100.17 and 100.28 in the assumption of equal fishing power and fishing power is proportional to hook size respectively. There was no significant difference between models ($P>0.05$). Other better fits followed by normal scale model based on deviance value were gamma (102.42), log-normal (105.88) and normal location 120.95 and 136.98 under the assumption of equal fishing power and fishing power proportional to hook size respectively.

In all the model analysis, deviance was greater than degrees of freedom (43) including better-fit normal scale model. Hence, the deviance of models fitted was evaluated further for a precision fit by referring it to a chi-square distribution through another tool called Dispersion parameter (D / DF). Estimated dispersion values were 2.33 for normal scale for both the assumptions, 2.38 for gamma model, 2.46 for log-normal and 2.8 and 3.19 for normal location model for the assumption of equal fishing power and fishing power proportional to hook size respectively. Estimated dispersion parameter

53 Selectivity curves of various models for different hook sizes and fishing powers for *Carangoides fulvoguttatus*

a : Equal fishing power

b : Fishing power α hook size

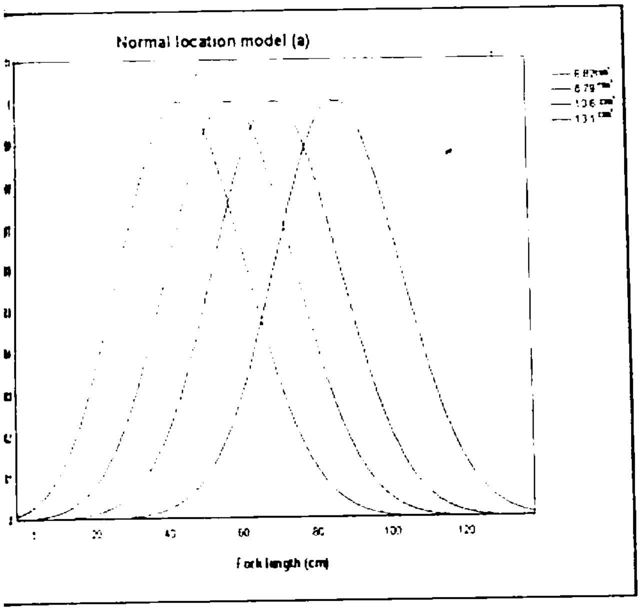


Fig. 53.1

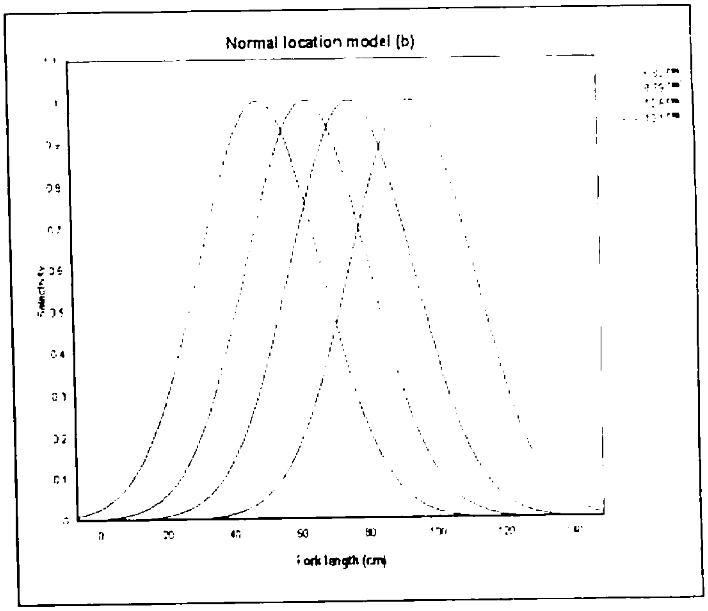


Fig. 53.2

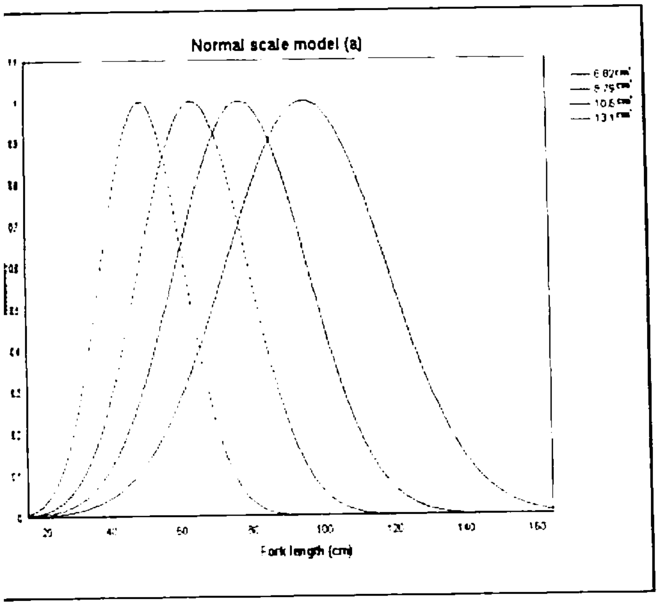


Fig. 53.3

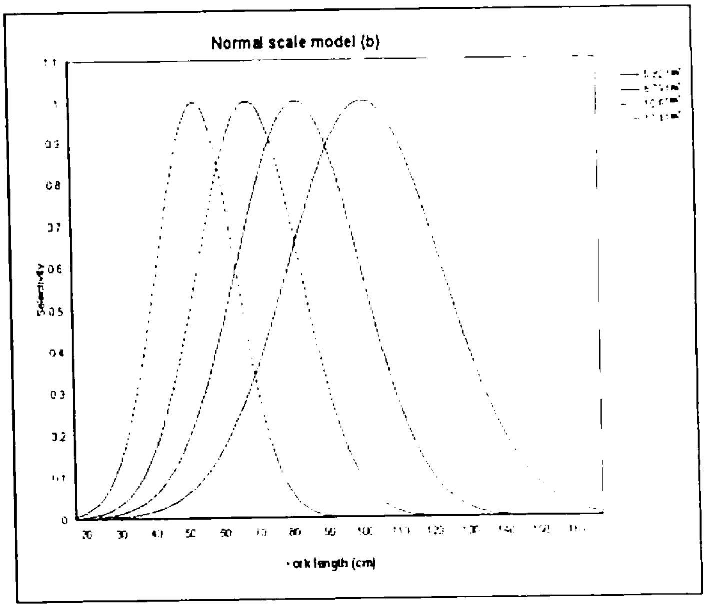


Fig. 53.4

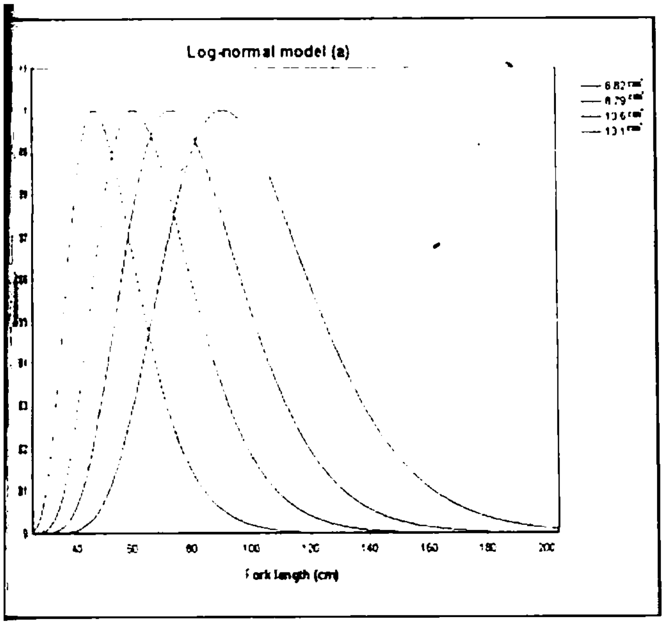


Fig. 53.5

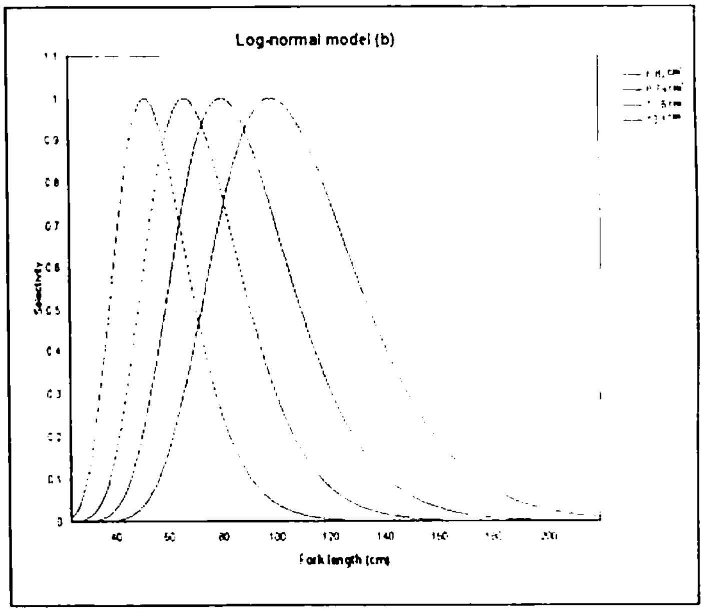


Fig. 53.6

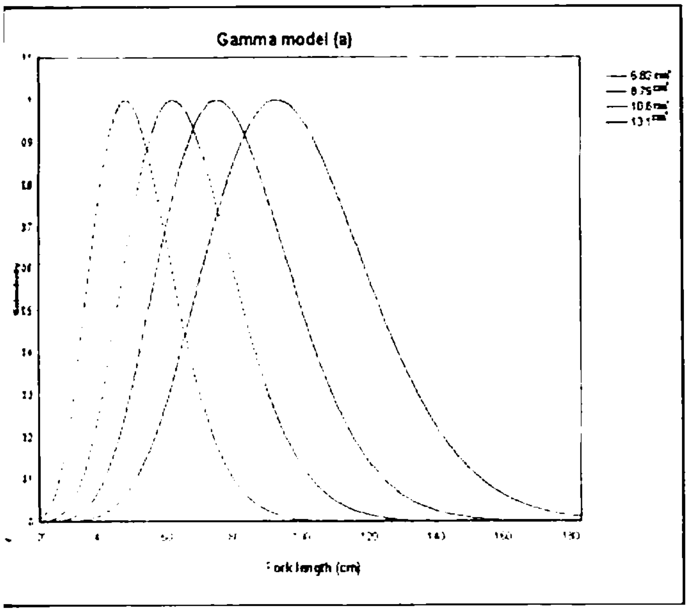


Fig. 53.7

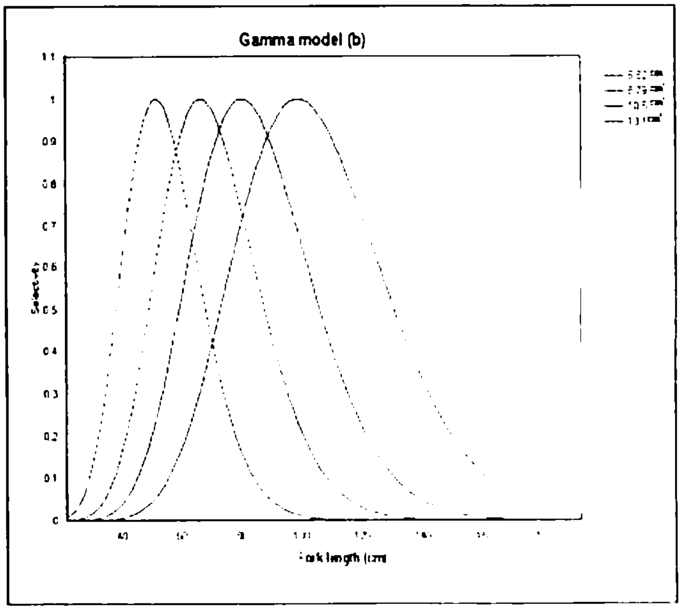


Fig. 53.8

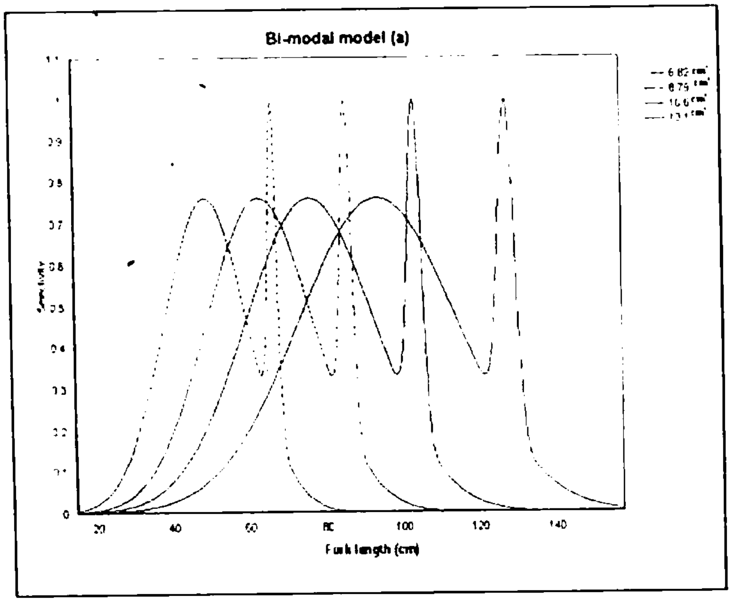


Fig. 53.9

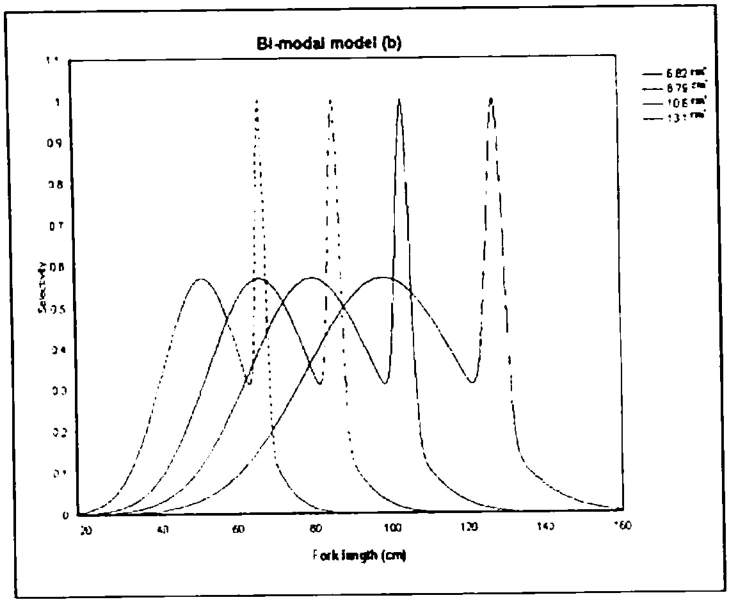


Fig. 53.10

was greater than one in all the models. It obviously indicated over dispersion in all the models including better-fit normal scale model. Over dispersion in turn showed lack of fit in normal scale model.

Model deviance and dispersion were alone need not to indicate lack of fit of modeled curve. Hence, evaluation of residual plot versus length of the concerned model was considered as important to obtain precision of the fit. Analysis of deviance residuals (Mcullagh and Nelder, 1989) of the all models for the species *Carangoides fulvoguttatus* were plotted (Fig. 54) under both the assumptions of equal fishing power and fishing power proportional to hook size.

Residual plots revealed the fishing powers of hook No.5, 6, and 8 were greater than hook size No.7 by the predominance of positive residuals. Of these three hook sizes, No.5 ranked first in all the models followed by No.8 and No.6 except the normal location where hook No. 7 was in third place. Fishing powers were equal in both the log-normal and gamma model by the presence of equal number of positive residuals in respective hook sizes. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to hook size in all the uni-models. It was found true in the better-fit normal scale model also. Residual plots showed wide range of larger length class group of fish were caught by hook No. 5 (52.5 - 92.5 cm) while smaller size in No.8 (36.5 - 68.5 cm). Hook No. 6 caught larger group (60.5 - 64.5 and 76.5 - 80.5 cm). Performance of hook No. 7 was very poor.

Model length and spread of the selection curves of different models for the different hook sizes were presented in the Table 33. Modal length and spread of the selection curves were increased with hook sizes in all the models except normal location model where spread is fixed over the hook size. However they varied between assumptions of equal fishing power and fishing power is proportional to hook size. Estimated modal length and spread of the better fit normal scale model were 49.9 cm - 95.9 cm and 11.68 - 22.41 for the equal fishing power and 52.6 cm to 100.9 cm and 11.32 to 21.72 for the fishing power is proportional to hook size.

Fig. 54 Residual plots of selectivity curves of various models for different hook sizes and fishing powers for *Carangoides fulvoguttatus* (Area of the circle is proportional to square of the residual)

a : Equal fishing power

b : Fishing power α hook size

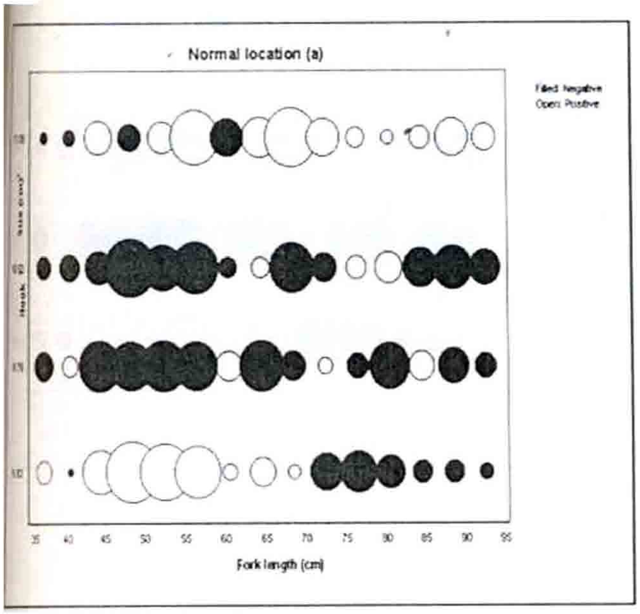


Fig. 54.1

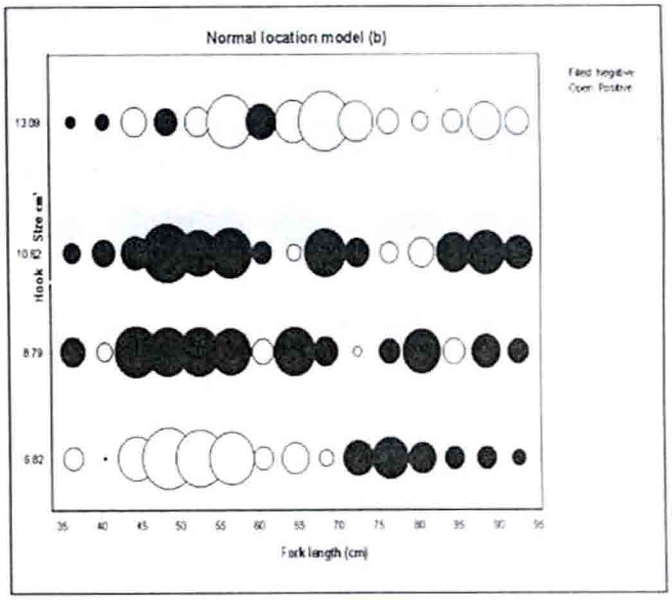


Fig. 54.2

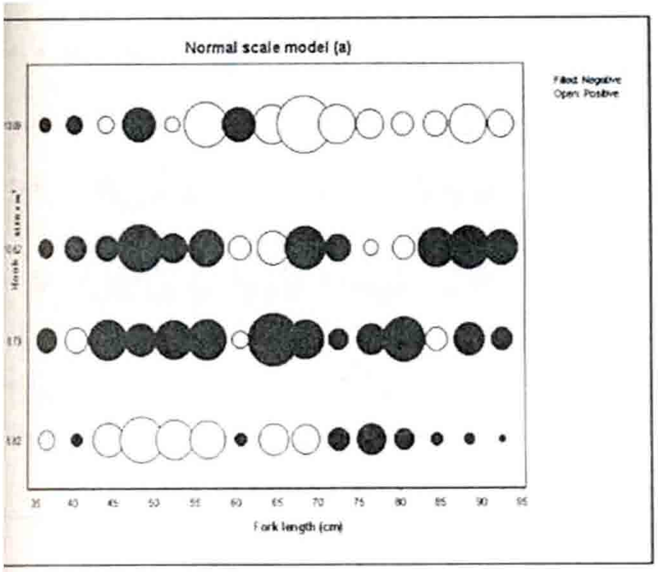


Fig. 54.3

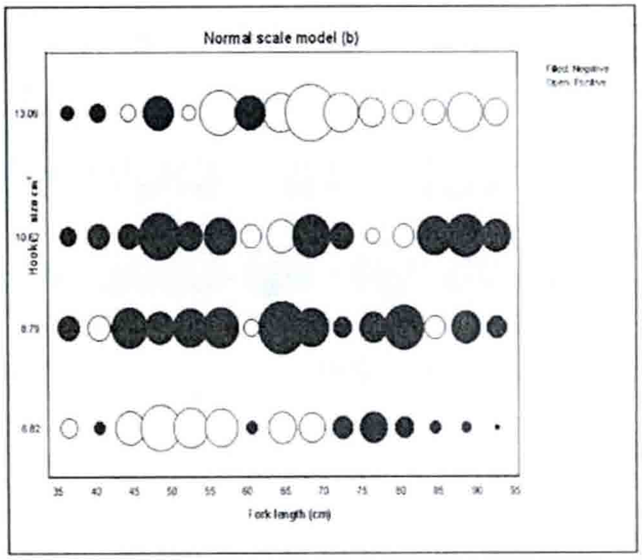


Fig. 54.4

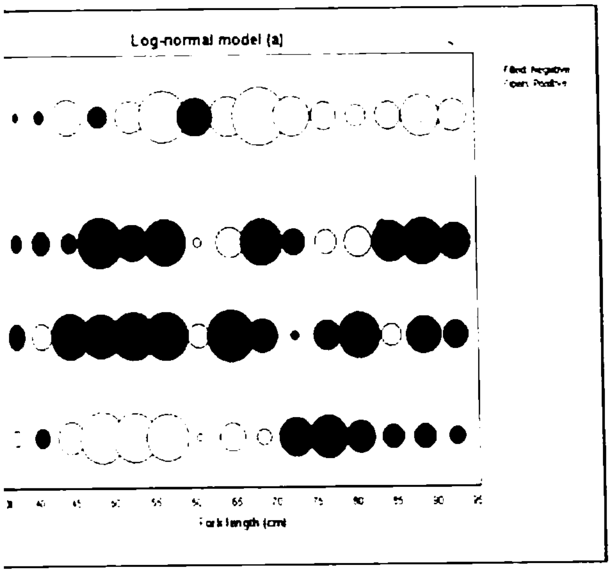


Fig. 54.5

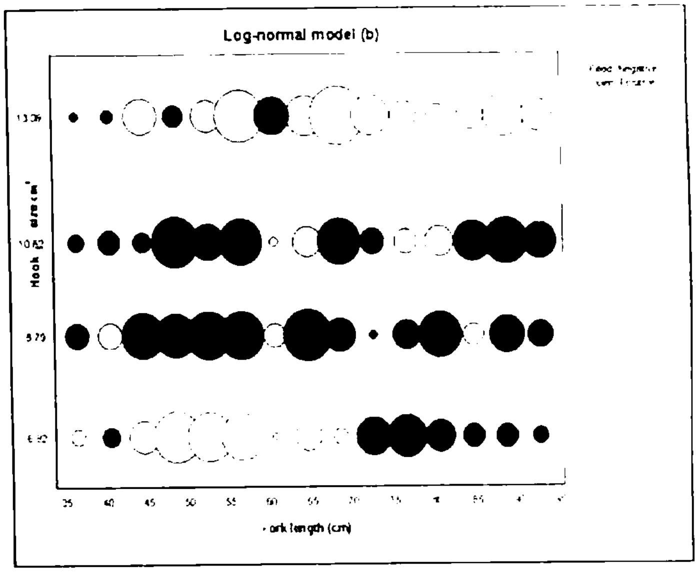


Fig. 54.6

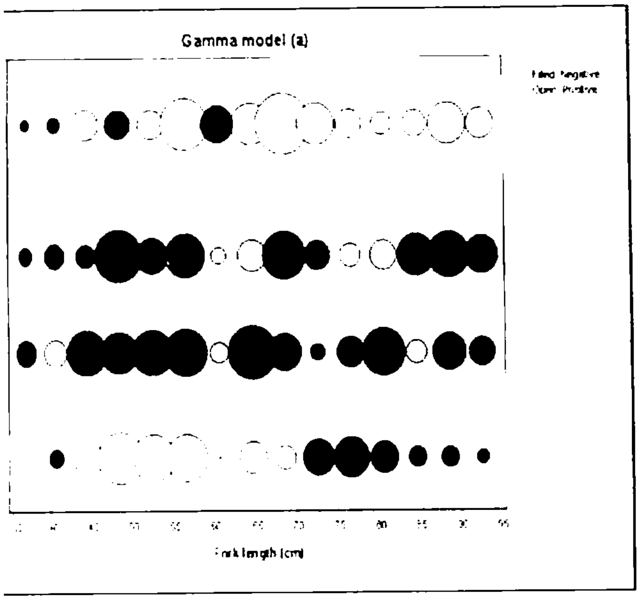


Fig. 54.7

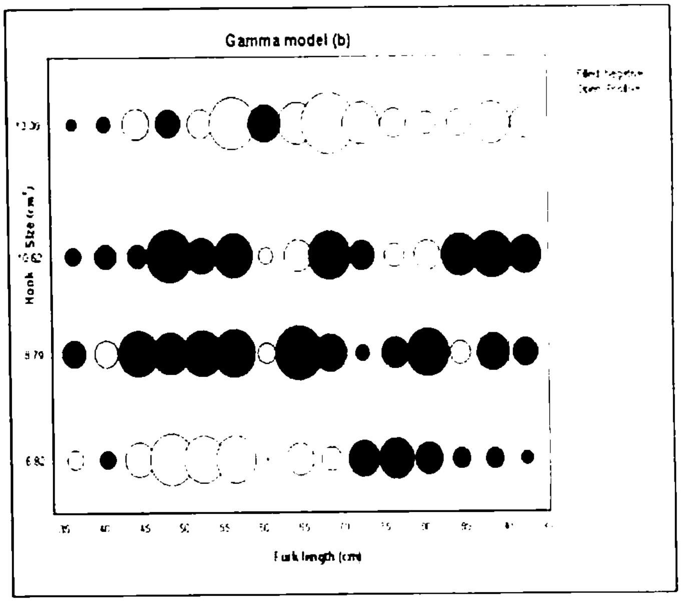


Fig. 54.8

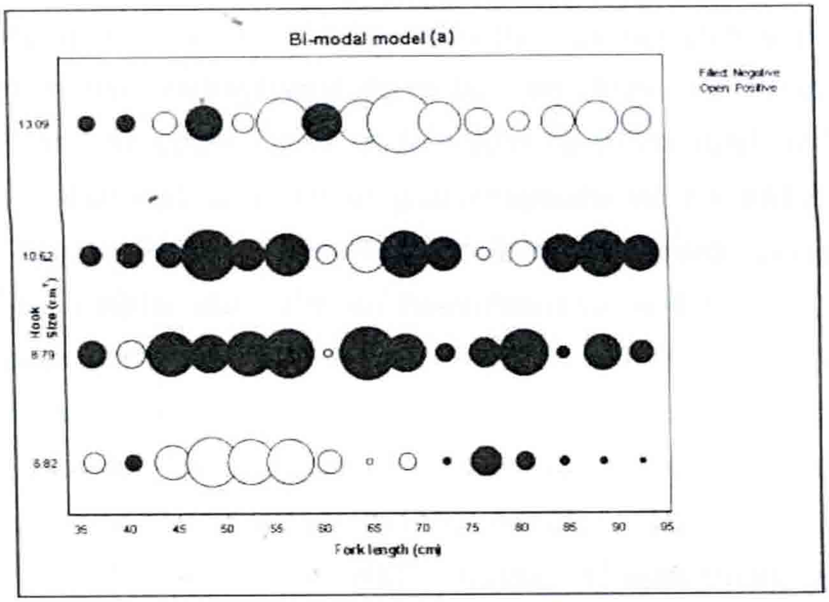


Fig. 54.9

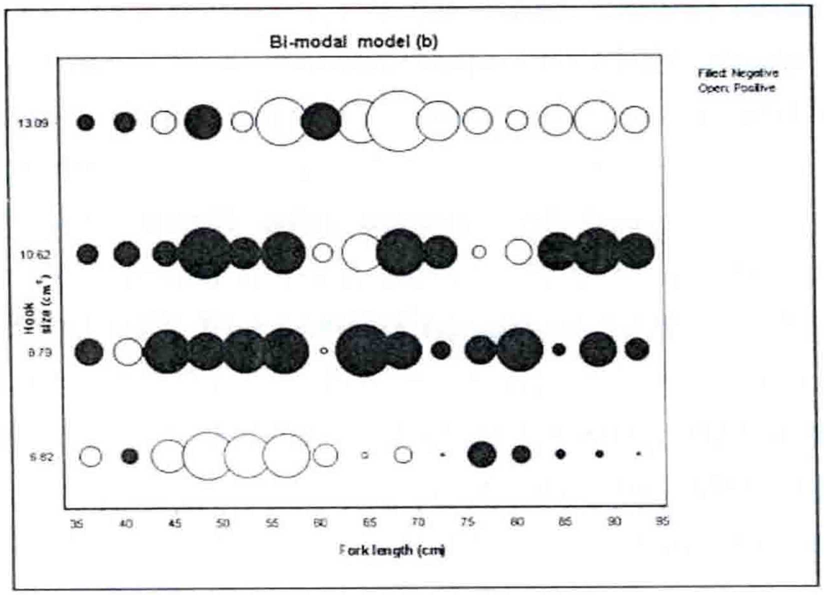


Fig. 54.10

4.7.2.1.1 Refitting of Models

Residual plot of better-fit normal scale model showed lack of fit by the presence of large sized both positive and negative residuals and systematic occurrence of residuals instead of random order. Another flaw in the plot was presence some of residuals having the value of greater than 2. Hence, refitting of the selectivity data for an improved model is required. Thus the uni-modal normal scale was extended to bi-modal or bi-normal model. Bi-modal selectivity curves and their parameters were estimated under both the assumption of equal fishing power and fishing power proportional to hook size and presented in Table. 32. DF of bi-modal was 40.

Model deviance of bi-modal model was slightly reduced to 96.07 and 96.12 for the assumption of fishing power proportional to hook size and equal fishing power respectively, despite the reduction was very less compared to uni-modal normal scale model (100.17). In order to find out goodness of fit of the bi-modal curve, dispersion parameter was also estimated. It was 2.4 for both equal fishing power and fishing power proportional to hook size. It revealed over dispersion of the model and moreover, it was little higher than value of uni-modal normal scale fit dispersion parameter (2.33), gamma (2.38), and lower than log-normal (2.46) and normal location (2.8 and 3.19) for equal fishing power and fishing power proportional to hook size respectively. Further there was no significant difference between deviances of bi-modal (96.07) and normal scale model (100.17). Selectivity curves appeared with bi-modes and differed in heights.

Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to hook size were 48.9 cm to 93.8 cm with the spread range of 10.86 to 20.85 and 51.2 to 98.2 cm with the spread of 10.55 to 20.25 respectively for the hook size of No.8 to No. 5. Modal length and spread of bi-modal were lesser than normal scale for all the hook sizes under the both the assumption. Modal length obtained from fishing power versus mesh size for every hook was greater than equal fishing power and it was reverse in the case of spread.

Residual plots of bi-modal function under both the assumption were presented in Fig. 54.9 & 54.10. Plots explained that the hook sizes of

No. 5, 6 and 8 were greater than modeled with the presence of more positive residuals. Residual plots of both uni-modal normal scale and bi-modal were almost similar despite the fishing power of hook No. 7 and 8 were different. In this model, the hook size No. 5 ranked first and the next effective hook size was No. 8 as existed in the normal scale model. Fishing power of rest of the hooks was in the following order viz., No. 6 and 7. It was reverse in the normal scale model. There no great difference was shown with normal scale model in terms of size groups caught. Residual plots were almost similar for both bi-modal and normal scale model. However, a slight reduction observed in the deviance of bi-modal than the uni-modal normal scale model selection.

4.7.2.2 *Caranx heberi*

Over all total catch of *Caranx heberi* obtained from four hook sizes was 562 numbers. Of which, 132 specimens were caught from hook size No.5 (13.09 cm^2), 125 from No.6 (10.62 cm^2), 137 from No.7 (8.79 cm^2) and 168 from No.8 (6.82 cm^2) (Table. 19).

Four families of uni-normal selection curves fitted to the data (Table. 15) are presented in Fig. 55. Total degrees of freedom (DF) for uni-modal curves were 49 and estimated standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve are presented in the Table 32 & 33.

Selection curves of normal scale and normal location model were symmetrical in shape while the selection curves of log-normal and gamma were skewed to right. After analyzing the model deviance and selection curves of all the models, it was found that all the selection curves did not give good fit. However, normal location model yielded better fit than other models having a small model deviance 134.7 under the assumption of equal fishing power. Deviance of this model under the assumption fishing power is proportional to hook size was 149,52 and it was higher than equal fishing power of the better-fit model. There was no significant difference between models (P>0.05). Other better fits followed by normal location model

ig. 55 Selectivity curves of various models for different hook sizes and fishing powers *Caranx heberi*

a : Equal fishing power

b : Fishing power α hook size

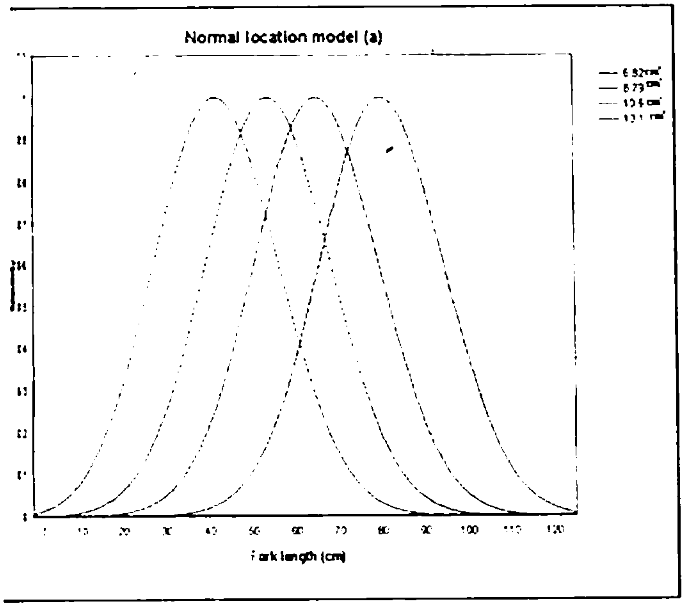

Normal location model (a)

Fig. 55.1

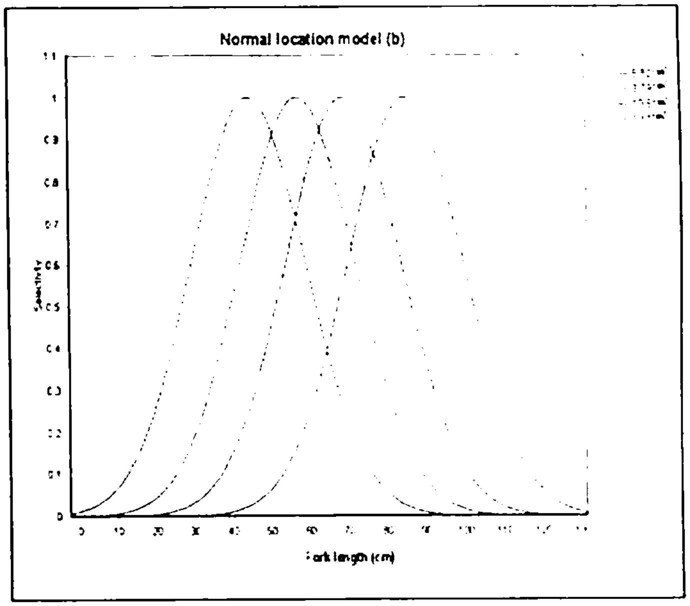

Normal location model (b)

Fig 55.2

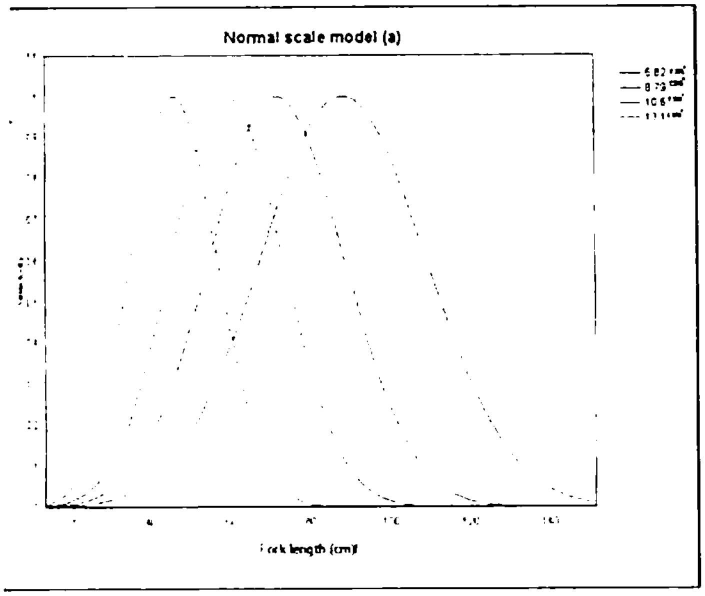

Normal scale model (a)

Fig. 55.3

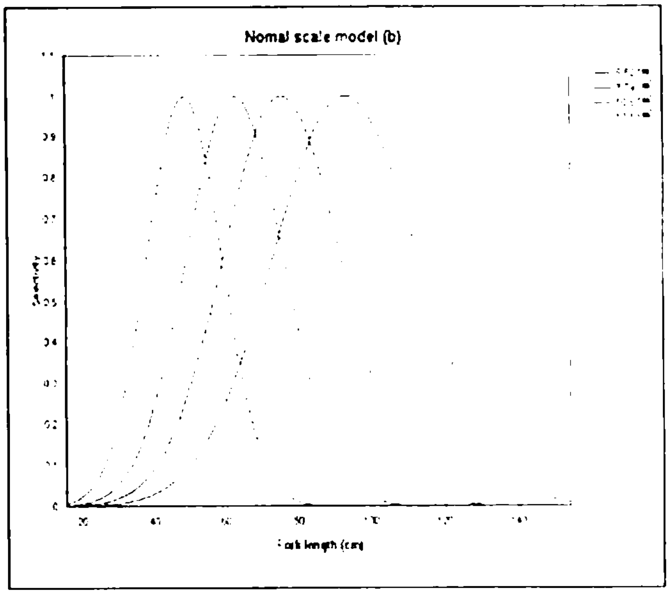

Nomal scale model (b)

Fig.55.4

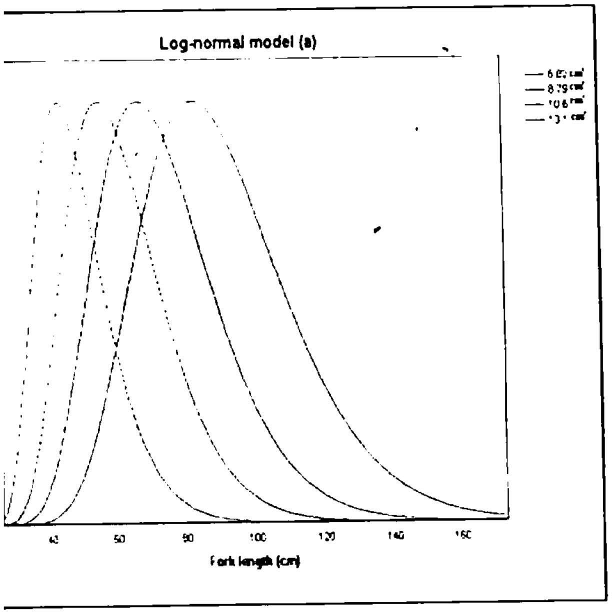


Fig.55.5

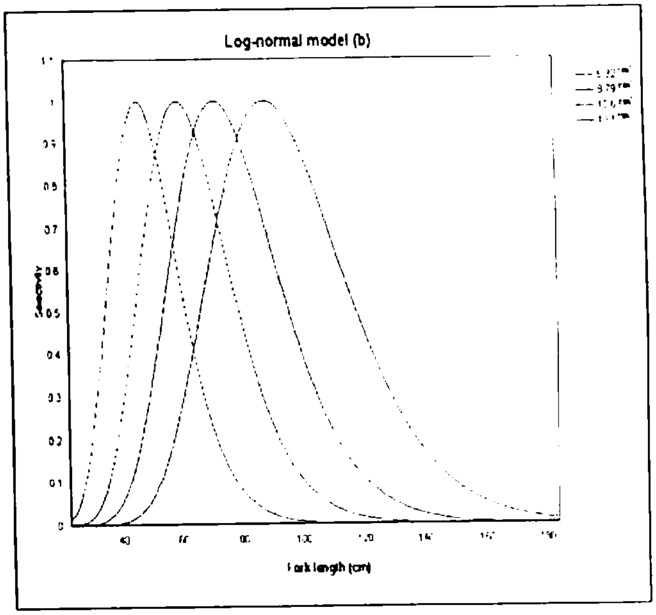


Fig. 55.6

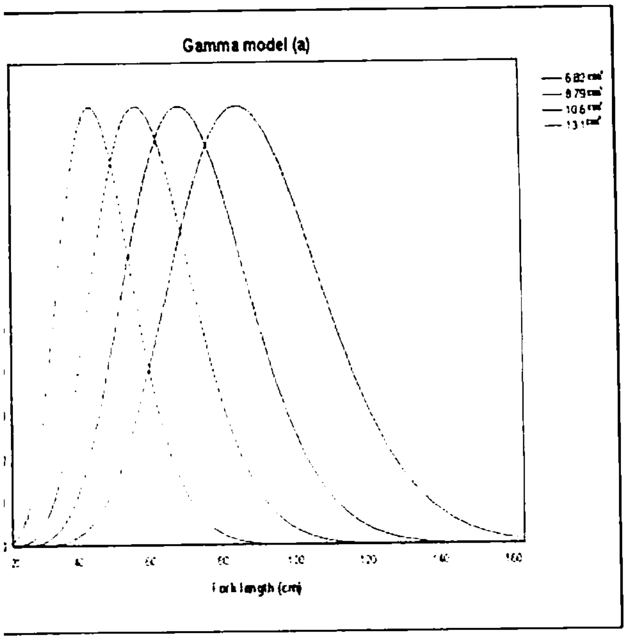


Fig.55.7

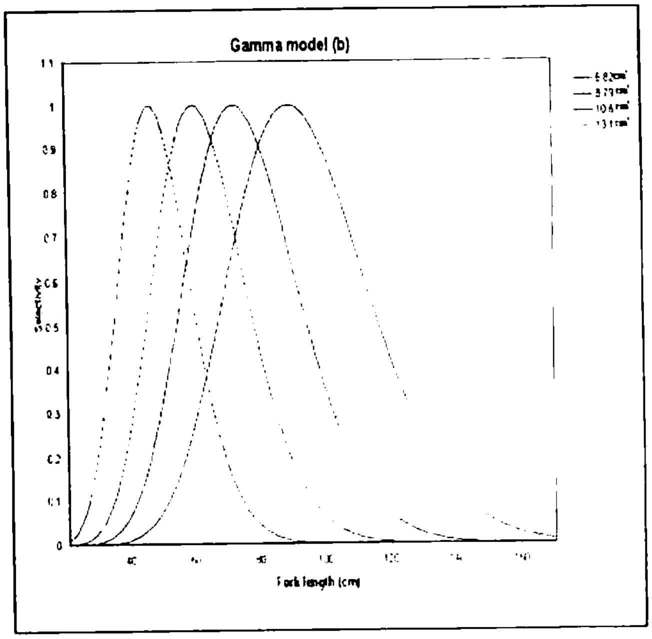


Fig.55.8

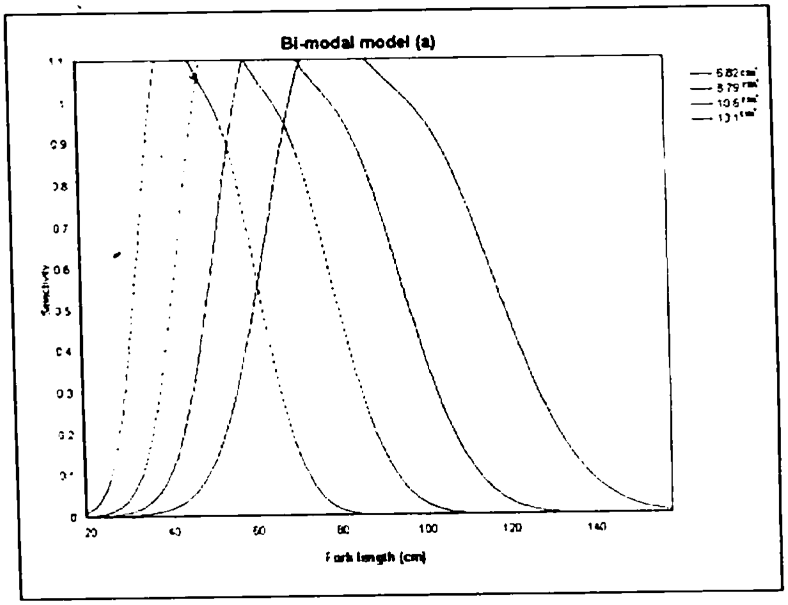


Fig.55.9

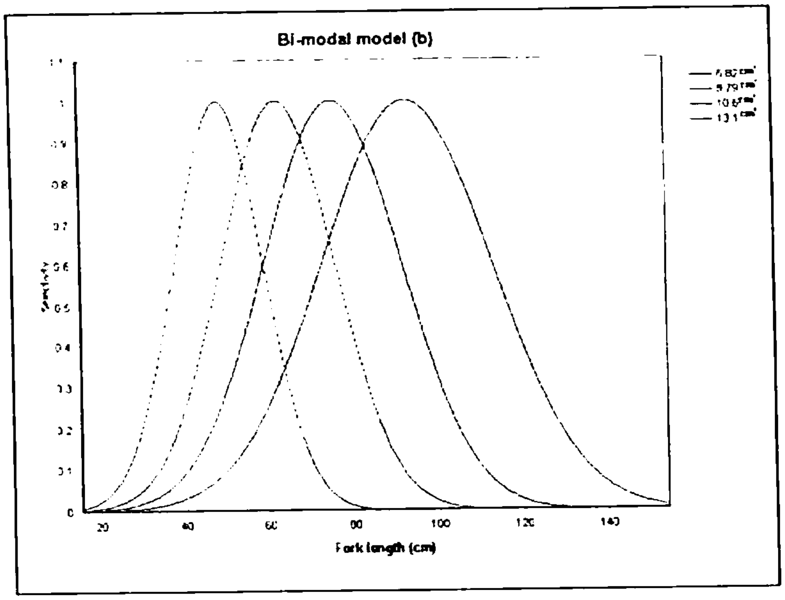


Fig.55.10

based on deviance value were log-normal (135.58), gamma (137.55), and normal scale 150.14 and 151.34 under the assumption of equal fishing power and fishing power proportional to hook size respectively.

In all the model analysis, deviance was greater than degrees of freedom (49). Hence, the deviance of models fitted was evaluated further using dispersion parameter. Estimated dispersion values were 2.75 and 3.05 for normal location for the assumption of equal fishing power and proportional to hook size respectively, 2.77 for log-normal 2.81 for gamma model, and 3.06 and 3.09 for normal scale for the assumption of equal fishing power and proportional to hook size respectively. Estimated dispersion parameter was greater than one in all the models. It obviously indicated over dispersion in all the models including better-fit normal location model. Over dispersion in turn showed lack of fit in normal location model.

Residual plots of all models are given in the Fig. 56 and they revealed the fishing powers of hook No.5, 6, and 8 were greater than hook size No.7 in all the uni-models by the predominance of positive residuals. Of these three hook sizes, No.5 ranked first in all the models followed by No.8 except in the normal scale and gamma model where fishing power of No.5 and 8 were same. Fishing powers varied between models. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to hook size in all the uni-models except better-fit normal location model. Fishing power of hook No. 6 and 7 had equal fishing power in normal scale as well as log-normal. Similarly, fishing power of the above hooks was similar between normal location and gamma model. Fishing power of hook No.5 and 6 was same both in normal location and log normal model. Residual plots showed larger length class group of fish were caught by hook No. 5 (52.5 - 96.5 cm) and 6 (64.5 - 88.5 cm). Fishing power of hooks No. 8 was wide on length group for smaller to larger (48.5 - 72.5 cm). Similarly hook No. 7 caught larger size group (64.5 - 88.5 cm)

Model length and spread of the selection curves of different models for the different hook sizes were presented in the Table 33. Modal length and spread of the selection curves were increased with hook sizes in all the models except normal location model where spread is fixed over the

56 Residuals plots of selectivity curves of various models for different hook sizes and fishing powers for *Caranx heberi*

(Area of the circle is proportional to the square of the residual)

a : Equal fishing power **b : Fishing power α hook size**

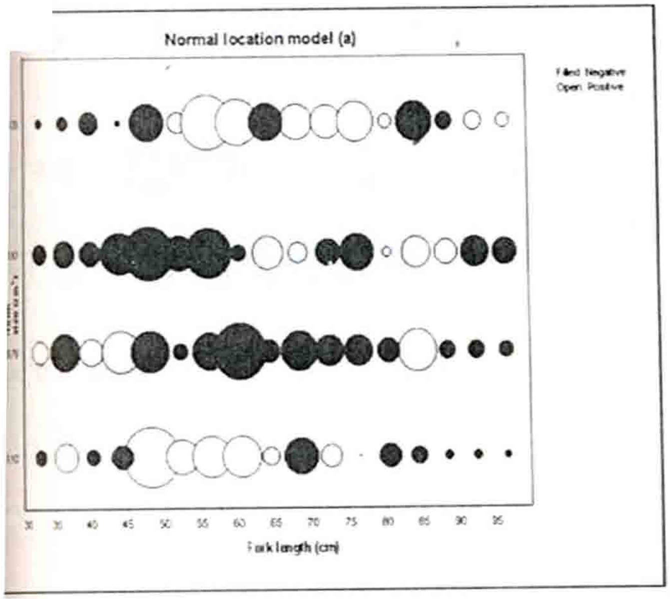


Fig. 56.1

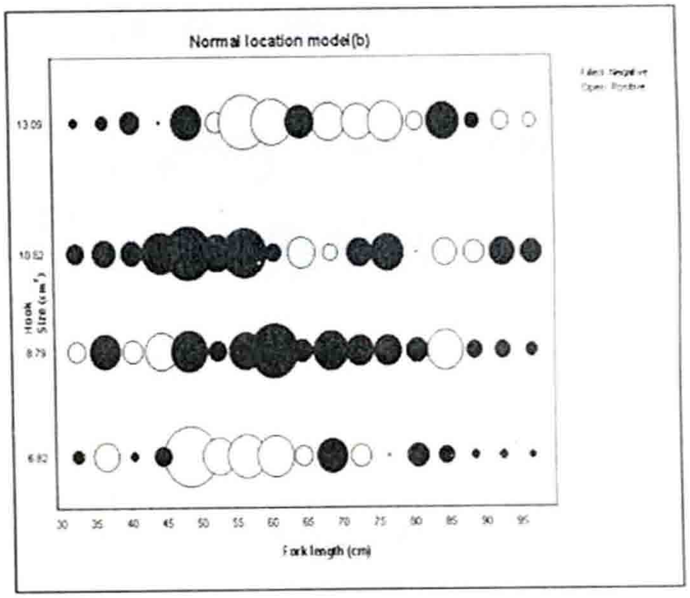


Fig. 56.2

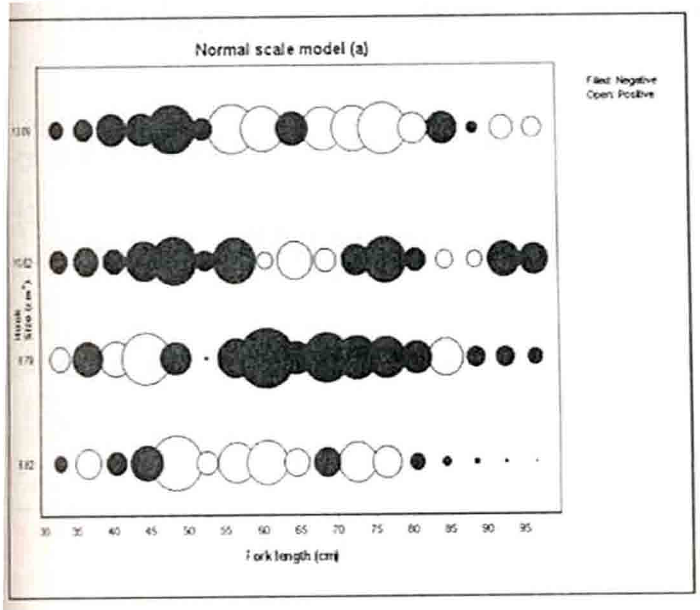


Fig. 56.3

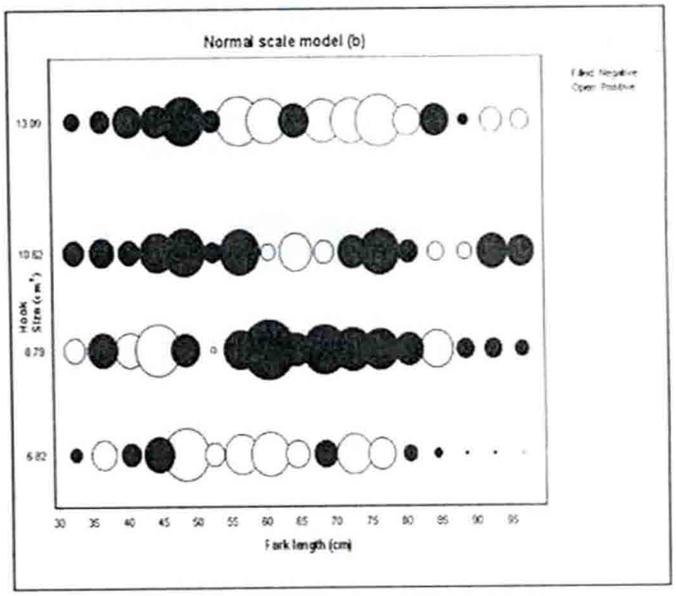


Fig. 56.4

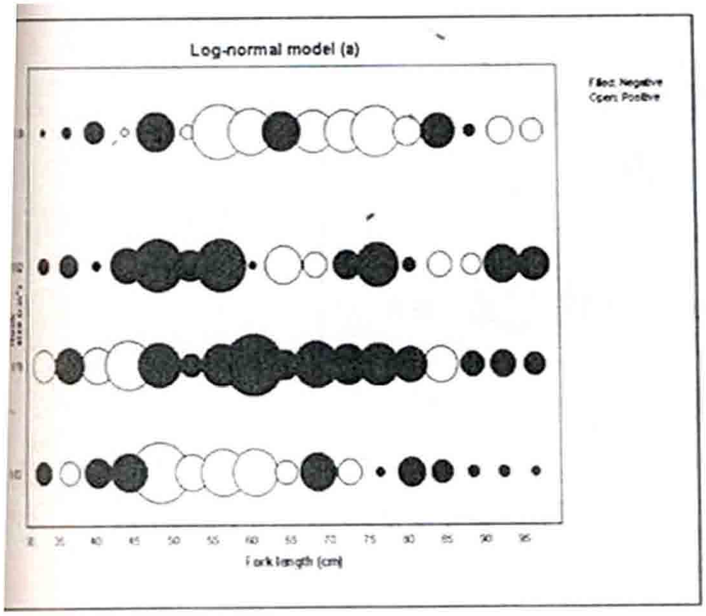


Fig. 56.5

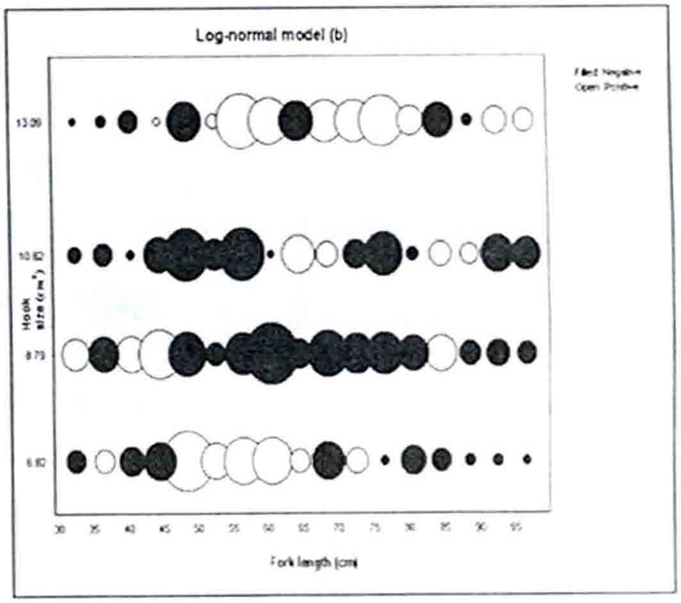


Fig. 56.6

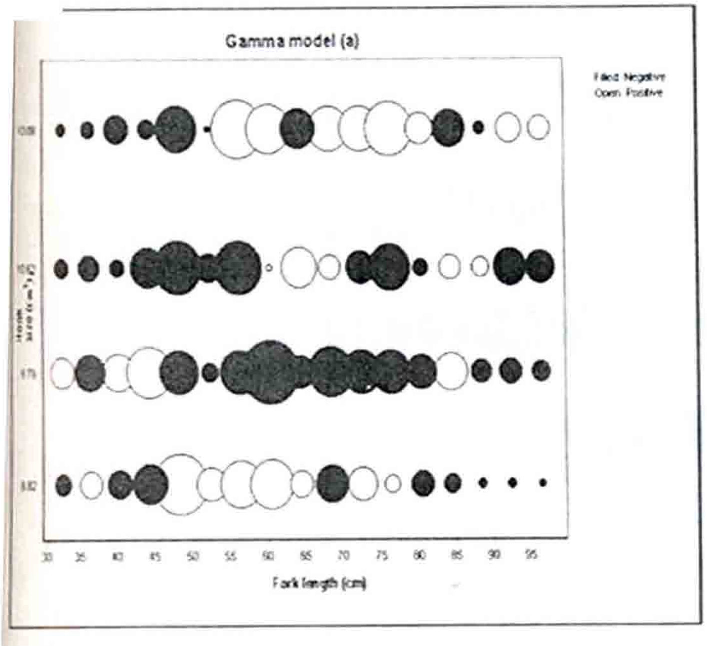


Fig. 56.7

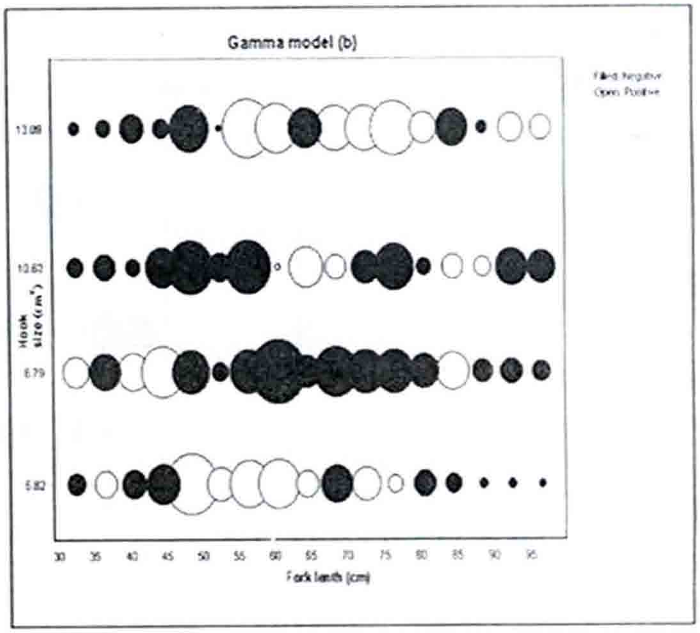


Fig. 56.8

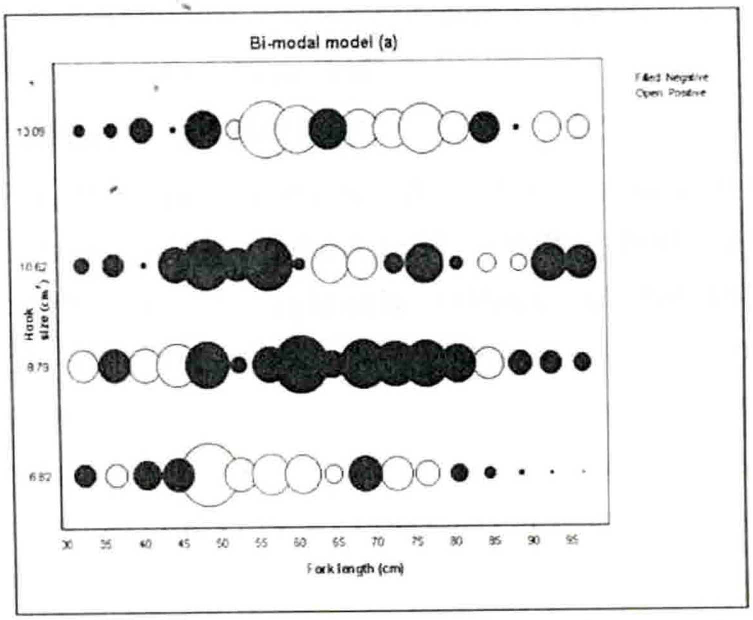


Fig. 56.9

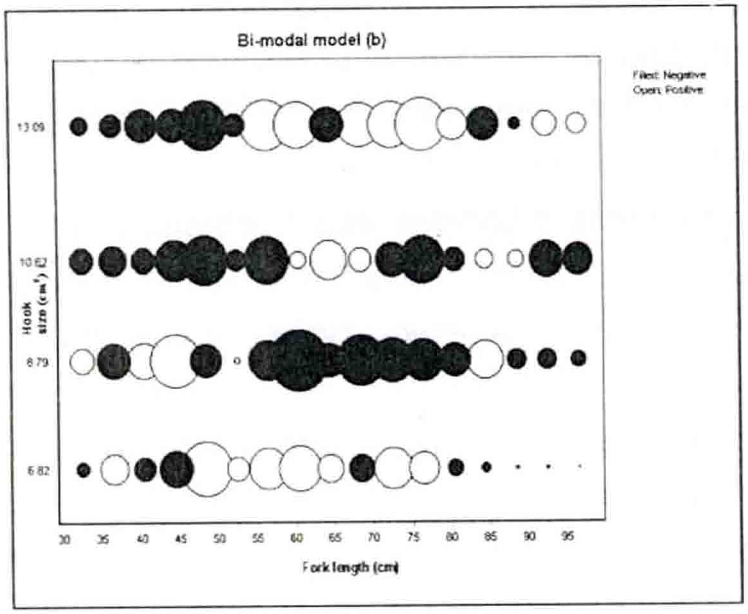


Fig. 56.10

hook size. However they were varied between assumptions of equal fishing power and fishing power is proportional to hook size. Estimated modal length and spread of the better-fit normal location model were 41.7 - 80 cm and 14.41 - 14.9 for the equal fishing power and 44.1 - 84.7 cm and spread was same as previous assumption for the fishing power is proportional to hook size since the model is fixed spread.

4.7.2.2.1 Refitting of Models

Residual plot of better-fit normal location model showed lack of fit by the presence of large sized both positive and negative residuals and systematic occurrence of residuals instead of random order. Uni-modal normal location was extended to bi-modal or bi-normal model since all residuals had the value of greater than 2. Estimated bi-modal selectivity curves and their parameters under both the assumption of equal fishing power and fishing power proportional to hook size are presented in Table 32. DF of bi-modal was 46.

Model deviance of bi-modal model was slightly higher (134.74) for the assumption of equal fishing power despite the increment was very meager compared to uni-modal normal location model (134.7). There was no significant difference (P>0.05) between bi-modal and normal location and little higher model deviance value than normal location. Dispersion parameter was also estimated. It was 2.93 and 3.29 for equal fishing power and fishing power proportional to hook size respectively. It revealed over dispersion of the model and moreover, the retention rate was also greater than one. Considering all these criteria, it was decided that bi-modal was not best fit.

Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to hook size were 37.7 - 72.4 cm with the spread range of 5.67 - 10.88 and 48.4 - 92.9 cm with the spread of 10.45 - 20.05 respectively for the hook size of No.8 to No. 5. Modal lengths of bi-modal were lesser than normal scale for all the hook sizes under the assumption equal fishing power and fishing power proportional to hook size. Similarly spreads of the bi-modal were lesser than normal scale for all the hook sizes under the assumption equal fishing power and equal under the assumption of fishing power was proportional to hook size. There was no great difference between plots of normal location and bi-modal and fishing power of hooks though hook No. 8 was little higher when fitting the normal location and hook No.6 was lower when fitting the normal location and in terms of size groups caught.

4.7.2.3 *Caranx ignobilis*

Over all total catch of *Caranx ignobilis* obtained from four hook sizes was 330 numbers. Of which, 95 specimens were caught from hook size No.5 (13.09 cm^2), 83 from No.6 (10.62 cm^2), 70 from No.7 (8.79 cm^2) and 79 from No.8 (6.82 cm^2) (Table. 19).

Four families of uni-normal model selection curves fitted to the selectivity data (Table. 16) are presented in Fig. 57. Total degrees of freedom (DF) for uni-modal curves were 49. Estimated standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve are presented in the Table 32 & 33.

Selection curves of normal scale and normal location model were symmetrical in shape while the selection curves of log-normal and gamma were skewed to right. Model deviance of each model was observed to find out best fit of the model. Analysis of the deviance and selection curves of all the models indicated that no selection curve gave good fit. However, normal scale model yielded better fit than other models having a small model deviance 75.99 under the assumption of fishing power proportional to hook size though the deviance of this model under the assumption of equal fishing power was 76.38 and it was higher than the assumption of fishing power is proportional to hook size. There was no significant difference between models ($P>0.05$). Other better fits followed by normal scale model based on deviance value were gamma (84.55), normal location 84.75 and 91.92 under the assumption of equal fishing power and fishing power proportional to hook size respectively and log-normal (90.48).

The deviance of models fitted was evaluated further by dispersion parameter since D was greater than DF. Estimated dispersion values were 1.55 and 1.56 for normal scale for the assumption of fishing power is proportional to hook size and equal fishing power respectively, 1.72

g. 57 Selectivity curves of various models for different hook sizes and fishing powers for *Caranx ignobilis*

a : Equal fishing power

b : Fishing power α hook size

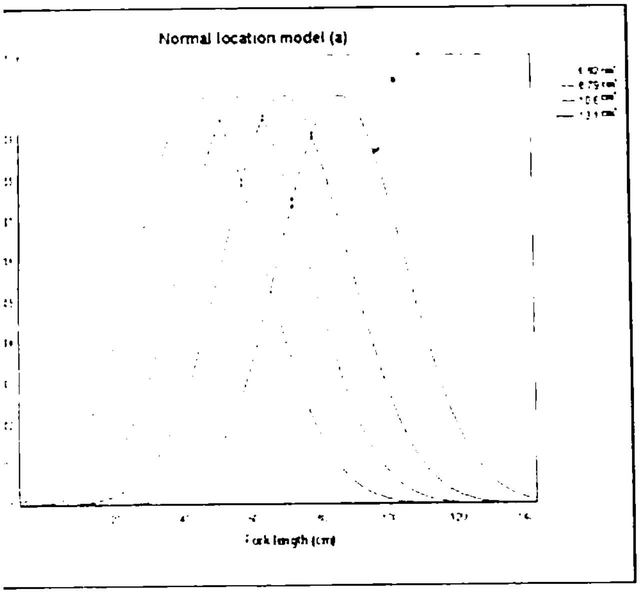


Fig. 57.1

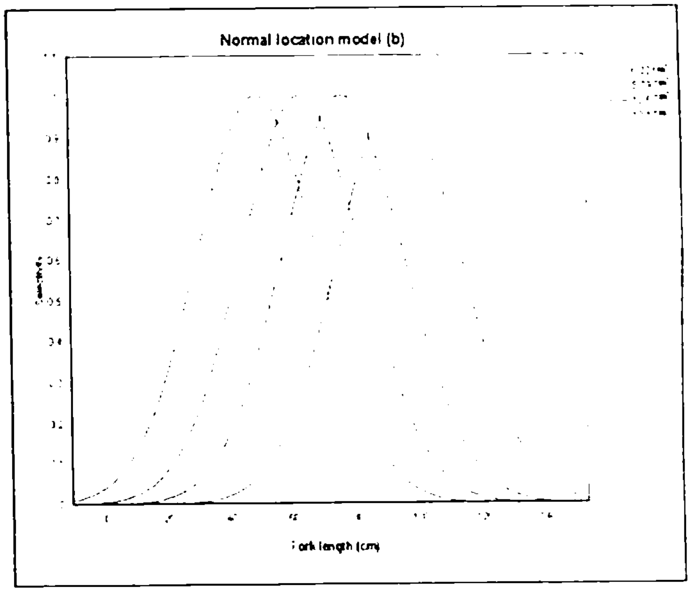


Fig.57.2

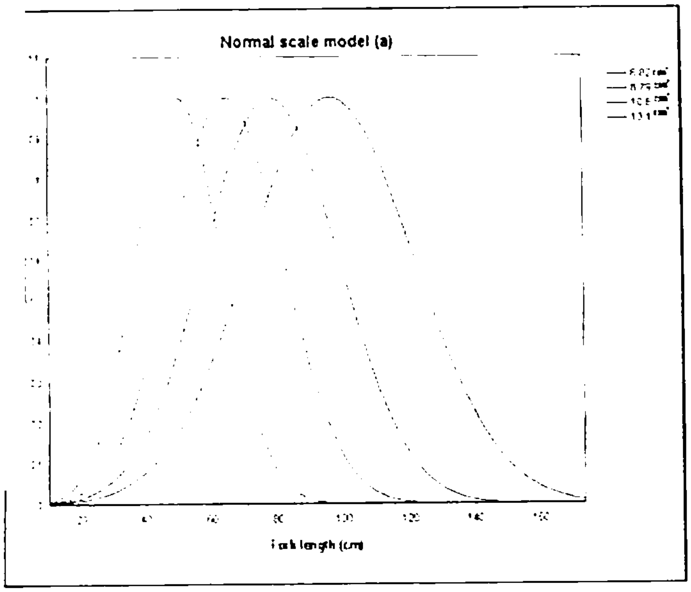


Fig. 57.3

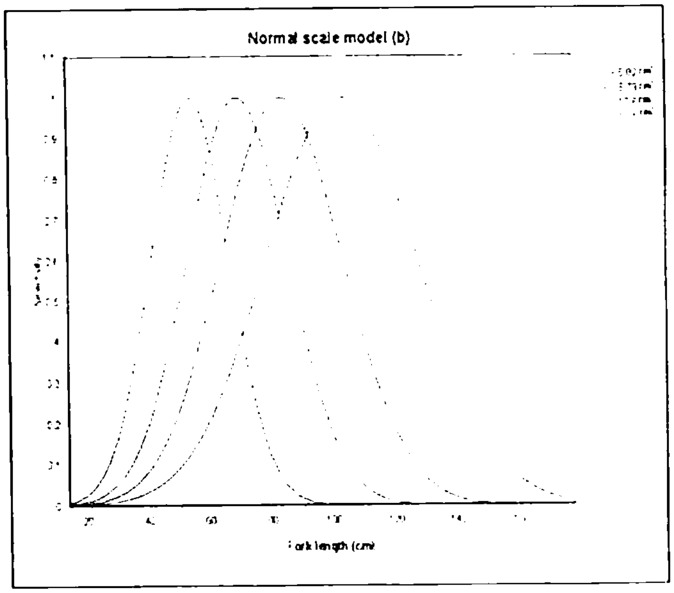


Fig. 57.4

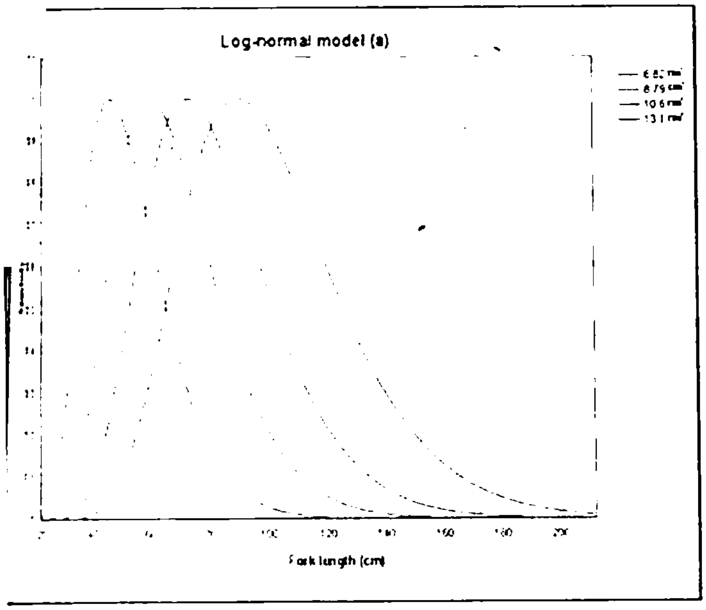


Fig. 57.5

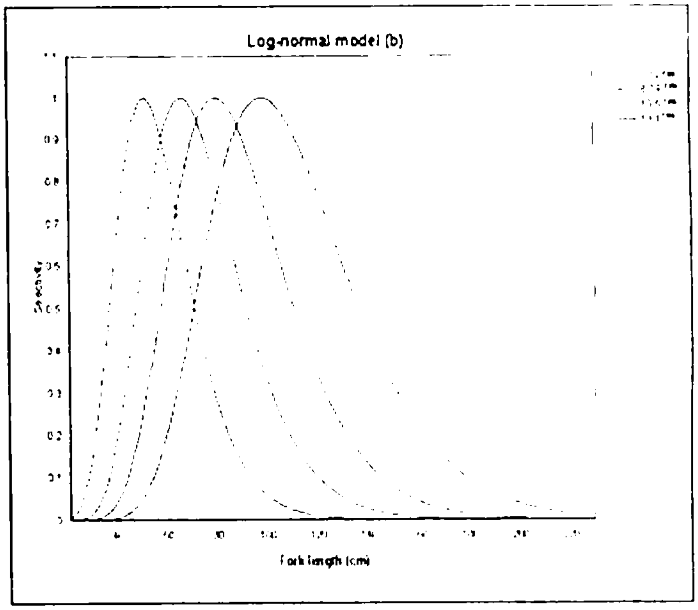


Fig. 57.6

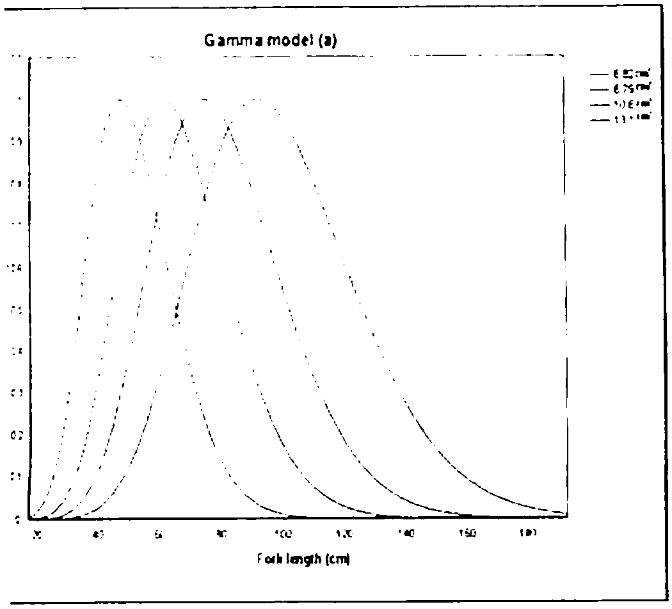


Fig. 57.7

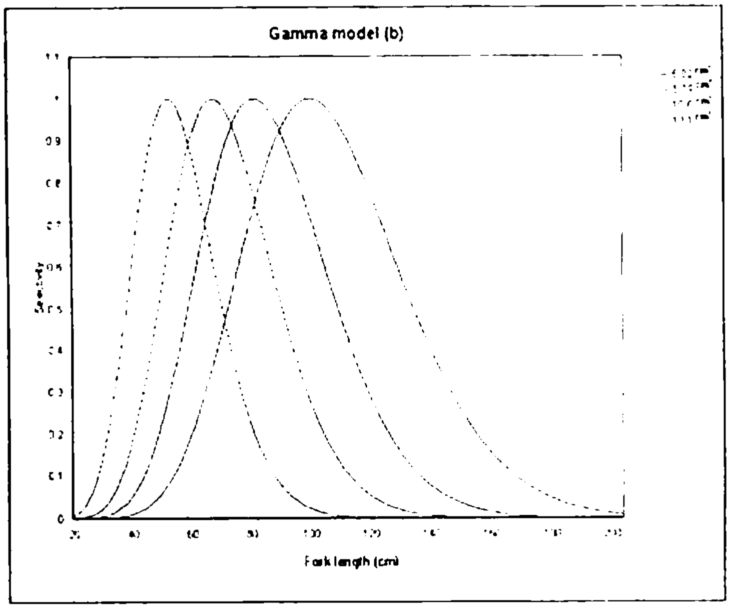


Fig. 57.8

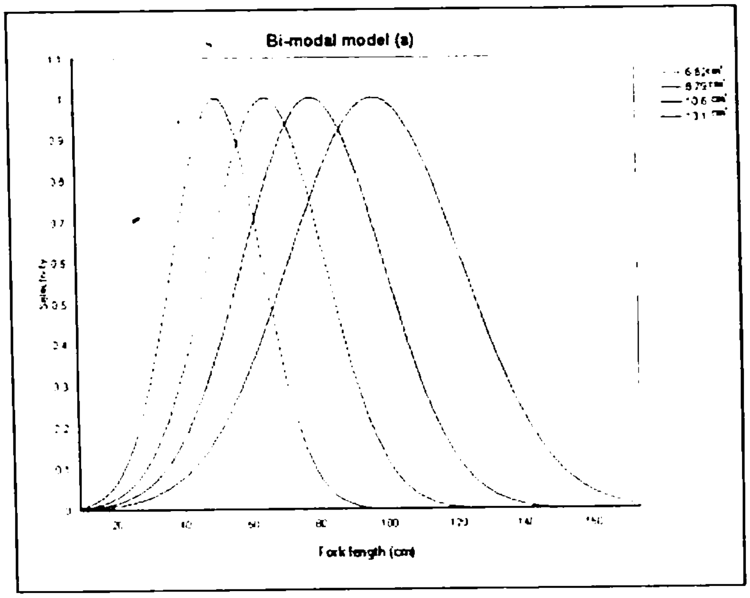


Fig. 57.9

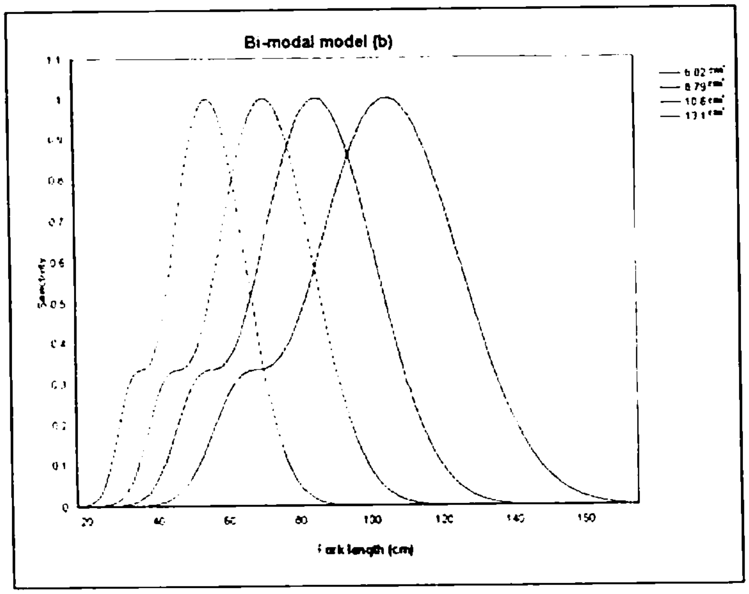


Fig. 57.10

for gamma model, 1.73 and 1.88 for normal location for the assumption of equal fishing power and proportional to hook size respectively and 1.85 for log-normal. Estimated dispersion parameter was greater than one in all the models. It obviously indicated over dispersion in all the models including better-fit normal scale model. Over dispersion in turn showed lack of fit in normal scale model.

Residual plots of all the models are presented in the Fig. 58. The plots revealed that the fishing powers of hook No.5, 6, and 8 were greater than hook size No.7 in all the uni-models by the predominance of positive residuals. Of these three hook sizes, No.5 ranked first in all the models followed by No.8 and No. 6 except in the normal location where hook No.7 ranked third place.

Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to hook size in all the uni-models except better-fit normal scale model. Fishing power of hook No. 7 and 8 had equal fishing power in normal scale as well as log-normal. Fishing power of hooks No. 5 and 6 were higher in all uni-models and these hooks including No. 8 were equal in both log-normal and gamma model. Fishing power of hook No. 8 was similar in normal scale, log-normal and gamma model. Residual plots showed wide larger length class group of fish were caught by hook No. 5 (52.5 - 104.5) while smaller size in No. 8 (40.5 - 72.5). Hook No.6 caught larger group (76.5 - 80.5). Performance of hook No. 7 was very poor.

Modal length and spread of the selection curves of different models for the different hook sizes were presented in the Table 33. Modal length and spread of the selection curves were increased with hook sizes in all the models except normal location model where spread is fixed over the hook size. However they varied between assumptions of equal fishing power and fishing power is proportional to hook size. Estimated modal length and spread of the better-fit normal location Scale model were 50.3 cm - 96.5 cm and 13.13 - 25.21 for the equal fishing power and 53.6 cm - 102.9 cm and spread was 12.69 - 24.35 for the assumption fishing power is proportional to hook size.

58 Residuals plots of selectivity curves of various models of different hook sizes and fishing powers for *Caranx ignobilis*

(Area of the circle is proportional to the square of the residual)

a : Equal fishing power **b : Fishing power α hook size**

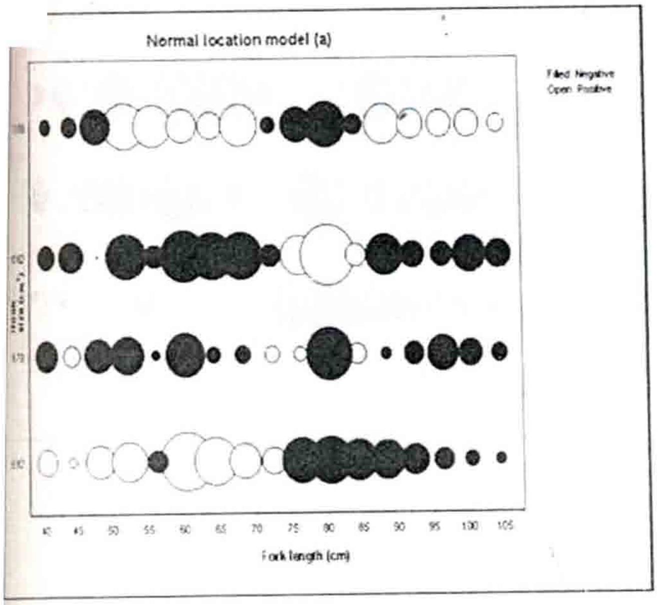


Fig. 58.1

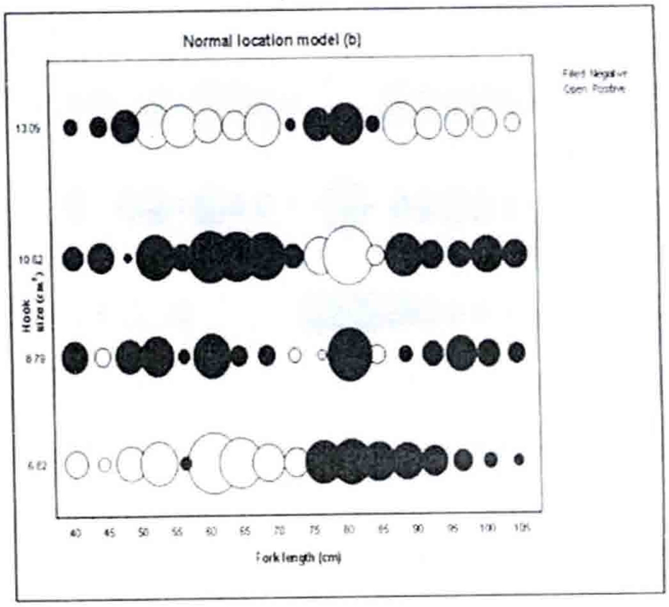


Fig. 58.2

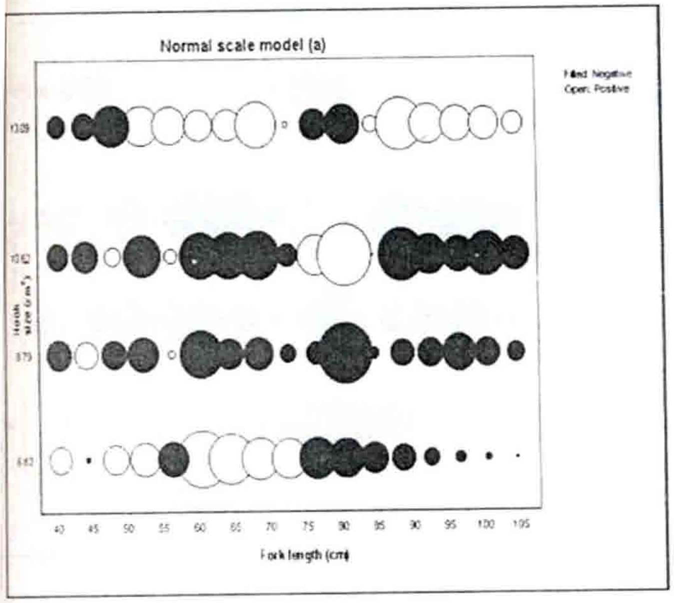


Fig. 58.3

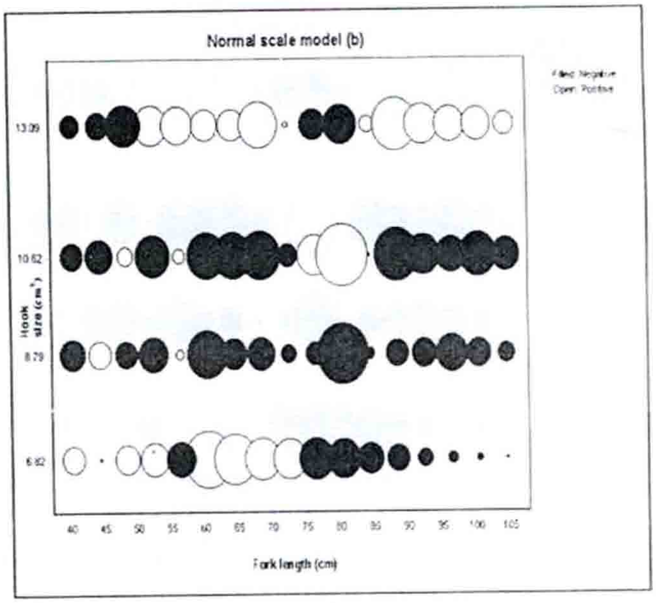


Fig. 58.4

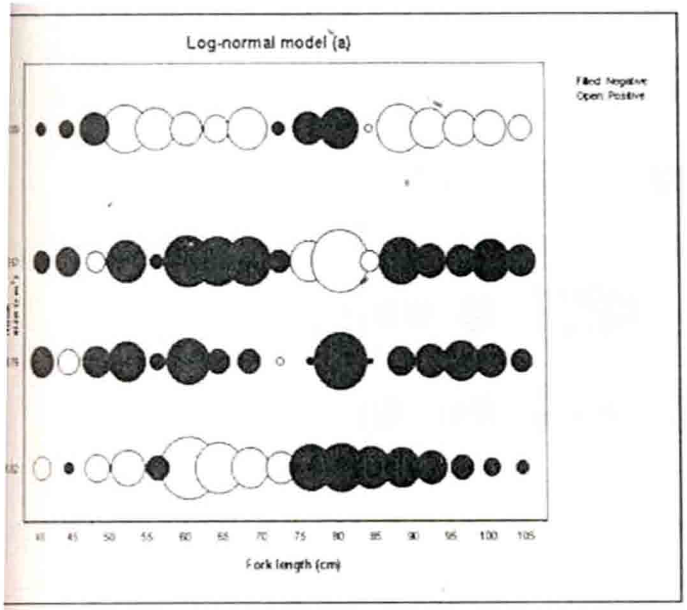


Fig. 58.5

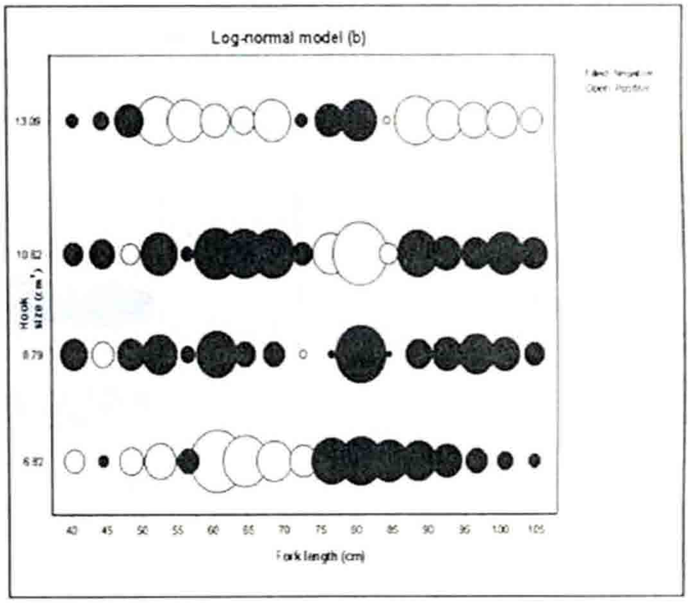


Fig. 58.6

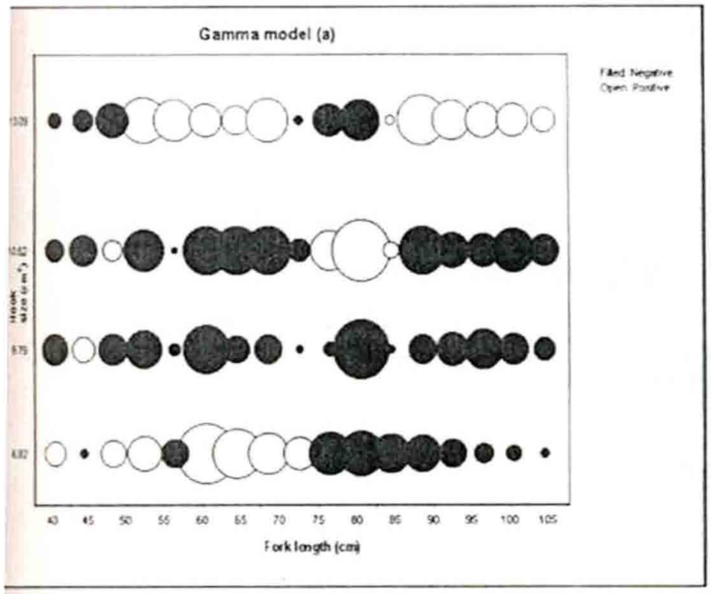


Fig. 58.7

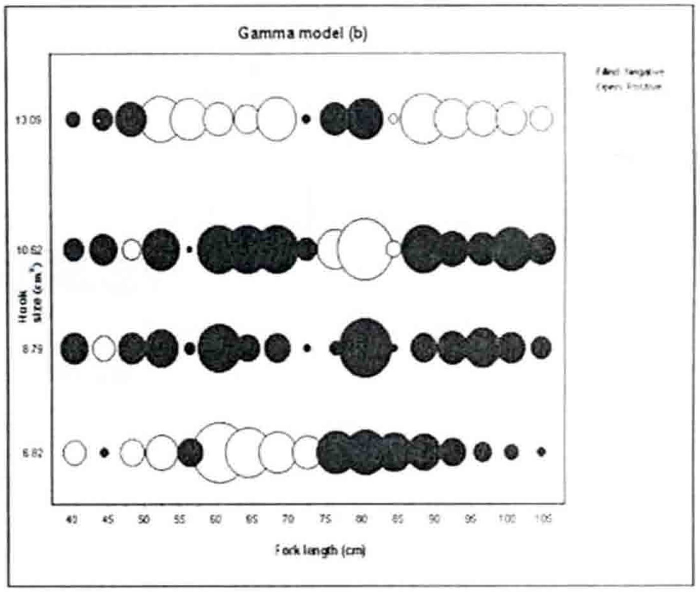


Fig. 58.8

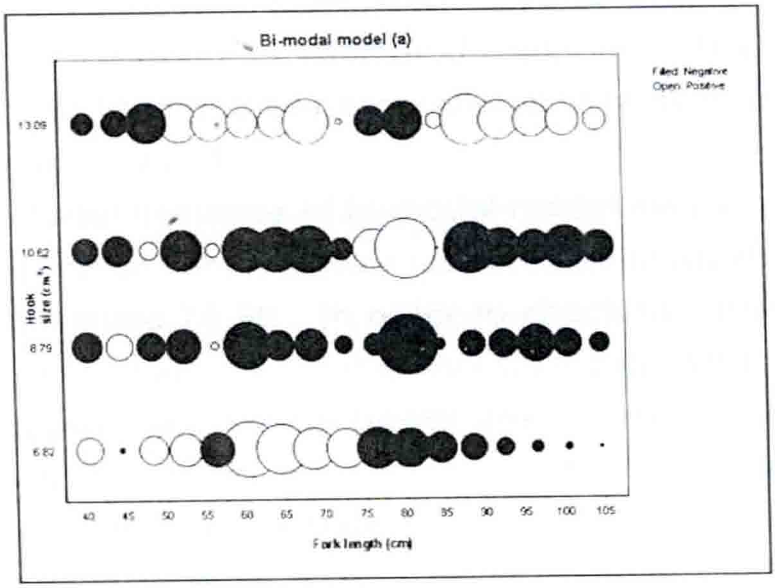


Fig. 58.9

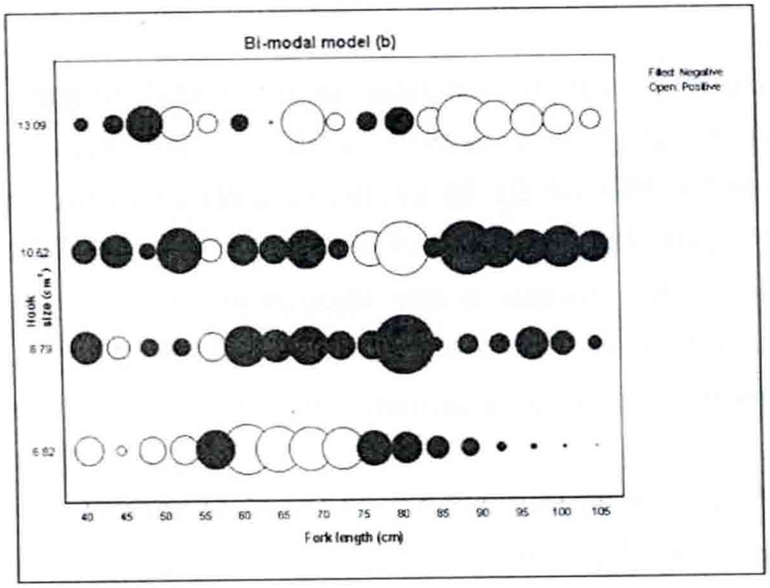


Fig. 58.10

4.7.2.3.1 Refitting of Models

Residual plot of better-fit normal scale model showed lack of fit. Thus the uni-modal normal scale was refitted to bi-modal or bi-normal mode since value of all the residuals were greater than 2. Bi-modal selectivity curves and their parameters estimated under both the assumption of equal fishing power and fishing power proportional to hook size are presented Table 32. DF of bi-modal was 46.

Model deviance of bi-modal model was slightly reduced to 68.45 for the assumption of fishing power proportional to mesh size from the normal scale model deviance 75.99 In order to check the goodness of fit of the bi-modal curve, dispersion parameter was also estimated. It was 1.49 for both equal fishing power and fishing power proportional to hook size respectively. It revealed over dispersion of the model. Other dispersion parameter of uni-models were 1.56 for normal scale for equal fishing power and 1.55 for fishing power proportional to hook size, 1.72 for gamma model, 1.73 and 1.88 for normal location for equal fishing power and fishing power proportional to hook size respectively and 1.85 for log-normal model. Selectivity curves for bi-modal was bi-mode with different length for the assumption of fishing power proportional to hook size and it was uni-modal for the assumption of equal fishing power.

Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to hook size were 50.3 - 96.5 cm with the spread range of 13.13 - 25.21 and 32.5 - 62.4 cm with the spread of 3.96 - 7.6 respectively for the hook size of No.8 - No. 5. Modal lengths and spread of bi-modal were equal with normal scale under the assumption of equal fishing power while they were lower than normal scale for all the hook sizes under the assumption of fishing power proportional to hook size.

Residual plots of bi-modal function under both the assumptions were presented in Fig. 58.9 & 58.10. Plots explained that hook sizes of No. 5. 6 and 8 were greater than modeled with the presence of more positive residuals. Residual plots of both uni-modal normal scale and bi-modal varied little in fishing power. In this model, the hook size No.5 ranked first and the next effective hook size was No. 8 as existed in the normal scale model. Fishing power of rest of the hooks was in the following order viz., No. 6 and 7. Fishing power of hook size 5 and 6 was lesser than normal scale and higher for hook No. 8. Performance of hook No.7 was very poor. There was no great difference shown with normal scale model in terms of size groups caught.

4.7.2.4 *Scomberoides commersonnianus*

Over all total catch of *Scomberoides commersonnianus* obtained from four hook sizes was 377 numbers. Of which, 86 specimens were caught from hook size No.5 (13.09 cm^2), 80 from No.6 (10.62 cm^2), 105 from No.7 (8.79 cm^2) and 106 from No.8 (6.82 cm^2) (Table. 19).

Selections curves belong to four families of uni-normal model fitted to the catch data (Table. 17) are presented in Fig. 59. Total degrees of freedom (DF) for uni-modal curves were 37 and estimated standard deviation (SD), model deviance (D), selectivity parameters and other selectivity statistics viz., modal length and spread of selection curve are presented in the Table 32 & 33.

Selection curves of normal scale and normal location model were symmetrical in shape while the selection curves were skewed to right in all other uni-modals. Observation of model deviance of each model, showed good fit in all the models with or without skew. Nevertheless, normal location model yielded better fit than other models having a small model deviance 130.27 and 140.91 in the assumption of equal fishing power and fishing power is proportional to hook size respectively. There was no significant difference between models ($P>0.05$). Other better fits followed by normal location model based on deviance value were gamma (134.4), normal scale 134.91 and 135.16 under the assumption of equal fishing power and fishing power proportional to hook size respectively and log-normal (135.58)

The deviance of models fitted was evaluated using dispersion parameter since, D was greater than DF. Estimated dispersion values were 3.52 and 3.81 for normal location model for the assumption of equal fishing power and fishing power proportional to hook size respectively, 3.63 for

59 Selectivity curves of various models for different hook sizes and fishing powers *Scomberoides commersonnianus*

a : Equal fishing power **b : Fishing power α hook size**

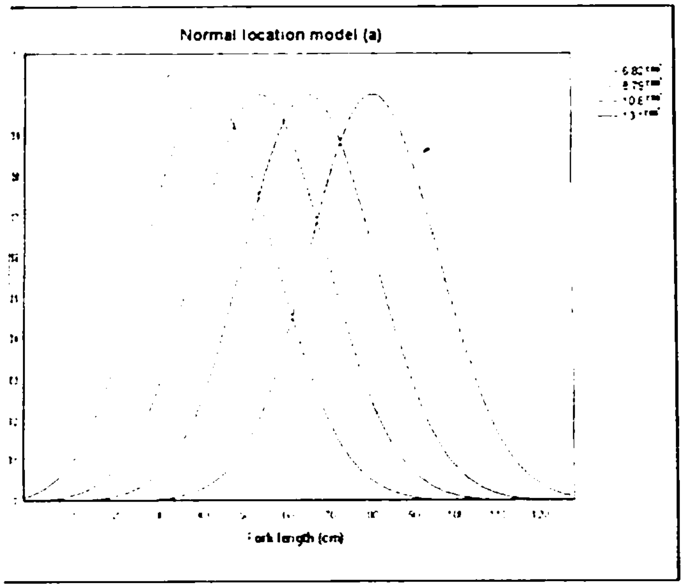


Fig. 59.1

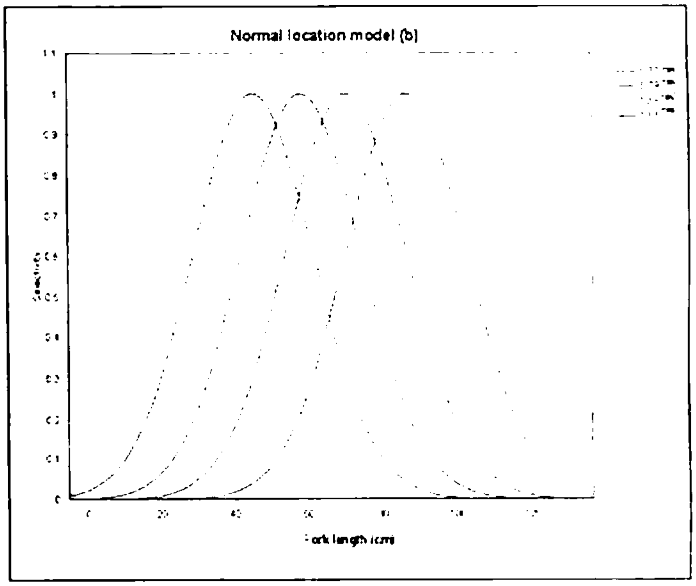


Fig. 59.2

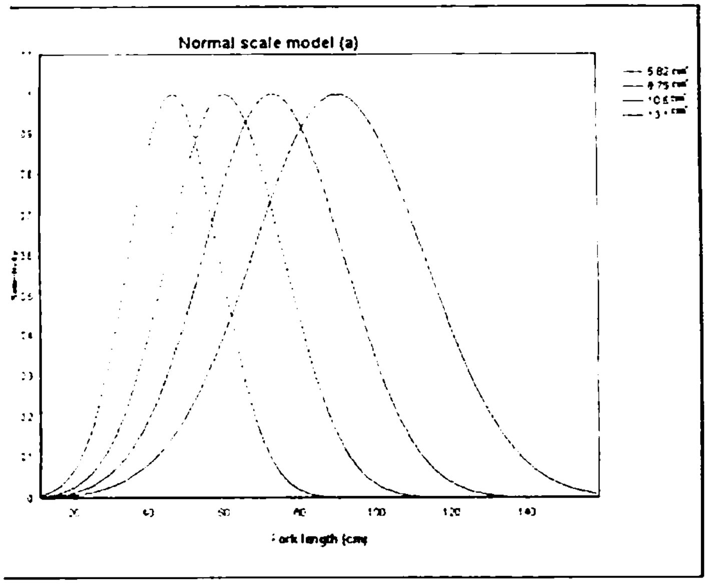


Fig. 59.3

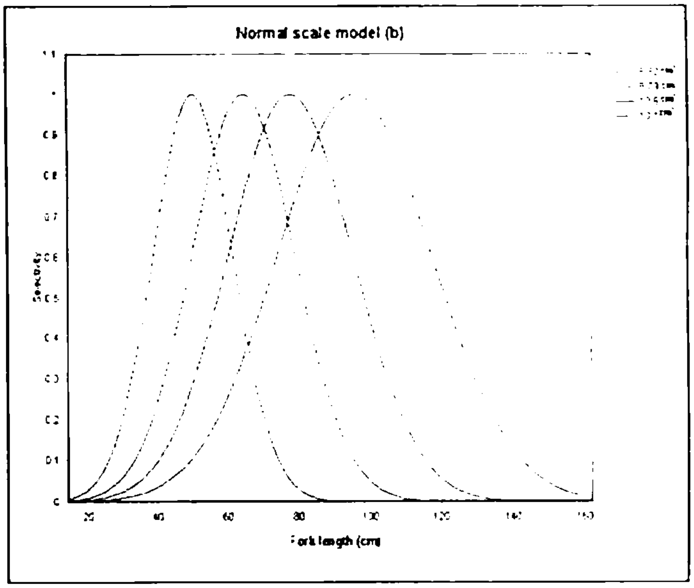


Fig. 59.4

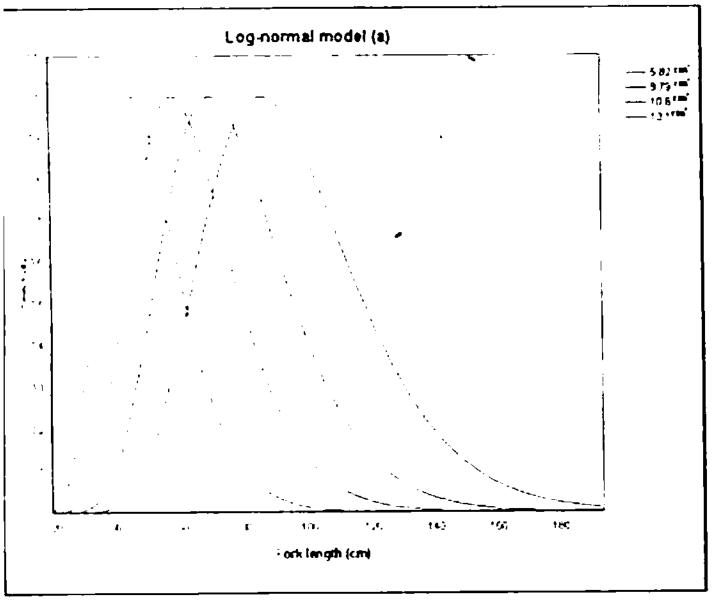


Fig. 59.5

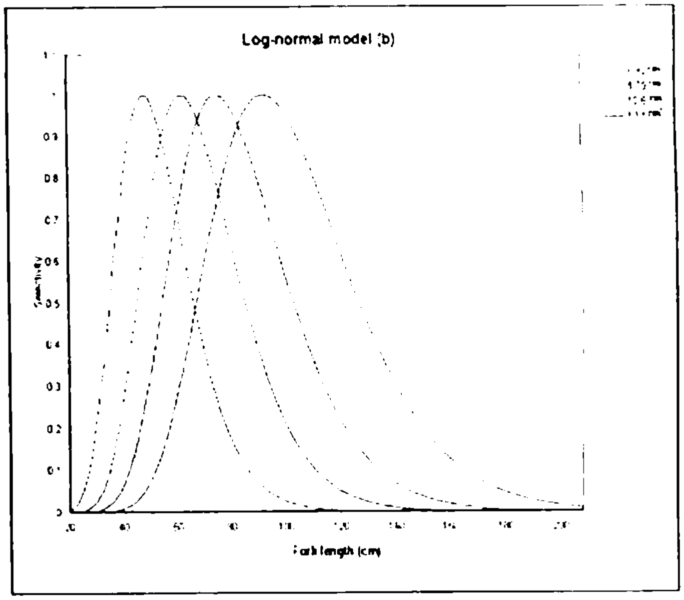


Fig. 59.6

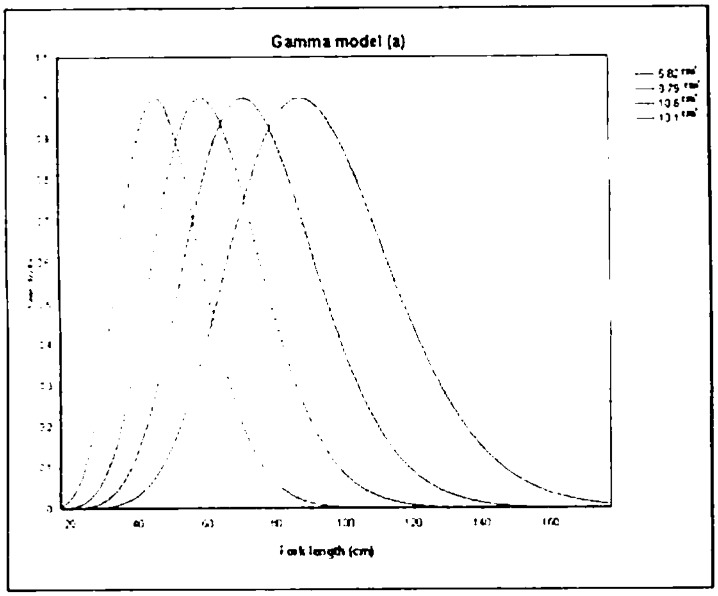


Fig. 59.7

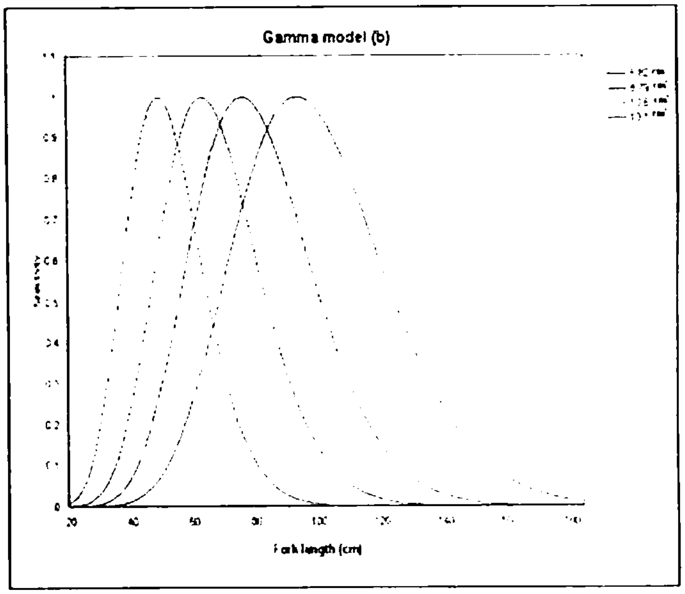


Fig. 59.8

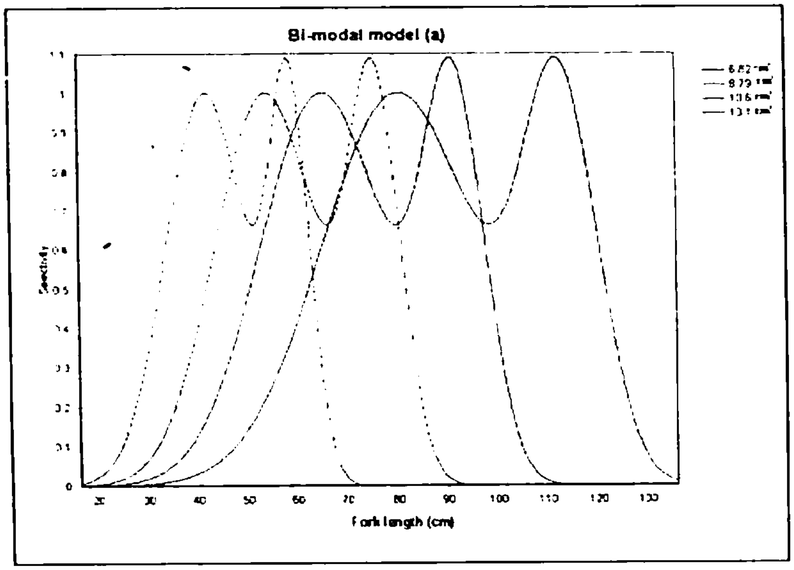


Fig. 59.9

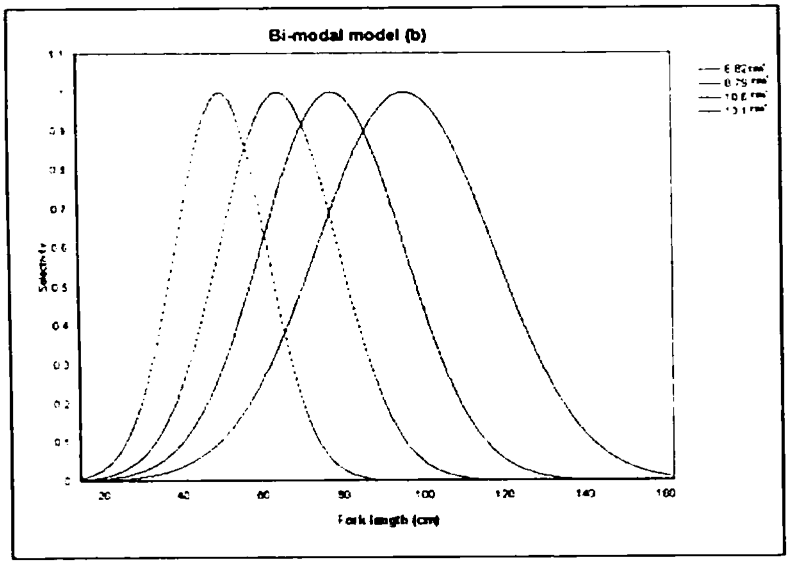


Fig. 59.10

gamma model, 3.65 for normal scale for both the assumptions, and 3.66 for log-normal. Over dispersion was observed in all the models including better fit normal location model and it indicated lack of good fit.

Residual plots of all models tested are presented in the Fig. 60. These plots revealed that the fishing powers of hook No.5, 7, and 8 were greater than hook size No.6 by the predominance of positive residuals. Of these three hook sizes, No.5 ranked first in all the models followed by No.8 and No.7. Fishing powers were equal in both the normal scale and gamma model by the presence of equal number of positive residuals in respective hook sizes. Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to hook size in all the uni-models. It is also true in the better-fit normal location model. Fishing power of hooks No. 5, 6 and 8 was equal in all the models though fishing power of hook No. 7 was equal with gamma model alone. Residual plots showed wide range of larger length class group of fish were caught by hook No. 5 (60.5 - 84.5 cm) while No.8 caught wide range of various length groups (36.5 - 64.5 cm) and smaller sizes by hook No. 7. (44.5 - 48.5 cm). Performance of hook No. 6 was very poor.

Model length and spread of the selection curves of different models for the different hook sizes were presented in the Table 33. Modal length and spread of the selection curves were increased with hook sizes in all the models except normal location model where spread is fixed over the hook size. However they varied between assumptions of equal fishing power and fishing power is proportional to hook size. Estimated modal length and spread of the better fit normal location model were 42.1 - 80.8 cm and 15.42 for the equal fishing power respectively and 45 - 86.3 cm and 16.35 for the fishing power proportional to hook size respectively.

4.7.2.4.1 Refitting of Models

Residual plot of better-fit normal location model showed lack of fit by the presence of large sized both positive and negative residuals and systematic occurrence of residuals instead of random order. Hence the uni-

60 Residuals plots of Selectivity curves of various models for different hook sizes and fishing powers for *Scomberoides commersonnianus* (Area of the circle is proportional to the square of the residual)

a : Equal fishing power

b : Fishing power α hook size

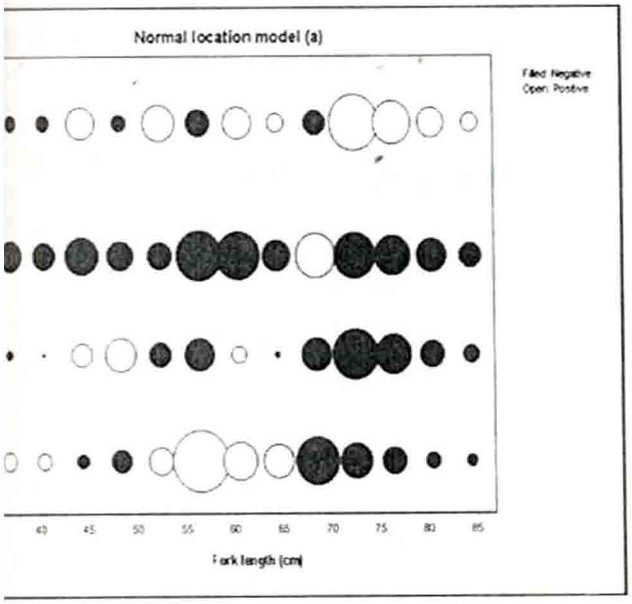


Fig. 60 .1

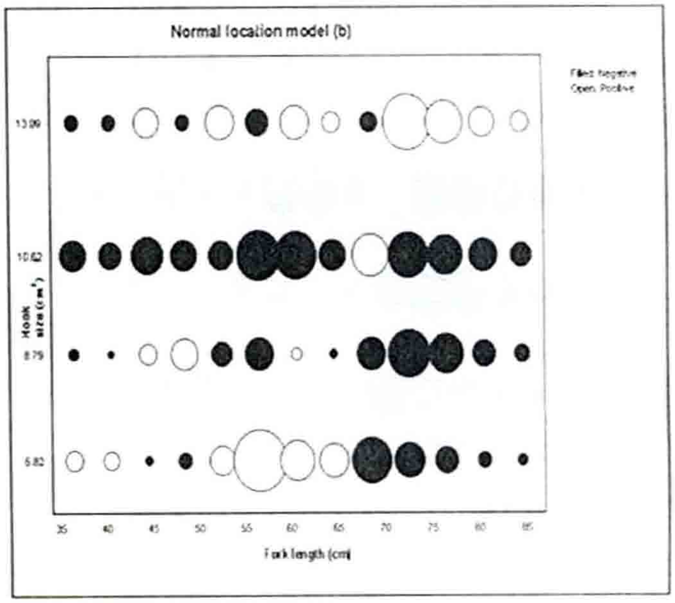


Fig. 60.2

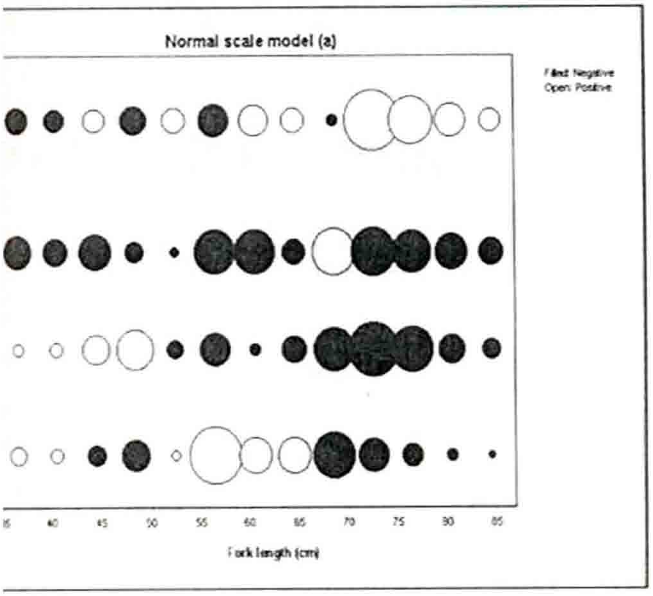


Fig. 60.3

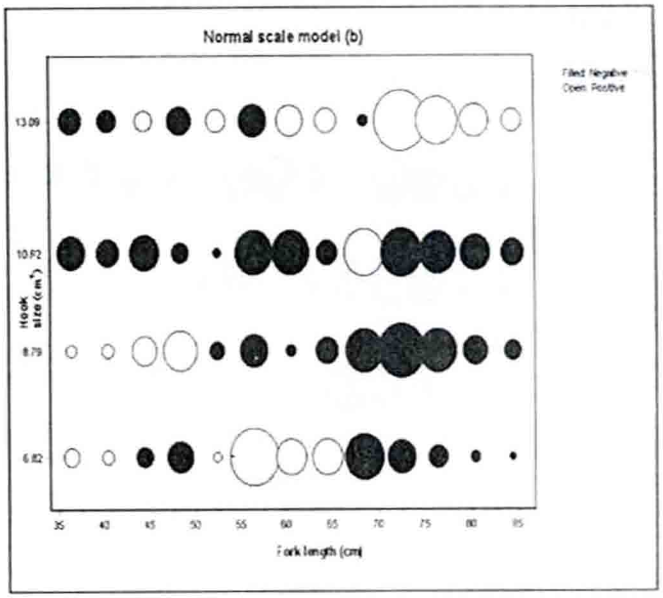


Fig. 60.4

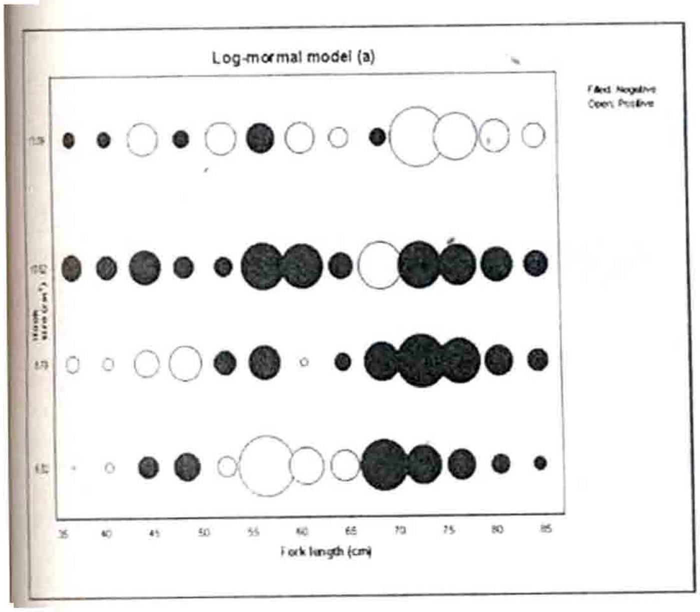


Fig. 60.5

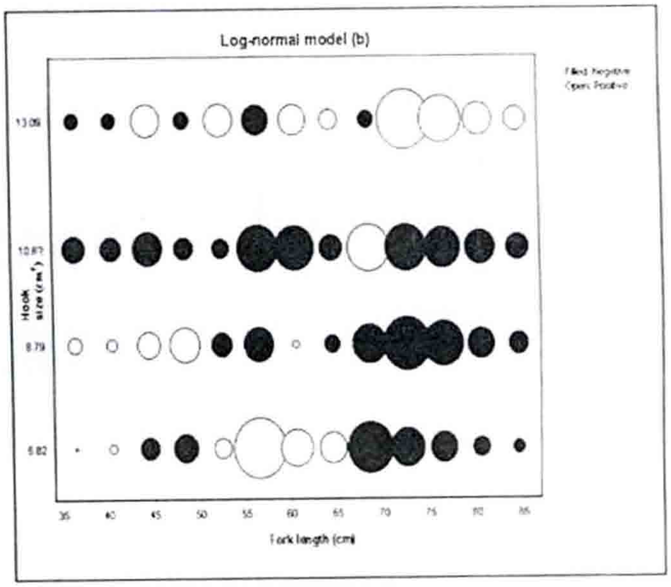


Fig. 60.6

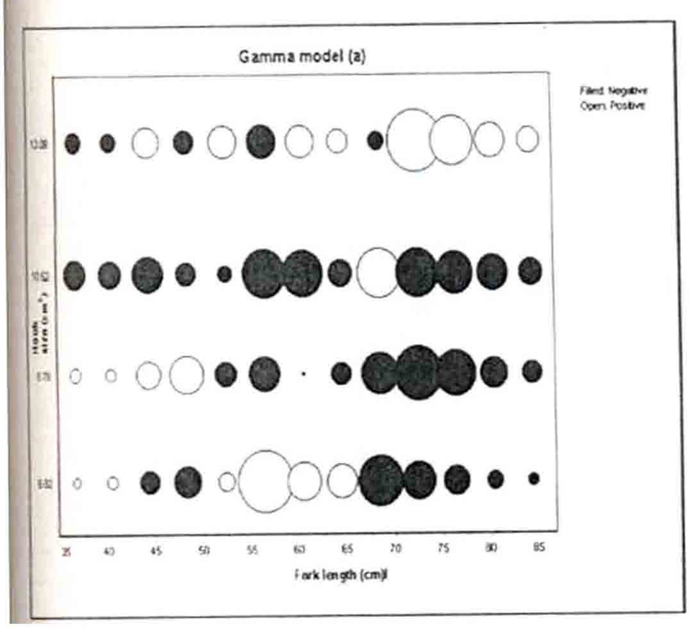


Fig. 60.7

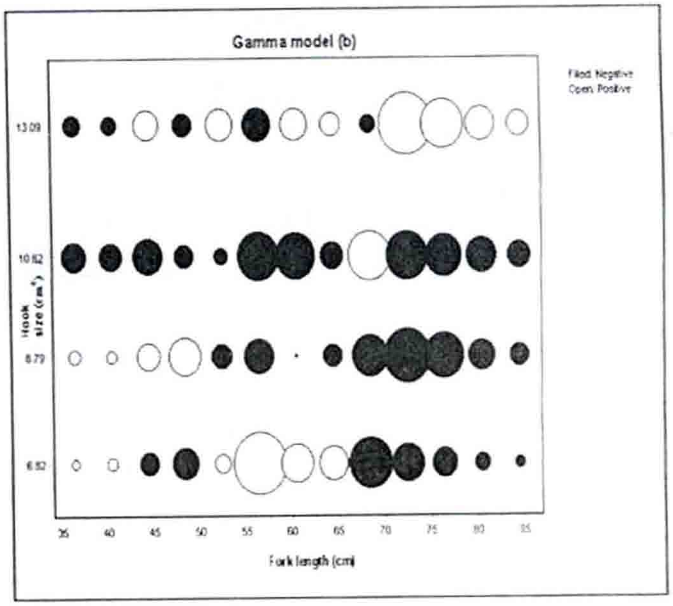


Fig. 60.8

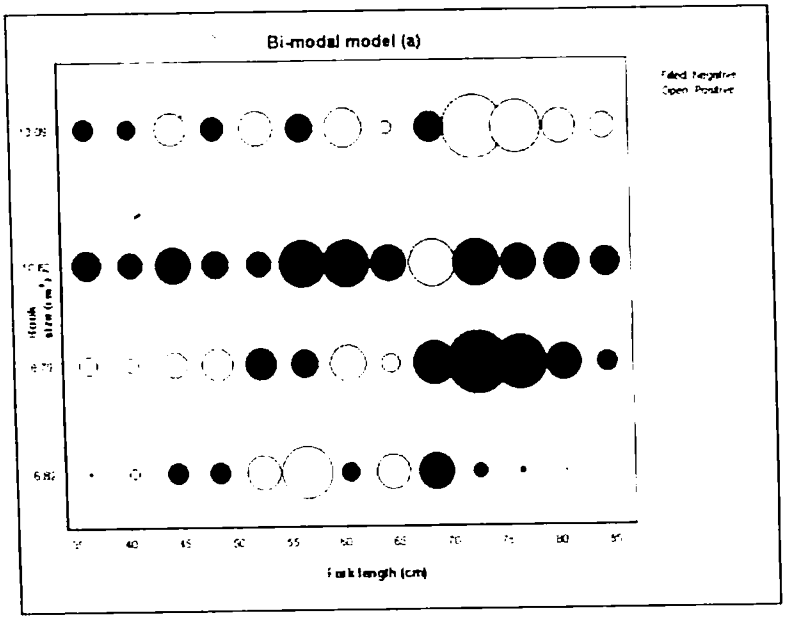


Fig. 60.9

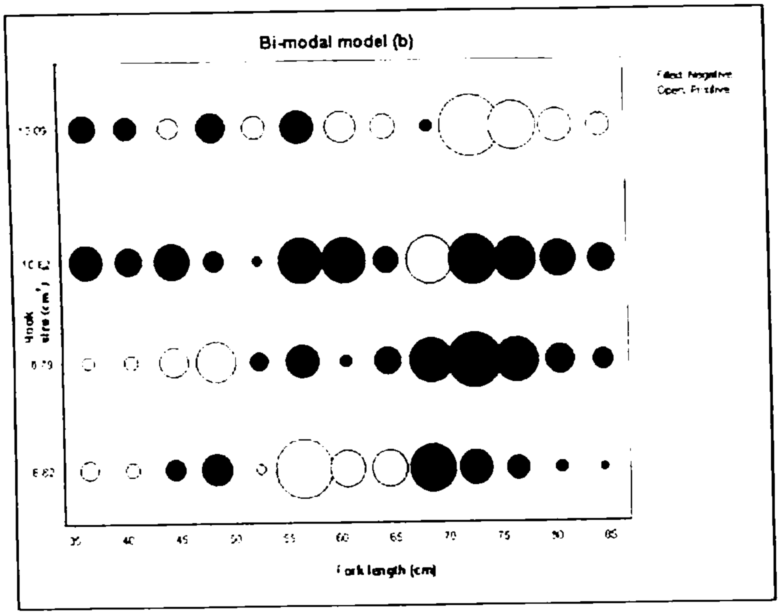


Fig.60.10

modal normal location was refitted to bi-modal or bi-normal model. Bi-modal selectivity curves and their parameters were estimated under both the assumption of equal fishing power and fishing power proportional to hook size and presented in the Table 32. DF of bi-modal was 34.

Model deviance of bi-modal model was slightly reduced to 113.49 for the assumption of equal fishing power from the uni-modal normal location model (130.27) under equal fishing power. Estimated deviance for bi-modal under fishing power proportional to hook size was 135.16. In order to find out goodness of fit of the bi-modal curve, dispersion parameter was also estimated. It was 3.34 for both equal fishing power and fishing power proportional to hook size. It revealed over dispersion of the model and it was lesser than value of uni-modal normal location fit 3.52 and 3.81 under the assumptions of equal fishing power and fishing power proportional to hook size respectively. Other dispersion parameters of the uni-modal curves were 3.63 for gamma 3.65 for normal scale under both the assumptions and 3.66 for log-normal model. Further there was significant difference ($P<0.05$) between deviances of bi-modal (113.49) and normal location model (130.27). Selectivity curves appeared with bi-modes and different heights between modes of each selection curve.

Modal length and spread of the bi-modal models increased proportionately with equal fishing power and proportional to hook size were 42 cm to 80.6 cm with the spread range of 8.1 - 15.55 and 49.8 - 95.6 cm with the spread of 11.32 - 21.72 respectively for the hook sizes of No.8 to No. 5. Modal length and spreads of bi-modal were lesser than normal scale for all the hook sizes under the assumption of equal fishing power while modal length obtained for the assumption of fishing power proportional to hook size was higher than normal location. Modal length and spread obtained from fishing power proportional to mesh size for every hook was greater than equal fishing power.

Residual plots of bi-modal function under both the assumption were presented in Fig. 60.9 & 60.10. Plots explained that the hook sizes of No. 5, 7 and 8 were greater than modeled with the presence of more positive residuals. Residual plots of both uni-modal normal location and bi-modal were almost similar despite the fishing power of hook No. 7 and 8 were different. In this model, the hook size No. 5 ranked first as existed in the normal location model and the next effective hook size was No. 7, followed by No. 8. It was reverse in the normal location model. There no great difference was shown with normal location model in terms of size groups caught. Residual plots were almost similar for both bi-modal and normal location model. However, a good reduction observed in the deviance of bi-modal than the uni-modal normal location model selection.

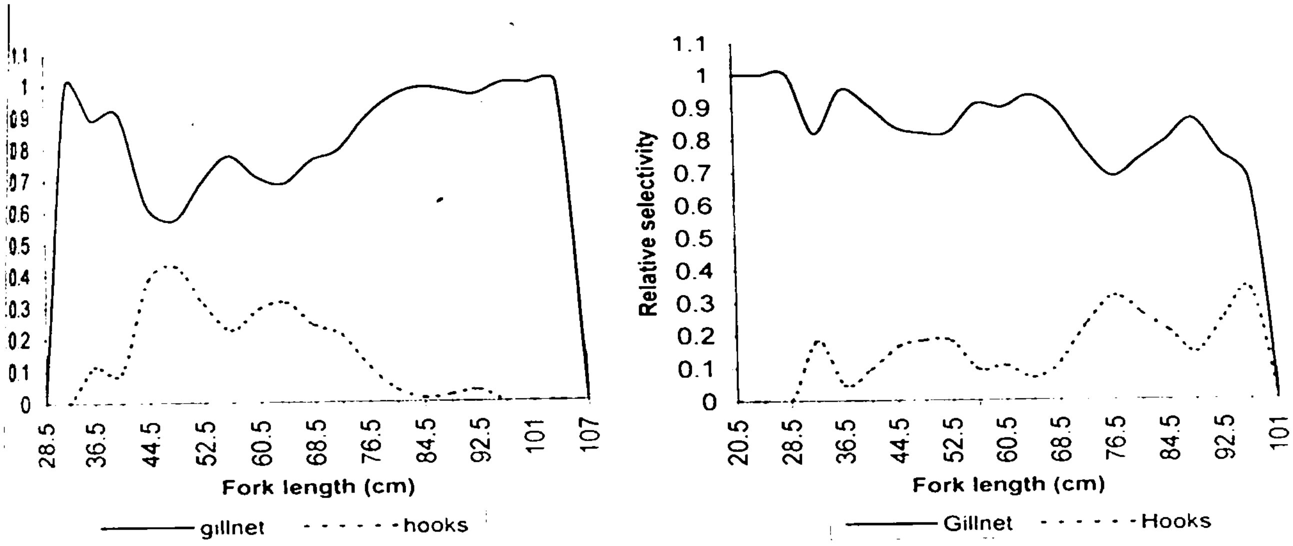
4.8 Relative Selectivity

Comparison of proportion of catch in each length groups in gillnets and hand lines revealed that the mean fork length of the species caught from gillnet varied from that of hand lines. Observed catch proportions of each length group in gillnets and hand lines are shown in Fig. 61. The size range varied from 21.2 to 101.4 cm in gillnets and 35.2 to 92.2 in hand lines for *Carangoides fulvoguttatus*. In the case of *Caranx ignobilis*, the size range caught was 17.8 to 96 cm in gillnets and 39.5 to 103 in hand lines. The size range caught was 23.5 to 93 cm in gillnets and 33.5 to 83.7 cm in hand lines for *S. commersonnianus*. Dominant size groups in the catch of gillnet and hook varied (Table. 23). Over all dominant length groups of *Carangoides fulvoguttatus*, was from gillnets and hooks were, 80.6 to 82.5 cm and 56.6 to 60.5 cm respectively. In the case of *C. heberi*, the dominant size group was 54.6 to 56.5 cm from gillnets and 48.6 to 52.5 cm from hand lines. The size group of 64.6 to 66.5 cm and 56.6 to 60.5 cm of *C. ignobilis* was dominated in gillnets and hand lines catch respectively. Regarding *S. commersonnianus*. the size group caught from gillnets and hooks were 62.6 to 64.5 cm and 52.6 to 56.5 cm respectively. There was no significant difference between mean size of catch obtained from gillnets and hooks ($P>0.05$, t-test).

4.9 Optimization of Mesh and Hook Size

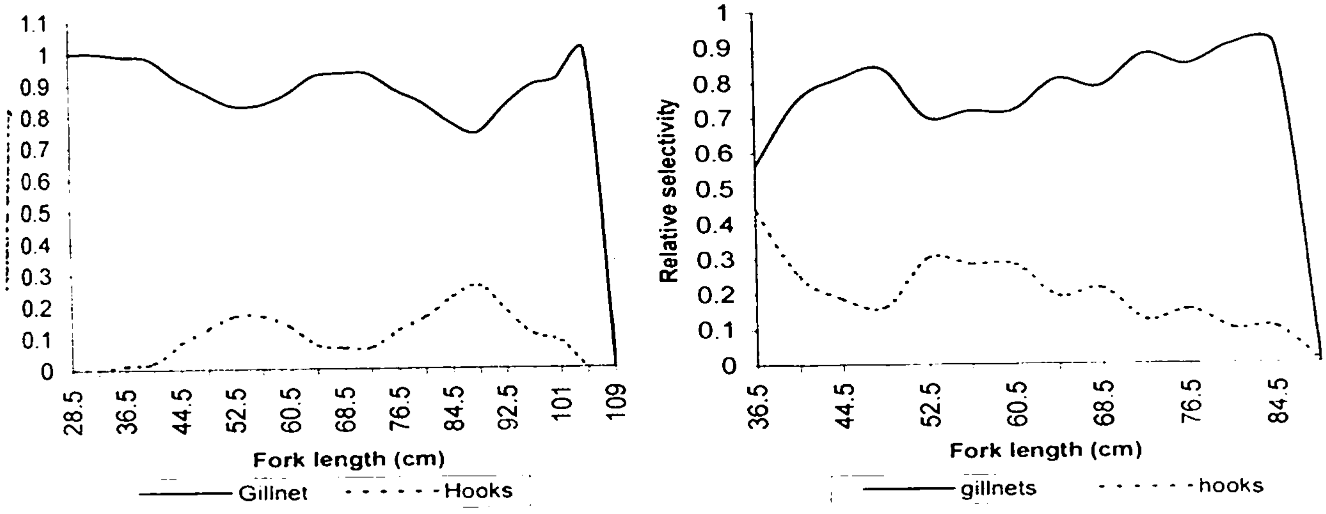
Species *Caranx ignobilis* had highest length at first maturity (Lm50) of 66.9 cm among the carangids caught. It contributed 14.7% and 18.4 % to the total landings of carangids from gillnets and hand lines respectively. It ranked second in abundance among carangids caught from

1 Relative selectivity between gillnets and hand line hooks for various carangid species



a) *Carangoides fulvoguttatus*

b) *Caranx heberi*



c) *Caranx ignobilis*

d) *Scomberoides commersonnianus*

gillnets. The maximum observed length of fish was 105 cm and 103 cm from the catch of gillnets and hand lines respectively. Maximum length (L_{max}) of 170 cm is reported for the species elsewhere (www.Fishbase.org). Calculated lengths at first capture for *C. ignobilis* was 66.9 cm from both gillnets and hand lines. Lengths at first capture for estimated mesh and hook size for other species are given in Table 34. Lengths at first capture thus estimated were higher than the respective lengths at first maturity and experimentally determined modal lengths in all the species in both the gears. The optimum mesh size and hook size recommended for all the species including *C. ignobilis* which had maximum Lm50 found as 15.3 cm and No. 4 respectively

Selectivity co-efficient varied from species to species and it was highest for *Caranx sexfasciatus* (0.146) and lowest for *Carangoides fulvoguttatus* (0.103) for gillnets. Estimated length at first capture was maximum for in *Carangoides fulvoguttatus* (74.37 cm) and minimum for *Caranx sexfasciatus* (52.68 cm) from gillnets. In the case of hand lines, selectivity co-efficient was highest for *C. ignobilis* and lowest for *C. fulvoguttatus* among the four species caught. Estimated length at first capture from the hand lines was maximum in *C. fulvoguttatus* and minimum in *C. ignobilis*.

4.10 Catch Per Unit Effort (CPUE)

Catch per unit effort (CPUE) of the ten species studied varied significantly with respect to gears variation was also significant between species (P<0.01). CPUE was high in the net with mesh size of 14 cm for all species studied followed by the net with13.5 cm mesh size for three species and the net with mesh size of 14.5 cm for one species. CPUE was inversely proportional to hook size except for the species C. *ignobilis* (Fig. 62) and was highest in the hook size of No.8 followed by hook No.5.

4.11 Other Catch Composition

Various species like tuna, seer fishes, sharks, rays and other non-target carangids were caught in the experimental gillnets and hooks along with the main catch. Other non-targetted species was less in gillnets

Table 34. Estimation of optimum mesh size and length at first capture for carangid species studied

S.No.	Species	Percentage contribution to landings	Lmax (cm)	Modal Length (cm)	Length at First maturity (Lm50)	selectivity Coefficient (k)	Mesh Bar/Hook Size (cm)	length at first capture
	*I : **Drift Gillnet***							
1	*Carangoides ferdau*	5.16	89	66.6	48.6	0.113	5.47	68.1
2	*Carangoides fulvoguttatus*	12.7	100.3	72.7	59.5	0.103	6.14	74.4
3	*Caranx heberi*	19.7	96	62.5	54.5	0.120	6.54	63.9
4	*Caranx ignobilis*	14.7	105.2	65.4	66.9	0.115	*7.67	66.9
5	*C. papuensis*	8.38	106	71.5	62	0.105	6.50	73.1
6	*C. sexfasciatus*	6.86	69.6	51.5	48.2	0.146	7.02	52.7
7	*C. tille*	8.94	97.4	70.6	49.9	0.106	5.30	72.2
8	*Scomberoides commersonnianus*	7.79	93	64.7	52.7	0.119	6.27	64.4
9	*S. lysan*	9.52	84	63	53.4	0.132	7.03	58.3
10	*S.tala*	6.34	74.4	57	50.6	0.116	5.87	66.2
	*II : **Drift Hand lines***							
1	*Carangoides fulvoguttatus*	29.22	93.3	98.2	59.5	0.020	1.22	105.3
2	*Caranx heberi*	31.34	95.8	80	54.5	0.025	1.37	85.8
3	*Caranx ignobilis*	18.4	103	62.4	66.9	0.032	*2.16	66.9
4	*Scomberoides commersonnianus*	21.03	83.7	80.6	52.7	0.025	1.32	86.4

* : Optimum mesh bar/hook size

Fig. 62 Catch per unit effort of various mesh sizes of gillnets for various carangids

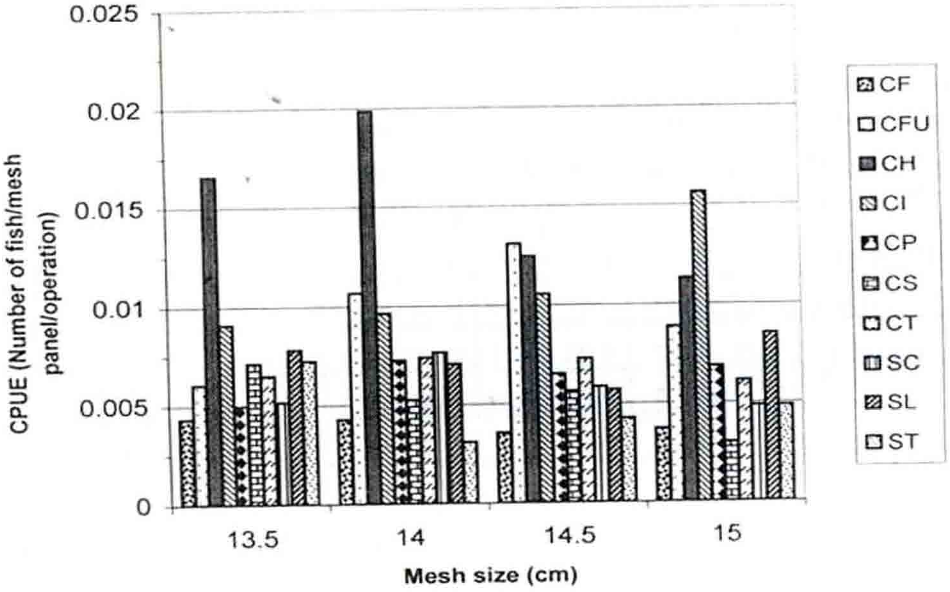
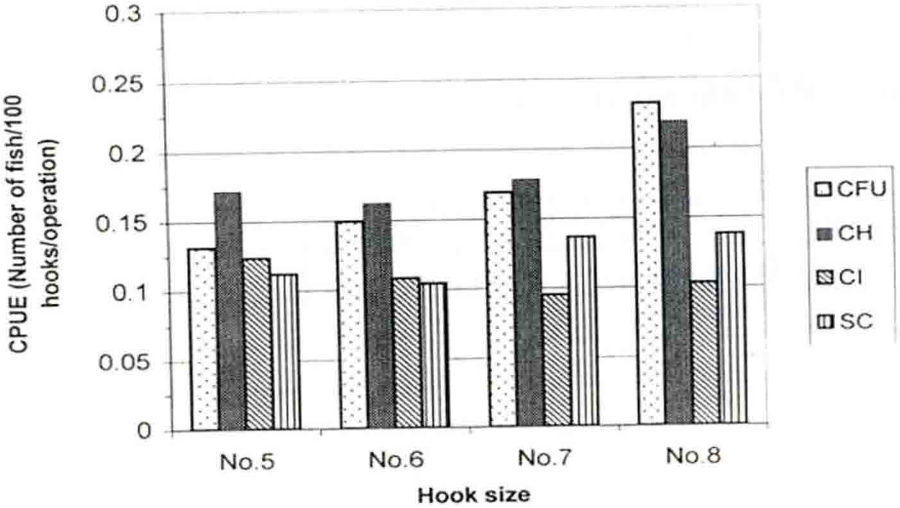


Fig. 63 Catch per unit effort of drift hand lines for carangid species



CU - *Carangoides ferdau*
CFU - *Carangoides fulvoguttatus*
CT- *Caranx tille*
SL - *Scomberoides lysen*

CH- *Caranx heberi*
CI - *Caranx ignobilis*
SC - *Scomberoides commersonnianus*
ST- *Scomberoides tala*

CP- *Caranx papuensas*
CS- *Caranx sexfasciatus*

Table. 35 Percentage of catch of targets species and By-catch from experimental gillnets and hand lines

S.No.	Species	Mesh size (cm)				Over all	Hook size				Over all
		13.5	14	14.5	15		No.5	No.6	No.7	No.8	
1	*Carangoides ferdau*	5.53	5.03	4.55	4.87	5	-◇-	-◇-	-◇-	-◇-	-◇-
2	*Carangoides fulvoguttaus*	7.78	12.6	17	11.8	12.3	22.1	26.62	25.74	31.06	26.63
3	*Caranx heberi*	21.3	23.4	16.1	15	19.1	28.8	28.94	27.13	29.32	28.56
4	*Caranx ignobilis*	11.7	11.4	13.7	20.8	14.3	20.7	19.21	14.46	13.79	16.77
5	*Caranx papuensis*	6.38	8.57	8.45	9.09	8.12	-◇-	-◇-	-◇-	-◇-	-◇-
6	*Caranx sexfasciatus*	9.14	6.17	7.3	3.92	6.65	-◇-	-◇-	-◇-	-◇-	-◇-
7	*Caranx tille*	8.36	8.72	9.45	8.12	8.67	-◇-	-◇-	-◇-	-◇-	-◇-
8	*Scomberoides commersonnianus*	6.62	9.03	7.57	6.41	7.45	18.8	18.52	20.79	18.5	19.16
9	*Scomberoides lysan*	10	8.33	7.37	11.3	9.22	-◇-	-◇-	-◇-	-◇-	-◇-
10	*Scomberoides tala*	9.3	3.61	5.46	6.41	6.14	-◇-	-◇-	-◇-	-◇-	-◇-
11	Non-target catch	3.88	3.1	3.04	2.35	3.1	9.61	6.713	11.88	7.33	8.892

Table. 36 Percentage of catch details of non-target catch obtained from gillnets and hand

S.No.	Species	Mesh size (cm)				Over all	Hook size				Over all
		13.5	14	14.5	15		No.5	No.6	No.7	No.8	
1	Tunas	27	22.5	15.6	17.6	21.4	22.7	27.59	15	33.33	23.43
2	seers	29.9	40.4	41.5	48	38.8	31.8	31.03	28.33	35.71	31.43
3	Lethrinids	12.1	12.6	8.15	6.86	10.3	-◇-	-◇-	-◇-	-◇-	-◇-
4	Cat fishes	9.77	7.28	5.93	8.82	8.01	25	13.79	35	14.29	24
5	Other carangids	13.2	11.3	17.8	12.7	13.7	15.9	10.34	15	11.9	13.71
6	Sharks and Skates	8.05	5.96	11.1	5.88	7.83	4.55	17.24	6.667	4.762	7.429
	Over all	31	26.9	24	18.1		25.1	16.57	34.29	24	

compared to hooks. They were 3.1 % and 8.9 % from gillnets and hooks respectively (Table 35). In gillnets, non-targeted catch was slightly high (3.88%) in net with smaller mesh size 13.5 cm than the net with other bigger meshes 14 cm (3.1%), 14.5 cm (3.04%) and 15 cm (2.35%). But in the case of hooks, non-targeted catch did not correlate with the hook size. Hook No. 7 caught more by-catch (11.88%) followed by No.5 (9.61%), No.8 (7.33%) and No.6 (6.71%).

Species-wise non-target catch from various meshes sizes and hooks are presented in Table. 36. Of them, contribution by seer fish was high in both gillnets (38.8%) and hooks (31.43%), followed by tunas (21.4%) in gillnets and cat fishes (31.43%) from hooks. The other species represented in gillnets were other carangids (13.7%), lethrinids (10.3%), catfishes (8.01%) and shark and skates (7.83%). In hooks, no lethrinids were reported though representations of other miscellaneous catch were similar to that of gillnets. Percentage contribution in miscellaneous catch in the hooks was in the order of 23.43 % by tunas, 13.71 % by non-targeted carangids and 7.43 % by sharks and skates.

Discussion

5. Discussion

Carangids form an important fishery in the Kanyakumari coast of Tamil nadu, even though this group forms only minor fishery along the Indian coast in general. Carangids are mainly caught by large meshed drift gillnets and hook and lines.

5.1 Size Distribution

Size selectivity of the gear is one of the important parameter in influencing the size distribution of the catch (Rollefsen, 1953). Comparative fishing experiments are conducted to analyse the factors which influence the degree of vulnerability of different species and their size classes to different gears, in order to ensure optimal exploitation and rational utilization of fishery resources (Clark, 1960; Stergiou and Erzini, 2002). In the present study, clear-cut differences was observed in the size distribution of catch from different experimental gillnets and hand lines. It may be attributed to selective nature of the gear, or age structure of the population available in the sea. It is evident that variation of size distribution in the catch obtained from different gears is widely reported (Engas *et al.*, 1993; Nedreaas *et al.*, 1993; Huse *et al.*, 2000 and Stergiou and Erzini 2002).

Results of this study showed significant increase in the length distribution for all the species as mesh and hook size increased as observed by Reis and Pawson (1999). In the case of hand lines, the catch rate decreased with increase in hook size. It may be due to less vulnerability of smaller fish as reported by Erzini *et al.* (1999) in the fishery of Algarve coast of Portugal. Overlapping of length frequency distribution between the hooks has been often met in the hook and line fishing (Erzini *et al.*, 1996a; 1996b; 1997c; and 1999). However, smaller hook size was less efficient in capturing larger fish and efficient in capturing good quantity of smaller fish (Koike and Kanda, 1978; Kanda *et al.*, 1978; Erzini *et al.*, 1996a; and 1999). Less catch in the larger hooks may be due to inability of the smaller fish to take the bait due to smaller mouth. Larger fishes of *Caranx heberi* and *C. ignbilis* dominated the catch. Allen (1963) and Skud (1972) reported that large fishes are preferentially caught in larger hooks. It may also be related to the density of large individuals in the population.

Length frequency of different sized hooks was found overlapping in all four species caught. This is in accordance with the observation of Erzini *et al.*, 1999 for the species of breams and hake in Algarve coast of Portugal. Larger fishes of *Carangoides fulvoguttatus* and *Scomberoides commersonnianus* contributed to the catch of gillnets with large meshes. This is in accordance with the findings of Huse *et al.* (1999) who found that gillnets caught large fishes than long lines. They further assumed that encounter rate of fish with mesh and hook would be equal for larger fishes for both the gears due to swimming capacity and there was no rigid mechanical selection in hooks unlike gillnets. The researchers further opined that length distribution of catches in long lining would be more variable than gillnets.

Variation in pooled length distribution of catches from gillnets with different mesh sizes and hand lines with different hook sizes were found (P<0.01, K-S test) (Table 21). It is supported by the finding of Huse *et al.* (1999) who found difference in the catch size distribution between gillnets and long lines for the species of Greenland halibut. In the present study, size distribution and diversity was higher for gillnets than for hand lines. It is supported by the findings of Stergiou *et al.* (2002) who studied selectivity in Portugal water.

5.2 Capture Mode

Catching process of gillnets depends on the ways of retention which include gilling, wedging and entangling (Olsen and Tjemsland, 1963; Hamley, 1975 and Huse *et al.*, 1999). Capture mode alters the length distribution of the gillnet catches. The way of retention was found to alter the selectivity curve by skewing the selectivity curve to right or left side (Losanes *et al.*, 1992). Boje and Hovgard (1995) observed that there is little difference in the length distribution of Greenland halibut while caught by entangling. Distinct difference in length distribution in the present study may also be attributed to the mode of capture. Capture by entangling was maximum for species such as *Caranx ignobilis* and *C. Papuensis* (Tabel. 22).

Gilling and wedging were the prevalent ways of capture in gillnets (Fabi *et al.*, 2002). Compressibility and elasticity nature of fish and twine respectively were found responsible for most of fishes captured by wedging rather than gilling (Hansen, 1974; Nashimoto, 1979 and Yokata *et al.*, 2001). Tangling of smaller and larger fishes of particular species may be due to abundance of size population in the sea. In the present study, larger fishes like *Caranx ignobilis* and *C. papuensis* tangled especially at head region and other, small fishes were found tangled with fins after passing through the mesh though they were caught gilled initially as reported by Pet *et al.*, (1995). Tangling of *Scomberoides* spp. in the fin region in the present study may be attributed to smooth skin and excess mucus secretion of the skin, which enables the fish to penetrate deeply into the mesh.

Retention of fish in the net depends on its morphology. Elongated fish like, *Scomberoides* spp. were normally caught at maximum girth while deeper bodied fish like *Carangoides ferdau* are mostly gilled and fish with medium tapering body like *Carangoides fulvoguttatus* were caught between gill and maximum girth. These findings are supported by observation of Hamley (1975). Smaller fish, which had smaller girth, than mesh circumference were captured mainly from the net with mesh size of 13.5 and 14 cm with the twine R-tex 737. It may be due to the thin twine that facilitated entangling from the anterior end of the base of first dorsal fin to behind the ventral fin. Similar conclusions were also made by Yokata *et al.* (2001).

5.3 Morphometric Relationship

In the present study, relationships between total length and fork length and vice versa and gill girth vs. total length, maximum girth vs. total length, gill girth vs. fork length and maximum girth vs. fork length were worked out using simple linear regression model. High degree of correlations ($P<0.01$, t-test) was observed in these relations. In all the ten species positive correlation was observed. Regression models based on length distribution could be used for selectivity estimation (Trent *et al.*, 1983; Pet *et al.*, 1995). Difference in girth sizes among the same species having the same length was observed in this study in almost all the species, especially *Caranx heberi, C.*

ignobilis, C. sexfasciatus and *C. tille*. It may be due to development of gonadal tissues, sex differentiation or amount of food in the gut as suggested by the works of Kilma (1959), McCombie and Berst (1969), Hamley (1975) Van-densen, (1987), Ehrhardt and Die (1988) and Salvanes (1991). Hence, there is differential increment in the size of maximum girth compared to gill girth, which grows more slowly, and this is reflected in length and girth relation. This might be the reason for the variation in the increased captures of smaller fish especially species like *C. heberi* and *C. sexfasciatus* by gilling. Recording of auxiliary information like catching process and girth measurements are important in order to formulate and evaluate the selectivity models. Girth information is also important to interpret the catch process since the enmeshed catches depend on a fit between fish size and mesh perimeter (Hovgard *et al.*, 1995a).

5.4 Length at First Maturity

Maturity status of the species is important in determining the the length at first capture for conservation objectives. Minimum landing sizes of the species caught are to be established based on their length at first maturity (Santos et al., 1998). In good fisheries management, it is important to ensure that fish have spawned at least once before being harvested (Montano, 1995). The present study revealed that the smaller mesh size viz., 13.5 and 14 cm and hook size No.7 and 8 captured high proportion of undersized fishes i.e. below length at first (Lm50%) maturity. The impact was evident in the species *Caranx heberi, C. ignobilis, C. sexfasciatus* and *S. tala*. Present study suggests capturing all the target species except *Carangoides fulvoguttatus, Caranx ignobilis* and *C. papuensis* at the mean fork length of 55 cm size since almost all the fishes attain maturity in this size. Fifty percent of the total catch obtained from the nets with mesh size of 13.5 cm and 14 cm for *Carangoides fulvoguttatus, Caranx ignobilis* and *C. papuensis C. sexfasciatus* and *S. tala* were much lower than their length at first maturity and hence they are subjected to growth overfishing. Petrakis and Stergiou (1996) observed similar phenomenen in *Pagellus erythrinus* and *P. acarne*. In the case of hand lines, fifty percent of total catch of *Carangoides fulvoguttatus, Caranx heberi, C. ignobilis and S. commersonnianus* got from hooks No. 7 and 8 were smaller than size of at length at first maturity. Therefore, these hooks also lead to growth over fishing of above-mentioned species.

5.5 Compressibility of Fish and Elasticity Nature of Netting Twine

Twine flexibility and stretchability have been reported to be important factors affecting selectivity of gillnets (Clark, 1960; Hamley, 1975; Petrakis and Stergiou, 1996 and Yokata *et al.*, 2001). Information on body compressibility and twine elasticity at retention girth is important to derive realistic gillnet selectivity model (Santos *et al.*, 1995). It has been reported that it is difficult to estimate both the mesh stretching, which occurs while fish enter into the net and the extent of compression of fish body compressibility. Incorporation of above factors in gillnet selectivity is important in determining selectivity estimation (Fabi *et al.*, 2002)

In the present study, the calculated 'K' values, which represent compressibility-elasticity characteristics, differed due to variation in girths. The 'K' value was high for gill girth than for maximum girth. It may be attributed to the less compressible nature and hard bony structure at the operculum region compared to the body girth region. This is reported by the findings of Ehrhardt and Die (1988), Winter and Wheeler (1990) for Atlantic hring and Pet *et al.*, (1995) for cyprinids species.

Lower mean 'K' values for twine size R-tex 737 than R-tex 786 might due to higher elasticity of the twine as thinner twine generally had better elasticity compared to thicker twine. Similar observation has been made by Hansen (1974) and Nashimoto (1979). However, in the present study the thicker twine caught more of larger fishes compared to thinner twine. It is supported by the finding of Yokata *et al.* (2001) that thicker twine had greater fishing power for rainbow trout of Japanese water.

Difference in the mean values of 'K' factors at different body positions between species was due to body shape and structure of body muscle and bones. *Scomberoides* spp. and *Caranx sexfasciatus* had less compressible body structure than other species since they had comparatively hard body muscle. Compressibility of body and elasticity of the netting twine increased the catch rate. High swimming speeds of the fishes have contributed to improvement in catch rate as reported by Potter (1983). Stretching of mesh caused overlapping of catch and selectivity curves as reported by Baranov (1948) and Potter (1983).

5.6 Selectivity of Experimental Gears

Fishing gear, its performance and characteristics and the fishing area influence the size and species selection of fishing gear (Huse *et al.*, 2000). Various models and methods have been developed for representing selectivity of different gears and for estimating the parameters of appropriate selectivity models (Regier and Robson, 1966; Hamley and Regier, 1973 and Hamley, 1975).

5.6.1 Selectivity of Gillnets

The bell shaped normal distribution of selectivity curves has been well estabilished (Olsen, 1959, Hamley, 1975; Kirkwood and Walker, 1986; Millar, 1995; Holst and Paulsen, 1995 and Huse *et al.*, 2000). Gillnet selection curve has a descending limb since largest fish often have less probability of being caught (Sparre and Venema, 1989).

5.6.1.1 Validity of Different Models of Gillnets Selectivity

In the present study, four uni-modal and bi-modal curves were fitted for ten species namely, *Carangoides ferdau, Carangoides fulvoguttatus, Caranx heberi, C. ignobilis, C. papuensis, C. sexfasciatus, C. tille, Scomberoides commersonnianus, S. lysan and S. tala* caught from the four different mesh sizes viz., 13.5, 14, 14.5 and 15 cm. The results were validated using various statistics tools and residual plots for assessing the goodness of fit. Simple fitting of various functional models to different selectivity data for various species would be less meaningful purpose unless they are validated through various statistical means (Millar and Fryer, 1999).

Statistical tool for validating the models used was model deviance (D). Deviance obtained from different models varied greatly for each species fitted for study. However, in all the models, deviance obtained from log-normal and gamma models under the assumptions of equal fishing power and fishing power proportional to mesh size were not influenced.

Estimated deviance values for the uni-modal models like normal scale, normal location, log-normal and gamma for all the ten species were substantially greater than their respective degrees of freedom (P<0.01, χ^2 test). The general rule of the thumb is that the deviance should be less than degrees of freedom (Millar and Fryer, 1999; Holst *et al.*, 1994 and Poulsen, 2003). Among the four uni-modal models tested, log-normal was found as better fit based on model deviance, for most of the species viz., *Carangoides ferdau* (357.63), *Caranx heberi* (621.18), *C. papuensis* (525.56), *C. sexfasciatus* (344.73), *C. tille* (458.56) , *Scomberoides commersonnianus* (531.33), *S. lysan* (362.85) *and S. tala* (212.02) except *Carangoides fulvoguttatus* (653.51) under the assumption that fishing power is proportional to mesh size and fish and *Caranx ignobilis* (522.79) under the assumption of equal fishing power where Normal Scale was found as better-fit for both the species since they had smaller deviance compared with other models. Significant differences (P<0.05) were observed among the models and larger deviance of other models indicated lack of good fit.

Difference in the model deviance of the two models is approximately a χ^2 distribution when the model has exact fit for the degrees of freedom given by number of length classes presented in the data minus number of parameters of the model (Wileman *et al.*, 1996). Deviance of all the models including better-fit model was evaluated by referring it to a chi-square distribution since justification or rejection of model should never be based on the deviance alone (Holst *et al.*, 1994). Evaluation of all the deviances obtained from different uni-modals tested for the ten species. It revealed over-dispersion including better fit models since, the dispersion ratio (D/DF) was greater than one in all the cases. Over-dispersion in better-fit models could be interpreted as lack of fit. Lack of fit indicated poor choice of model or violation of the assumption underlying Poisson distribution. Lack of fit based on large model deviance and over dispersion need not imply the fitted selectivity curve is not a good model of the selectivity of the gear, unless the residual plot versus length shows no clear structure in which case the lack of fit might be due to over-dispersion (McCullagh and Nelder, 1989). Since, the over-dispersion is of more a rule than exception and this is particularly true for many biological phenomena where individuals fail to behave independently (Holst *et al.*, 1994), residual plots are used as a tool to assess the better-fit models.

A thorough source of information on the goodness of better-fit models can be obtained by inspecting the residuals such as type, size, and type of distribution (McCullagh and Nelder, 1989 and Holst *et al.*, 1994). It was noticed that almost all residual plots of better-fit models such as log-normal and normal scale for the ten species studied, indicated a lack of fit. Lack of fit was shown by the presence of less number of positive residuals, large in size, systematic arrangement of residual points instead of random presence and overlapping of residuals one over the other as reported by Millar and Holst (1997). In the present study none of residual plots indicated better fit. Therefore, refitting of curves was done using more appropriate models.

Residual plots of all ten species revealed some curious features of the selectivity data. Residuals were not distributed in a standard normal distribution N (0,1). In the present study, value of the most of the residuals was not within the range of '2'. It indicated that the model did not give good fit under Poisson distribution. (Holst *et al.,* 1994). In general, modal length and spread of the curves of better fit models of all the species increased proportional to mesh under both the assumptions. But in normal location where modal length is proportional to mesh size but the spread of the curve was fixed over the mesh size (Hamley, 1972; Rudstem *et al.*, 1984; Wulff, 1986; Jensen, 1986; Ehrhard and Die, 1988; Erzini and Saila, 1988; Santos *et al.*, 1995). However, in other models there was a lot of difference by either increasing or decreasing of modal length and spread between mesh sizes in all ten species. Normal location is a fixed spread model and has same spread in all the models fitted for all the species (Table 31). Modal lengths obtained through better-fit log-normal model were lower than the modal lengths obtained from other models.

On the contrary, modal length obtained from better-fit normal scale for two species viz., *Carangoides fulvoguttatus* and *Caranx ignobilis* were higher than modal length obtained from other uni-modal models including log-normal model. However, the spreads varied between models tested for all ten species. Stergiou and Erzini (2002) found that modal lengths worked out based on SELECT differed from the estimation of modal length by Petrakis and Stergiou (1995 and1996) using Holt model. Variation in the modal length between the models may be attributed to the model differences and availability of wider size range of species in the sea. It may be common in the case of overlapping of catch distribution since model follows principle of proportionality of Baranov (1914) (Stergiou and Erzini, 2002). Assessment of goodness of fit statistics and thorough inspection of residuals of better-fit models for ten species revealed over-dispersion and lack of fit. Over-dispersion may be due to shoaling nature of carangid species as reported by Millar and Holst (1997) and it may be common problem with larger fish (Erzini, Per. Comm.). Hence refitting of selectivity data for an improved model that decreases the model deviance and avoids systematic trends in the residuals was attempted.. Thus, uni-modal curves of normal scale for *Carangoides ferdau* and *Caranx ignobilis* and log-normal for remaining species were extended to bi-modal.

Model deviance of fitted bi-modal model was reduced drastically compared to the uni-modal models (Table 31). However, deviance of bi-modal model was higher than uni-modal for the species *Carangoides fulvoguttatus*, *Caranx tille* and *Scomberoides commersonnianus*. In *Carangoides fulvoguttatus*, better-fit uni-modal normal scale model had smallest deviance and bi-modal function did not converge. It may be due to single mode of capture and retention of the fish either by wedging or gilling. Similarly, for the species, *Caranx tille* and *Scomberoides commersonnianus*, deviance value was higher than better-fit uni-modal log-normal model and equaled to the normal scale model. Further, bi-modal parameters could not be estimated properly for both the species and hence abnormal parameter values existed (Table 30). Selectivity curves also did not converge properly in the case of *Caranx tille* though the curve fitted properly for *Scomberoides commersonnianus*. It may be due to more number of parameters involved in the bi-modal model (Erzini, Per. Comm.) or lack of required quantity of data or uni-modal catchability process of the species. Hence, it could be concluded that uni-modal normal scale would be best fit for *Carangoides fulvoguttatus* and log-normal for other two species viz., *Caranx tille* and *Scomberoides commersonnianus*.

Deviance of the bi-modal models was lesser than uni-modal log-normal for remaining species under the assumption of equal fishing power though small deviance was obtained for the species *Carangoides ferdau* was for the assumption of fishing power proportional to mesh size. Hence, bi-modal model was considered as best fit for these seven species. Bi-modal distribution may be due to mixture of different year class of recruited population in the environment (Millar and Holst, 1997). Difference in the fitting of model may be due to influence of enmeshing of fish at different location of body and incorporation of this parameter in the model may lead to fit of realistic model for the target species (Trents and Pristas, 1977; Marais, 1985; Hovgard *et al.*, 1999). Best fitting of bi-modal model for many species may be due to involvement of more parameters (4 to 6) in the estimation of model unlike the uni-modal where only two parameters are involved and more parameter models describe the different catch process (Hovgard *et al.*, 1999). Existence of bi-modal may be combination of two-selection mechanism such as enmeshing and entangling which includes snagging also (Hamley, 1975).

Deviances of bi-modal fit were evaluated as was done in the case of uni-modals. The dispersion parameters were also estimated. They also revealed over-dispersion though relatively lower than uni-modal models. The residual plots of the bi-modal models of all seven species were inspected for further precision to determine the best fit. There was corresponding improvement in the residuals and hence bi-modal fit is by far the superior model. Hence, it was concluded that bi-modal model improved the fit of the selectivity data for the seven species studied for bi-modal analysis as reported by Fujimori and Tokai (2001). Modal lengths obtained from these models for all the species increased proportionately with mesh size under both the assumptions of equal fishing power and fishing power proportional to mesh size. Modal lengths obtained from the best-fit bi-modal model for each species were higher than the other uni-modal except the normal scale model. In the present study, uni-modal curves yielded wider selection range than bi-modals for almost all the species around the modal length and narrow selection range in the bi-modal was due to constant random entangling which same time leads to better fit (Hovgard *et al.*, 1999). Hence, it could be concluded that bi-normal model was the best fit for other seven species namely, *Carangoides ferdau, Caranx heberi, C. ignobilis, C. papuensis, C. sexfasciatus, Scomberoides. lysan and S. tala.*

5.6.1.2 Fishing Power

In the present study each selection curve for the all ten species were fitted twice first under two assumptions viz., i) Fishing power is equal among mesh sizes and fishing power is proportional to mesh size. Variation in fishing power between experimental nets influences the selectivity (Hamley and Regier, 1973 and Borgstrom, 1989). The SELECT model used in the study included both the assumptions. Relationship between fishing power and mesh size was again supported by Fujimori and Tokai (2001) that relative fishing intensity was a function of mesh size since there was same number of meshes in each net and the lengths of the net were proportional to mesh size.

Variation in fishing power generally confounds selectivity models. It has been proved in the present study that it became difficult to differentiate the effect of fishing power between the log-normal or gamma selectivity model since estimates of deviance values from these models were same in both the assumption of constant fishing power and fishing power proportional to mesh size. However, the deviance obtained from normal scale and normal location was influenced by fishing power. It may be due to confounding of parameters in the model (Millar and Holst, 1997). In this study, fishing power influenced the models to determine the best fit of uni-modal models for various species like *Carangoides fulvoguttatus* in which deviance value was 653.6 for equal fishing power and 653.51 for fishing power proportion to mesh size under the normal scale model and *Caranx ignobilis* with deviance value of 522.79 for equal fishing power and 522.81 for fishing power proportion to mesh size under the normal scale. However, best fit of model has been selected based on model deviance irrespective of the assumption related to fishing power.

After assessment of models, refitting of models was done in order to improve the fit. In this, bi-modal, normal scale and log-normal were found suitable for various species. Of these models, normal scale and bi-modals were influenced by fishing power while log-normal was not influenced. In the case of bi-modal, deviance value varied between both the assumption of equal fishing power and fishing power proportional to mesh size. Influence of fishing power determined the best-fit model based on model deviance for many species. Deviance variation between equal fishing power and fishing power proportional to mesh size for bi-modal model for various species were, *Carangoides ferdau* (356.02, 366.9*), Caranx heberi* (546.64, 547.11), *Caranx ignobilis* (366.1, 366.31) *C. papuensis* (461.41, 461.6). *C. sexfasciatus* (335.02, 335.06), *Scomberoides lysan* (223.67, 223.69) *and S. tala* (207.07, 207.11). Fujimori and Tokai (2001) reported that estimation of relative fishing intensity improves the fit of the selectivity data. Residual plot showed the effect of fishing power for different mesh sizes and between the assumptions. Fishing power of different mesh sizes are important since catch rates vary between various adjacent mesh size to a greater extend (Hovgarad *et al.*, 1999). Carlson and Cortes (2003) reported that individual catches were independent of mesh sizes and fish were randomly distributed throughout meshes. However, Kirkwood and Walker (1986) and McLoughlin and Stevens (1994) expressed that assessing the equal fishing power directly at maximum selectivity was difficult.

5.6.1.3 Shapes of Selectivity Curve

Selectivity curve will have different shapes for different species and gears. Different shapes of selectivity curve are uni-modal symmetrical or skewed, bi-modal or multi-modal. Shapes of the curve rely on various features of gear and fish (Hamley and Regier, 1973; Hamley, 1975; Salvanes, 1991; Losanes *et al.*, 1992a; Santosh *et al.*, 1995). Various factors which influence the shape of the curves are mesh size, gear fabrication and behaviour of fish (Hamley, 1975; Von Brandt, 1975).

In the present study, selectivity curves of uni-modal and bi-modal for ten species were fitted. They varied among themselves in shape including spread and height though most of uni-modal graphs appeared similar for some species. Uni-modal curves of normal scale and normal location, gamma and log-normal in all the species were similar as reported by Hovgard *et al.* (1999). However, log-normal and gamma model curves had slight right skew since they are basically uni-modal skewed curve with a longer tail on the right side than the normal (Millar and Fryer, 1999). In this study, bi-normal selectivity curve was found best suited for various species like, *Carangoides ferdau* under the assumption of fishing power proportional to mesh size and for *Caranx papuensis* and *Scomberioides lysan* under equal fishing power. However, uni-modal log-normal curve also showed best fit for all these species and they could not be distinguished from each other though the deviance value of these models varied greatly.

Similarly, best-fit selectivity curve of *Caranx ignobilis* was bi-modal under the assumption of equal fishing power. This curve was similar in appearance with better-fit uni-modal normal scale model under equal fishing power for the same data. Identical nature of selectivity curve for both the uni and bi-modal models may be attributed to well fitting of data in the length interval where there were significant catches (Raltson, 1990; Millar, 1995; Hovgard *et al.*, 1999). Millar (1995) reported that two different models might give precisely the same fit. Hence a particular curve never could be established as right one. In some of species, the selectivity curves were found with slight skew ness for e.g., *Caranx heberi* in which best fit model for the selectivity data was bi-modal model with right skew obtained under the assumption of equal fishing power among both uni and bi-modal models. However, log-normal was found as better fit among the uni-modal curves for the above species.

Selectivity curves differed in shape unlike the curves obtained for *Carangoides ferdau, Caranx papuensis* and *Scomberoides lysan* where there was a similarity between uni and bi-modal curves. It may be due to entanglement of larger fishes in the gillnets due to snagging or tangling of body projections like fins, maxilla and spines etc. in netting. This process might make the selectivity curve to be skewed or multi-modal (Hamley, 1975). In each case bi-modal curve may be more appropriate than normal curve. Other skewed selectivity curves obtained in this study were for the species of *Caranx sexfasciatus*, and *Scomberoides tala*. In these species best fit was identified as bi-modal under equal fishing power among both uni and bi-modal models tested. In the case of uni-modal, better-fit model found was log-normal for these species. Bi-modal curve varied slightly with uni-modal curve with right or positve skew. Skew ness may be attributed to two different levels of other methods of capture like gilling and entangling (Hovgard *et al.*, 1999).

Gulland and Herding (1961) reported that normally larger fishes are caught firmly in any single mesh and later they are entangled in several meshes. It leads to longer upper tail of selectivity curve. Various factors involve in the skewness and bi-modal nature of the selectivity curve. However, bi-modal distribution was mainly due to high entangling effect as reported for various species viz., wall eye (Hamley and Regier, 1973), pike perch (Van Densen, 1987) and *Glossogobius giuris* (Pet *et al.*, 1998). Millar and Holst (1997) reported that length distribution of bi-modal or multi-modal type was due to recruitment of mixture of different year classes into population. It was supported by Millar and Fryer (1999) that bi-modal nature of curve might be due to entanglement of fish or occurrence of multi-modal distribution of fishes.

Ehrhardt and Die (1988) reported the same that occurrence of multi-modal distribution in the pooled length distribution of Spanish mackerel indicated that selectivity was not only a direct function of length but also of girth. In the present study, the girth varied according to the length in almost all species. The girth also varied for the same length of species which might have caused bi-modal selection in the gillnet study as reported by Salvanes (1991), Hovgard (1996) and Fujimori and Tokai (2001). Selectivity curves of most of the species except *Carangoides fulvoguttatus*, *Caranx tille* and *Scomberoides commersonnianus*, was bi-modal. Fujimori and Tokai (2001) stated that almost all the selectivity curves of gillnet in recent studies are represented by asymmetrical curve. In this study, bi-modal fits gave a reduction in the model deviance compared to uni-modal curves. Hence, bi-modal is considered as superior over uni-modal due to significant improvement in the plot of deviance residuals (Millar and Fryer, 1999). Hovgard *et al.*, (1999) also opined that two parameter models (uni-modal) fit the data much worse than bi-modal or multi-modal models.

Indirect method of gillnet selectivity assumes equal shape and height of the curves while comparing two or more meshes (Hamley, 1975). In the present study, almost all best fit uni-modal and bi-modal curves showed almost equal height approximately "1" though little variations (0.94 to 1.0) were observed between curves of each mesh size of individual model. However, maximum height of selectivity curve of all gear is determined by one of the consequences of geometric similarity of the gear. Estimated selection depended on model selection than observed data (Millar, 1995; Hovgard *et al.*, 1999). The model should provide adequate degree of explainable variation and ease of interpretation. Plots of selection curves give convenient presentation of overall approximation, which leads to quick and qualitative presentation of the fit.

5.6.2 Selectivity of Hooks

Selectivity pattern of hook is still under debate and there is confusion whether it follows selectivity pattern of gillnets or trawls. However, various models have been tried by researchers to model hook selectivity. Holt (1963) and Pope *et al.* (1975) described that hook selection follows uni-modal right skewed and may be modeled as log-normal density function. Similarly, many researchers tried to fit the hook selection to logistic function (Chatwin, 1958; McCracken, 1963; Saetersdal, 1963; Raltson, 1982; Halliday and Kenchington, 1993; Huse *et al.*, 1999; Stergiou and Erzini, 2002). Many researchers believed that bell shaped normal curves can be employed for size selectivity as used for gillnets selection (Koike *et al.*, 1968; Myhre, 1969; Pope *et al.*, 1975; Kanda *et al.*, 1978; Koike and Kanda, 1978; Ralston, 1990; Hovgard and Riget, 1992; Millar and Walsh, 1992; Nedreas *et al.*, 1996; Huse *et al.*, 2000). Asymmetrical and flattened curves were brought by Leclerc and

Power (1980) and Zaragoza *et al.* (1989) for hook selection. Erzini *et al.* (1997) used skew normal selectivity model with linear and polynomial function for hook selection.

Wulff (1986) developed a new model to estimate hook selectivity by maximum likelihood function. Millar (1995) tried to fit the hook selectivity data for various models like normal, log-normal, gamma and logistic and found that normal and gamma selection curve gave good fit. Millar and Holst (1997) opined that log-linear model could be applied for hook selection data. Otway and Craig (1993) found that neither logistic nor normal model could be employed directly to hook selectivity.

In the present study, SELECT model implemented in GILLNET software was used for fitting the hook selectivity data for the carangid species of *Carangoides fulvoguttatus, Caranx heberi, C. ignobilis* and *Scomberoides commersonnianus*. They were caught from the drift hand line with round bent hook of size of No.5, 6, 7 and 8 (Mustad, Norway). The collected data were fitted to four uni-modal such as normal location, normal scale, log-normal and gamma models and bi-modal forms.

5.6.2.1 Validity of Different Models

All the fitted uni-modal models such as normal location, normal scale, log-normal and gamma models were validated by various statistical tools like, model deviance, dispersion parameter and residual plots. Estimated deviance between the four models for all the four carangid species varied greatly and were higher than degrees of freedom ($P<0.01$, χ^2 test). It was against the rule of thumb that deviance and degrees of freedom should be within the same magnitude (Holst *et al.*, 1994; Millar and Fryer, 1999 and Poulsen, 2003). Among the four models tested, normal scale was found as better fit for the species *Carangoides fulvoguttatus* (100.17) under the assumption of equal fishing power and *Caranx ignobilis* (75.99) under the assumption of fishing power proportional to hook size while normal location was found better-fit for *Caranx heberi* (134.7) and *Scomberioides commersonnianus* (130.27) under the assumption of equal fishing power.

Better-fit model was chosen based on existence of smallest deviance among the uni-models tested. There was no significant difference (P>0.05) between models for all the species. Millar (1995) found that log-normal model provided better fit for long line selectivity data.

All the uni-modal models were subjected for further scrutiny to get best fit since justification or rejection of model should never be based on deviance alone (Holst *et al.*, 1994). Evaluation of all four deviances including better-fit model reveáled over-dispersion since the dispersion ratio was higher than one. Over-dispersion and larger deviance than degrees of freedom could be interpreted as lack of fit or violation of poisson distribution. Over-dispersion may be attributed to larger fishes present in the catch and shoaling behaviour of fishes. It is also true that all carangids are shoal forming fishes. Owing to larger deviance and high dispersion ratio, the better-fit models still lack the desired precision. So, it is necessary to inspect the residual plots to find out the best fit. Residual plots of all uni-modal models revealed poor fit by the presence of less number of positive residuals, large size of residuals and systematic arrangement (Millar and Host, 1997). Further, value of residual was more than two, which also indicated poor fit.

Modal length and spread of the better fit models of normal scale and normal location of all the species increased proportional to hook size under both the assumptions of equal fishing power and fishing power proportional to hook size. Similar findings have been reported by Hamley (1972), Wulff (1986), and Erzini and Saila (1988). However, Bertrand (1989) and Ralston (1990) reported that size selectivity in hand line was not affected by changing hook size. The spread of the curve was constant in the case of normal location (Table 33) since it was fixed spread model. Modal length was higher in better fit normal scale model than other models including other better-fit normal location model in all the species studied. However, magnitude of spread varied between models in all four species. Variation in the modal length between the models may be due to the overlapping of catch distribution because of wider ranges and density in the sea (Engas *et al.*, 1996). It may also be reasoned that the models follow Baranov's (1914) principle of proportionality (Stergiou and Erzini, 2002).

Assessment of goodness of fit statistics and thorough inspection of deviance and residuals plots of four species revealed over-dispersion and indicated lack of fit. Hence, refitting of selectivity data for an improved model was required. Thus, uni-modal curves of normal scale for *C. fulvoguttatus* and *C. ignobilis* and normal location model for *C. heberi* and *S. commersonnianus* were extended to bi-modal fit.

Deviance obtained from bi-normal fit was substantially reduced from the value of uni-normal deviance for all the four species except for the species *Caranx heberi,* where deviance was slightly higher than uni-modal normal scale model with the difference of 0.04 (Table. 32). It may be due to over-parameterization or lack of quantity of data (Erzini, Per. Comm.). Hence. uni-modal normal location under the assumption of equal fishing power was considered as best fit for *C. heberi*. As described earlier, deviance value of bi-modal models was smaller than better-fit normal scale. The bi-modal model was found as best fit for the rest of the three species *C. fulvoguttatus*, and *S. commersonnianus* under equal fishing power and *C. ignobilis* under fishing power proportional to hook size. Best fit of bi-modal model may be due to involvement of more parameters (say, 5) in the estimation of the model (Hovgard *et al.*, 1999). Dispersion parameter for the bi-modal model was worked out to determine the degree of fitness of best model. They also revealed over-dispersion and showed lack of fit. But there was significant improvement in the residuals plot and reduction in the deviance and hence. bi-modal fit is considered as superior over uni-modal (Millar and Fryer, 1999).

Modal length and spread obtained from this model for all the four species increased proportionately with hook size under both the assumptions of equal fishing power and fishing power proportional to hook size. Modal length of bi-modal were lower than modal length from the better-fit normal scale model for the species *C. fulvoguttatus* under both the assumptions, *C. ignobilis* under fishing power proportional to hook size and *S. commersonnianus* under equal fishing power. Modal length and spread of bi-modal models were equal with normal scale for *C. ignobilis* under equal fishing power and *S. commersonnianus* under fishing power proportional to hook size. Difference in the modal length between models for every species may be due to model difference (Stergiou and Erzini, 2002).

5.6.2.2 Fishing Power

In the present study, it was observed that fishing power was proportional to hook size as stated by Hamley and Regier (1973). It could be viewed from the drastic change in the deviance between the assumptions of equal fishing power and fishing power proportional to hook size for different models. Deviance obtained from normal location and normal scale were influenced by fishing power while deviance value was same for other two models since fishing power did not influence the models. It may due to confounding of fishing power with selectivity models (Millar and Holst, 1997). Effect of fishing power could be easily distinguished in the better fit model based on difference in the model deviance. It could be easily explained obviously in this study that normal scale was found better fit for the species *C. fulvogutattus* and *S. lysan* under equal fishing power, *C. ignobilis* under fishing power proportional to hook size and normal location model was better fit for *C. heberi* under equal fishing power.

After refitting of better-fit models, normal location and bi-normal models were found best fit. Of them, normal location was already explained. Bi-modal fit for other three species were influenced by fishing power by yielding different deviance for the same model under the assumption of equal fishing power and fishing power proportional to hook size. Estimation of fishing power is important since it improves the fit of selectivity data (Fujimori and Tokai, 2001).

Residual plots of the best-fit models explained the difference in the fishing power between hooks and the assumptions. Fishing power of hook No. 5 was high and followed by 8 and 6 for all the species except for the species *S. commersonnianus* where the order of performance of the hooks was 5, 8 and 7.

5.6.2.3. Shapes of Selectivity Curves

Hook selection curves are suspected of being very broad and uni-modal curves (Myhre, 1969; Pope *et al.*, 1975; Ralston, 1990 and Nedreaas *et al.*, 1996), broad flattened curves (Koike *et al.*, 1968), asymmetrical, flattened curve (Zaragoza *et al.*, 1989) and right skewed uni-modal curves (Erzini *et al.*, 1996a and 1998).

In the present study, selectivity curves for uni-modal and bi-modal for four species were fitted. Uni-modals such as normal scale, normal location, log-normal and gamma fitted for all the species. Uni-modal curves such as normal scale and normal location appeared as symmetrical curve for all the species and other two log-normal and gamma were right skewed. Normal scale curve was chosen better fit among uni-modal models. However, after refitting the selectivity data into bi-modal, the it was found as best fit for the species of *C. fulvoguttatus* and *C. ignobilis* under the assumption of fishing power proportional to hook size and *S. commersonnianus* under the assumption of equal fishing power. Shape of curve of better-fit uni-modal and best fit were entirely different for all the species unlike gillnet selectivity curves where there was similarity for most species.

In the case of *C. fulvoguttatus*, uni-modal normal scale curve was symmetrical in shape while bi-modal curve appeared with two prominent modes. Of which, one mode was short and another mode was large in height. In the species of *C. heberi*, best-fit curve was normal scale and the bi-modal curve exceeded the retention probability of 1. It may be due to lack of fit of selectivity data though deviance was almost equal to normal scale. Better-fit curve for the species *C. ignobilis* was normal scale under fishing power proportion to hook size, which appeared symmetrical in nature with slight left skew. It may be attributed to the capture of smaller or under sized fishes. But the best-fit curve was bi-modal under fishing power proportional to hook size. This curve had one with very small and other with very large mode. In the species, *S. commersonnianus*, the better-fit model was normal location under equal fishing power. It appeared as exactly symmetrical curve without skew since it followed constant spread. It indicates good fit of selectivity data.

However, based on deviance value bi-modal curves was selected as best fit and it had two modes with almost equal height. Maximum height of selectivity curves may depend on gear variant though this is often confounded used to have same maximum height since the true relative height of the curves is often confounded with relative fishing intensity parameter (P_j) (Millar and Fryer, 1999). Hence, it is enough to model relative selectivity curves with unit height and allow Pj to quantify the relative height of selective curve.

Bi-modal nature of curve may be due to occurrence of mixture of different year class recruits or multi-modal density distribution of fishes in the sea (Millar and Holst, 1997; Millar and Fryer, 1999). Another opinion about this curve is that it may be adequately refitted into uni-modal form with other techniques as reported by Halliday (2002) using three-parameter logistic models. Logistic fit may give satisfactory fit for the hook data than using 4 or 5 parameters model. Hence, it is concluded that the logistic model may also be tried to fit the hook selectivity data though it was not tried in this study.

5.7 Relative Selectivity

Comparison of the selective effects of different gears is complex since the mean size of fish caught from the gears varies due to various factors either biological or environmental factors. Biological factors include availability, abundance, age, sex, and size, etc., and the environmental factors include fishing ground, depth, etc., (Huse *et al*., 1999).

Selectivity curve of gillnets and hand lines of the present study are assumed as bell shaped either uni or multi-modal type (Fig. 61). True model for hook is difficult to establish (Huse *et al.*, 1999). However, different models may give good fit but may be influenced based on fish behaviour and catching process (Millar, 1995). Present study indicated that gillnets could be better selective than hooks since gillnets showed clear size selection with larger mesh sizes catching larger fishes. It is supported by the findings of Stergiou and Erzini (2002) for the species of *Pagellus* spp. and *Diplodus* spp. from Aegean Sea of Portugal.

5.8 Optimization of Mesh and Hook Size

Selectivity coefficient 'k' was less than 0.15 for all species caught both for gillnets and hooks. It indicated that all fishes have slim or lean body shape as inferred from Andreev (1962) who classified the fish based on 'k'. Estimated optimum mesh size 15.3 cm and hook No. 4 will catch only larger fishes well above the length at first maturity (Lm50). It will give adequate opportunity for the fishes to spawn atleast once and grow to better size at first capture. Estimated length at first capture sufficiently higher than Length at first maturity for all the species constituting the catch from both the gears. Pusty and Borowski (1997) reported that larger mesh size had favourable selective properties by reducing selective range of fish to be caputredd. Otway and Craig (1993) reported that a small increase in hook size yielded good selective capture by reducing undersized fishes of snappers. Mean size of fish captures increases with increasing mesh size (Marais, 1985; Petrakis and Stergiou, 1996 and Santos *et al.*, 1998). The study has shown that *C. ignobilis* contributing substantially to the carangid fishery off Kanyakumari coast. It is subjected to growth over fishing as the fish is exploited even before the fish attains the length at first maturity (Table 34) both by large mesh gillnets and drift hand line operation and it may ultimately lead to collapse of fish stock.

Based on the study, it can be recommended that the mesh size 15.3 cm will improve the length at first capture of the species *C. ignobilis* to 66.9 cm from the present 65.4 cm. This will give the species opportunity to attain maturity and breed atleast once before being caught. All the other species contributing to the carangid fishery will grow to better size and will have multiple breeding opportunities before fishing mortality takes place. Similarly, in the case of drift hand lining, currently used hook sizes are leading to growth over fishing of *C. ignobilis*. The length at first capture can be improved beyond length at first maturity for the species by using larger hook size (Mustad round bent sea hook quality 2315 or equivalent). The length at first capture of all the species will be improved by giving the opportunity for multiple breeding. Adoption of recommended mesh size and hook size will lead to thus better profit due to better size group landed and ensures long time sustainability of carangid resources in the fishing ground of Kanyakumari district.

5.9 Catch Rate and Catch Composition

The difference in the catch between the nets with different mesh sizes and hand lines with different hook sizes was statistically significant. This may be due to equal accessibility of fish to all the meshes and hooks as reported by Rogers and Jantg (1993) for sockeye salmon.

Calculated CPUE among mesh sizes and hook sizes did not vary significantly in the present study. Schweigert *et al.* (1981) reported that CPUE was greater for large mesh for roe herring.

Non-targeted catch was high in hooks indicated clearly the inability of fishes to escape after biting the hooks unlike gillnets where probability of escapement was high. Nonetheless non-targeted catch was high in smaller mesh such as 13.5 cm than larger big meshes. It may be due to entanglement effect of the gears. Similarly hook No. 7 caught more non-targeted catch. Dominance of non-targeted species may be due to their wide abundance in the fishing ground as opined by Lokkeborg and Bjordal (1995).

Summary

Summary

Gillnet and hand line fishery of India is a small-scale traditional fishing method, involves less investment and use of traditional technology. Large meshed meshed gillnets i.e., net with mesh size greater than 45 mm mesh size, are used to capture large pelagic resources off Tamil nadu coast of India. Drift gillnets and drift hand lines are commonly used for capturing carangids in Kanyakumari coast of Tamil nadu. Present study concentrated on estimating selectivity characteristics of large meshed drift gillnets and drift hand lines.

The selectivity study was carried out for a period of two years from September 2002 to April 2004 and one year from June 2003 to May 2004 for drift gillnets and drift hand lines, respectively. The study was conducted in different fishing grounds, having latitude and longitude of 08°.01.145'N; 77°.49.137'E to 08°.00.821'N; 77°.45.192'E for gillnets and area around the position of 08°.02.425'N; 77°.34.590'E for hand lines in Kanyakumari coast. Drift gillnets were operated from FRP boat with OAL of 8.4 m and hand lines were operated from four logged catamarans with OAL of 8.13 m. 80 fishing operations were conducted for both the gears during the period. Gillnets constituted of 36 nets with four kind of mesh sizes viz., 13.5, 14, 14.5 and 15 cm. Hand lines comprised of four lines of different length with three hooks of different sizes in each line and sufficient weight was added to position the line in different depths. Hooks used in this study were No.5, 6, 7 and 8 (MUSTAD round bent sea hook 2315). In this study, four set of hand lines were operated and in the case of gillnet one fleet of gillnet with different mesh sizes was operated. After every fishing operation, fishes were identified to species level and data like total length, fork length, gill girth, gilled girth, maximum girth, and individual weights were recorded for further analysis.

Research findings of the present study are summarized as follows:

1) Check list of carangid species available in the Kanyakumari coast was prepared and based on the data ten species were found available in good quantity throughout the year and they were identified as target species for the selectivity study.

2) A total of 17,568 carangids were caught from drift gillnets, and 1,793 from drift hand lines.

3) Catch of gillnets was constituted by ten species of carangids belonging to three genus such as *Carangoides ferdau* (5.16%), *Carangoides fulvoguttatus* (12.7%), *Caranx heberi* (19.7%), *C. ignobilis* (14.7%), *C. papuensis* (8.38%), *C. sexfasciatus* (6.86%), *C. tille* (8.94%), *Scomberoides commersonnianus* (7.79%), *S. lysan* (9.52%) and *S.tala* (6.34 %).

4) Of these ten species, four species namely *Carangoides fulvoguttatus* (29.22%), *Caranx heberi* (31.34%), *C. ignobilis* (18.4%), *Scomberoides commersonnianus* (21.03) constituted in the catch of hand line.

5) There was significant ($P<0.05$) difference in the size distribution of species caught from gillnets with different mesh sizes and hand lines with different hook sizes except few species like *C. ferdau, C. sexfasciatus* and *S. tala* caught from gillnets and *S. commersonnianus* from both gillnets and hocks. The overlapping of catch in length frequency is observed from selectivity graphs.

6) There was no significant difference ($P>0.05$) between gillnets of different mesh sizes and hand lines of different hook sizes in terms of number of fish caught except for the species *C. fulvoguttatus* ($P<0.05$).

7) Modal length of fish caught increased with increase in mesh size and hook size.

8) Length frequency data of catch obtained from gillnets showed both uni-modal and bi-modal distribution. However, but in the case of hand lines length frequency data showed bi-modal distribution only for most of the species.

9) Mean, minimum and maximum value of length and girth were calculated and maximum girth increased with gill girth.

10) Maximum girth varied from species to species and gill girth and maximum girth increased with mesh size except *S. commersonnianus* and *S. lysan*.

11) Significant difference ($P<0.01$) could be observed between pooled catch size distribution of gillnets and hand lines of four species studied.

12) In gillnets, multiple process of capturing such as gilling, wedging and entangling were noticed in the species studied.

13) Wedging was the common process of capture in the gillnets for many species such as, *C. fulvoguttatus, S. lysan* and *S. tala,* gilling was in the species of *Carangoides ferdau, C. heberi* and *C. tille,* entangling by snagging by head in the larger species of *C. ignobilis,* and *C. papuensis* and entangling by fins in small quantity were *C. sexfasciatus. C. heberi* and *S. lysan.*

14) Total length-Fork length relationship was worked out and significant positive correlation ($r= 0.9$) was observed in all the species.

15) Girth-length relationships were estimated using simple linear regression model for all species and showed significant positive correlation ($r=>0.9$).

16) Length at which fifty percent of the individuals' attained maturity (Length at first maturity Lm50) was worked out for all the species and it was highest for *C. ignobilis* (66.9 cm).

17) More than 50 % of undersized fishes were observed in all the species except *C. tille* (25.9 %) from the net with mesh size of 13.5 cm. In the case of net with mesh size of 14 cm, undersized fishes were *C. ferdau* (27 %), C. *heberi* (56.9 %) *S. tala* (58 %), and *C. ignobilis* (84.9 %) and *C. sexfasciatus* (88.5 %).

18) Net with mesh size of 14.5 cm and 15 cm caught comparatively less number of undersized fishes except for *C. ignobilis* and no undersized fish was observed in *C. ferdau* and *C. tille.*

19) In the case of hand line fishing, undersized fishes were high for all the species viz., *C. ignobilis* (57.6 %) *C. fulvoguttatus* (53.4 %), C. *heberi* (50.2 %) and S. *commersonnianus* (28.11 %). Catch of undersized fishes were comparatively less in the hooks of No.5 and 6.

20) Based on size of fish, which had highest length at first maturity, length at first capture and selectivity coefficient were worked out for all species. Optimum mesh and hook size was estimated for efficient harvesting of carangids fishes of Kanyakumari coast, Tamil nadu. They are 15.3 cm mesh size for for drift gillnets and hook No. 4 for drift hand lines.

21) Compressibility and elasticity factor (K) was worked out at different mesh sizes and twine sizes R-tex 737 and R-tex 786

22) K value was highest at gill girth and lowest at maximum girth and K value varied depended on body position of fish.

23) Estimated K value of twine R-tex 737 was lower than R-tex 786, which indicated good elasticity of Rtex 737 twine. K value was high for the species of *Scomberoides* spp. and *C. sexfasciatus*.

24) Models such as uni-modal which includes normal scale, normal location, log-normal and gamma model were fitted to the selectivity data obtained from gillnets and hand lines using GILLNET software which had extended log-linear model called SELECT.

25) Based on model deviance or log-likelihood ratio, the better-fit model was worked out. In the gillnet data, log-normal was found to be better-fit model for almost all the species except *C. fulvoguttatus* and *C. ignobilis*. For these two species, normal scale was found as better-fit model. In the case of hand lines, normal location was better-fit model for *C. heberi, S. commersonnianus* and normal scale was better fit for *C. fulvoguttataus* and *C. ignobilis*.

26) Residual plots were evaluated for finding out the quality of fit. But none of the uni-modal models supported the best fit. Hence, better-fit uni-modal model was extended into bi-modal.

27) Residual plots revealed the fishing power of the mesh size and hook size. Effect of fishing power of each mesh size varied from species to species.

28) After refitting of models in the case of gillnets and hand lines, bi-modal was found as best fit for most of the species except *C. fulvoguttatus*, *C. tille* and *S. commersonnianus* from gillnets and *C. heberi* from hand lines

and already derived better fit uni-modal model such as log-normal and normal scale emphasized as best fit model for the species of *C. tille*, *S. commersonnianus* and *C. heberi* and *C. fulvoguttatus* respectively.

29) Residual plots of bi-modal fits were inspected thoroughly for finding effective fitting of model and fishing power of mesh and hook sizes.

30) Comparison of proportion of catch in each length group in gillnets and hand lines revealed the mean fork length of species caught from gillnets varied from that of hand lines.

31) Catch Per Unit Effort (CPUE) of drift gillnets and hand lines did not vary significantly. It indicated that both the gears exerted equal effort on the fish population.

32) Catch other than targeted species were recorded from both gillnets (3.1%) and hand lines (8.9%). They included various species such as tuna, seer fishes, sharks, skates other carangids, lethrinids and catfishes.

33) Non-targeted species was less in the mesh size of 14.5 cm (3.04%), and 15 cm (2.35%) compared to other two meshes of 13.5 cm (3.88%) and 14 cm (3.1%). Similarly, hook No. 6 (6.71%), and 8 (7.33%), had lesser non-targeted catch than hook No. 5 (11.88%) and No.7 (9 .61%).

34) The present study emphasises the following aspects towards rational utilization of the carangid resources in the Kanyakumari coast of Tamil nadu.

- Based on length at first maturity and length at first capture, estimated mesh size of 15.3 cm and hook size of No.4 are optimum mesh and hook size for the commercial exploitation of carangid fishery along the Kanyakumari coast in a long term sustainable basis with better economic return.

- Minimum landing size (MLS) may be restricted to at least 67 cm fork length instead of present size landed i.e., 30 to 35 cm by using large mesh size and hook size as recommended

- Best suitable model for fitting the selectivity data of gillnets are log-normal and bi-modal models. Log-normal model indicates capturing of fish mainly by gilling or wedging while bi-modal indicates capturing mainly by entangling.

- In the case of drift hand lines best-fit model was bi-modal and normal scale. However, it is opined that these bi-modals could be adequately reduced to uni-modals by other statistical means like negative binomial models or other processes.

- Over-dispersion was common in all the uni-modal and bi-modal models. It may be due to shoal forming nature of larger size fishes of carangids. It is believed that it is a common problem encountered with data of larger sizes of fishes in the selectivity models.

- Wedging and snagging were the common capture process in gillnets for almost all the species.

- By using increasing mesh size and hook size non-targeted catch could be reduced.

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