CHAPTER I

Introduction and Review of Literature

1.1 Introduction

Fishing has been a traditional occupation of a section of people all over the world from time immemorial. In India, the fisheries sector contributes significantly towards strengthening nutritional security, income, employment, foreign exchange earnings and livelihood opportunities. These facts established the fisheries sector as an important enterprise of Indian economy. During the last six decades, Indian fisheries had made tremendous progress, with the annual fish production increasing from 0.75 million tonnes in 1950 to 6.4 million tonnes in 2006, indicating over eightfold increase during the period. As per the latest available data, marine fishery sector earns a foreign exchange of Rs. 8000 crores annually through seafood export.

The fish production in the sea is depended upon the productivity of the sea, the availability of fish at a given point of time, the fishing effort expended, accessibility and vulnerability of the resources and a number of other factors. Man has a lot of control on land-based resources whereas in marine fishery resources the only opportunity for man to intervene is through management of the capture process. In the case of agricultural
crops, production can be increased by means of high quality seeds, fertilizers, irrigation, pest management and so on. Unlike the land-based resources, marine fisheries resources are invisible, frequently migrating and easily affected by the changes in the sea. These characteristics make it unique and complex and hence difficult to monitor, manage and intervene. This uniqueness of marine fisheries makes it a challenging task for scientists to explore the dynamics of the fishery and the fishery managers to make management interventions. For interventions aimed at any developmental or management agenda in this sector constant and continuous monitoring of the resources is essential.

1.2 Central Marine Fisheries Research Institute

Recognising the importance of the fisheries sector to the state's economy, the need to establish a Fisheries Research Station in the country had become very strong. Accordingly, a Fisheries Research Station was established on 3rd February 1947 in the University of Madras. Following this, several fisheries research stations were established in different states of the country under the Ministry of Food and Agriculture. The Fisheries Research Station at Madras was shifted to Mandapam Camp, Tamil Nadu in 1949 and became the head quarters of the Research Stations. Later on this station was developed into a full-fledged Marine Fisheries Research Institute and renamed as Central Marine Fisheries Research Institute (CMFRI) in 1962. The Institute is mandated to carryout research and developmental activities in marine fisheries. In October 1967, the management and
administrative control of the Institute was transferred from the Ministry of Food and Agriculture to the Indian Council of Agricultural Research (ICAR). The headquarters of the Institute was shifted to Cochin, Kerala in 1971. The CMFRI contributed greatly to the understanding of fishery biology and fishery oceanography enabling the rational exploitation of several fish stocks. The institute is mandated

(i) to monitor the exploited and assess the under-exploited marine fisheries resources of the Exclusive Economic Zone,

(ii) to understand the fluctuations in abundance of marine fisheries resources in relation to changes in the environment,

(iii) to develop suitable mariculture technologies for finfish, shellfish and other culturable organisms in open seas to supplement capture fishery production,

(iv) to act as a repository of information on marine fishery resources with a systematic database,

(v) to conduct transfer of technology, post graduate and specialized training, education and extension programmes and

(vi) to provide consultancy services.

To carry out these tasks effectively, the Institute has established Regional Centres at Mandapam Camp, Veraval and Visakhapatnam, Research Centres at Minicoy, Mumbai, Karwar, Mangalore, Kozhikode, Vizhinjam, Tuticorin, Chennai and Kakinada and 28 Field Centres all along the coastal line of the country. The entire activity is coordinated by the
headquarters at Cochin. The CMFRI has, over the years, built up laboratory and field facilities at all its centres for carrying out research programmes and has been upgrading the same to meet the changing needs and additional requirements. The multidisciplinary researches in capture and culture fisheries are conducted under following ten divisions:

- Fisheries Resources Assessment
- Pelagic Fisheries
- Demersal Fisheries
- Crustacean Fisheries
- Molluscan Fisheries
- Fishery Environment Management
- Marine Biotechnology
- Socio-Economic Evaluation and Technology Transfer
- Mariculture
- Marine Biodiversity

Inter-divisional and inter-institutional programmes were carried out for greater utilisation of expertise and facilities. Besides, the Institute takes up research projects on important and priority areas funded by outside agencies in the country and abroad, and offers consultancy services to the clients from government organisations as well as industry.

The marine living resources are dynamic and renewable and hence regular assessment and monitoring of factors like their resource size, dynamics, exploitation rates and replenishment capacities are essential.
The management of marine living resources requires time series data on all these factors. The major mandate of CMFRI is to monitor and assess the exploited marine fishery resources and render policy support to the Union and State Governments. The data on catch, effort and biological aspects are the essential requirements for assessing the exploited stock. In India, we have a multi-species, multi-locational, multi-gear, seasonal fishery which is being exploited through an open access regime without any serious management interventions. Fish landings take place all along the coast line in all seasons during day and night. In such a complex situation, the collection of landing statistics becomes a formidable task. The cost, operational difficulties and non-sampling errors of a continuous survey covering all landing centres would be of very high magnitude. Hence, a scientifically planned sampling strategy is the only answer to enable estimation of landings by the large number of mechanised and non-mechanised units operating in the coastal belt.

Soon after its inception in 1947, attempts were made by the Fishery Research Station to evolve scientific methods of collecting marine fish catch statistics. In the beginning, not much information was available on the marine fishing villages, landing centres, fishing crafts and gears which could form a frame for developing sampling plans. Also, fishing practices differed from region to region and also from season to season. Keeping this in view, CMFRI along with the ICAR conducted a series of pilot surveys to collect such information as was required for formulating a sampling design. The
limited resources at the disposal of the Institute were another constraint in conducting large-scale surveys. However, a stratified multistage random sampling design was developed by the Institute for estimating the exploited fish stocks which became a landmark and was adopted by the Food and Agricultural Organisation of the United Nations for use in other countries. The stratified multistage sampling design was first put into operation in the State of Kerala in the middle of 1959 and was gradually extended to other states of the west coast of India. From 1961, the design was introduced along the entire coast of the mainland. The sampling scheme employed for the estimation of marine fish landings was basically the same but it varied to some extent in details from region to region in view of the varying field conditions. In tune with the fast changing marine fisheries scenario, the scope, the structure and administration of the resource data collection was periodically modified.

The Fisheries Resources Assessment Division of the Institute is primarily responsible for the fulfilment of the Institute's mandate on the monitoring and assessment of the exploited marine fishery resources in the Indian Exclusive Economic Zone. The development of methodologies on data collection for fishery monitoring and assessment were done through a continuing research project titled “Assessment of Exploited Marine Fishery Resources”. The project aims to arrive at an estimate of marine fish landings and fishing effort in different regions of the country with species-wise and gear-wise break up of the exploited resources. It also envisages maintaining
and updating the database on the Marine Information System existing at the Institute. At present a stratified two stage sampling design was employed to collect and estimate the landings of the exploited marine fishery resources. The planning, execution and co-ordination of field work, processing of data and updating database, developing suitable formats for storage and retrieval are done by the division.

1.3 Development of CMFRI Sampling Methodology

Pilot surveys

The first attempt to build up a planned survey for the estimation of fish catch on an all-India basis was made by the CMFRI. In the pilot survey conducted in 1948-49, village-wise data were collected on the area exploited, the number of persons engaged in marine fishing, the number of various types of fishing boats and nets, fishing seasons, type of fish caught and the number of landing centres. This brought forth a complete picture of fishing activities. Afterwards fisheries data were collected on regular basis from 1950 onwards by dividing the entire coastline into twelve homogenous survey zones. With the availability of more funds and additional staff, the survey zones were increased to cover more landing centres. Between 1950 and 1956, the ICAR also initiated a number of pilot surveys with various designs in different regions of the country with a view to evolve the most suitable sampling design for the estimation of fish landings in the country.
The pilot surveys and their results have influenced a great deal in moulding the sampling design currently used by CMFRI.

In 1950-51 a pilot survey was undertaken in Malabar coast over a coastline of hundred miles. As in any sampling problem, the first efforts were to define the population to be sampled and an appropriate sampling unit. A fixed number of fishing boats were selected from each village in the coast which were kept under observation over time for estimating:

(i) the percentage number of times they went out for fishing and
(ii) the average catch per boat on the basis of sub samples of these boats.

But in a village the number of boats was a highly variable factor; further boats of a village did not often land in the same village. So the practice of selecting village was abandoned. In its place it was found easier to consider the boats where they had landed or first became available for recording. Finally it was agreed that the fishery data may be based on the number of distinct landing places each of which can be considered as a sampling unit. The number of boats landed in the landing centre over a period was determined and the average catch per boat was estimated on the basis of a sub sample of boats landed. The total catch for the period was then estimated as the product of the average catch per boat and the total number of boats landed.

A group of continuous landing centres formed a stratum in space and weeks provided time strata. A landing centre was the primary sampling unit
Twenty-minute time intervals were the secondary units (SSU) and an operating fishing boat was the tertiary unit (TSU). The SSU was the ultimate sampling unit for estimating the count and the TSU was the ultimate sampling unit for observing catch. The observations on count and catch were made in distinct intervals. Thus a three stage stratified sampling design was evolved for the collection of marine fishery data.

In 1953-54, another survey was carried out on Malabar coast. The coverage was also extended to include 60-mile coastal part of the southern half of the South Canara district (Karnataka State), as it is geographically contiguous and has similar fishing practices and conditions to those on the Malabar coast. Here the design was one of the 3-stage stratified sampling for recording data on count of fishing boats landed, while there was a further stage for recording data on catch and other ancillary information. Here, also the landing centres formed a stratum in space but months were the strata in time. A month was considered more convenient as a time stratum, as it is sometimes necessary to study monthly trends and partly because of administrative convenience. The centres, days and time intervals were the successive stage of sampling units in observing boats. A fishing boat landed corresponds to the further stage of sampling in the case of observing catch. At each of the centres, four days were randomly selected in a month. Two days were allocated to observe count and the remaining two to observe catch.
Another extension survey was conducted during 1954-55 in order to finalise the technique for routine data collection. The coverage was the same as in the earlier survey. Here, the stratification used over space, was by fish-curing yard which was proved to be useful as it was convenient for field work. The month continued to be the stratum in time. Initially one single landing centre was selected at random. Four days were randomly chosen in a month and within a day the selected centre was kept under observation for three evenly spaced two hour intervals. In each interval one hour was meant for observing count of fishing boats landed and the other for recording the catch of a few selected boats. In 1955-56, some modification in the selection of centres was introduced. For a stratum, a fresh selection of centres was made for each day of the four days. In other aspects the design remained the same as that of the previous year.

On the basis of the experience gained in pilot surveys, a full-fledged survey was launched in an area of 200 miles of Travancore-Cochin coast consisting of 123 landing centres. Sukhatme et al. (1958) describe this sampling methodology and discuss the lack of a sampling frame in the absence of compulsory registration of boats. A group of contiguous landing centres is taken as a stratum in space and week was taken a stratum in time. The primary unit of sampling within each stratum was a landing centre. The centres were selected afresh every week. Each centre was kept under observation for two days (secondary stage units) selected at random out of the working days of the week. A day was divided into two clusters of
three evenly spaced two hour intervals. The first comprises of intervals 0600-0800 hrs., 1000-1200 hrs., 1400-1600 hrs. and the second of intervals 0800-1000 hrs., 1200-1400 hrs. and 1600-1800 hrs. On each selected day, the field work was conducted for one cluster selected at random. In each two-hourly interval of a cluster, one hour was assigned for counting the number of boats landed and the other hour for recording the catch details.

The estimation procedure followed in the pilot surveys is given below.

The method of estimating total catch in the surveys conducted on the Malabar coast involved estimation of two factors, average catch per fishing boat \( \bar{y} \), and the total number of boats operated \( M \). These factors were used to arrive at the estimate of catch for any period or region, assuming that \( \bar{y} \) and \( M \) are not correlated.

The total catch for a stratum and month was estimated by the product of \( \text{(Total count for the stratum in a month)} \times \text{(Average catch per fishing boat)} = \hat{M} \hat{y} \).

Variance of total catch is determined using the formula

\[
V(\hat{M} \hat{y}) = \hat{y}^2 V(\hat{M}) + \hat{M}^2 V(\hat{y})
\]

On the basis of the results obtained in the pilot surveys, the following broad conclusions were drawn about the different stages of design of large-scale sample survey for estimating fish production.
(i) Stratification: space stratification is to be followed. It is to be examined if grouping of centres according to amount of catch in the centres will improve the design. Time stratification is also to be introduced.

(ii) Size of the primary unit: In the two-fold stratification over space and time the primary unit may be (a) a centre-day, (b) a centre-group of days, (c) cluster of centre days, and (d) cluster of centres-group days. From the organisational point of view, while a field staff is put in charge of a stratum over space, the cluster of centres-day may not be possible. Among the rest a centre-day or a centre-group of days may be used as primary unit depending on field conditions.

(iii) Size of the ultimate unit: It is seen that the ultimate unit would be an interval of time (one hour, two hours etc.) in a day. The length of the interval has to be divided on the basis of statistical and field considerations. The sampling of interval within a day may however be done systematically.

(iv) Observation on count and catch: The pilot survey showed that observing count and catch in different time intervals entailed considerable loss of data, whenever there was no boat to be observed in the subsequent time interval. Therefore count and catch are observed simultaneously in the same interval.

Similar pilot surveys conducted in Madras coast, Andhra coast, South Canara and North Mumbai with minor modifications.

Census

The first Marine Fisheries Census was carried out in 1957-58. The initiation of data collection using a stratified multi-stage sampling scheme in
the west coast of India was done in the year 1959. The second Marine Fisheries Census was carried out in 1961-62. During 1960-69, the survey scheme, has crossed the level of experimentation, entered into the phase of evaluation. During 1970-79, there was a spurt in the implementation of mechanization in the fisheries sector which yielded in dramatic increase in the quantum of data collected. The previous list of more spatially spread zones demanded a relook. As a few landing centres recorded very heavy landings due to increased harbour facilities and marketing avenues, they demanded for better representation in the scheme. Hence the move to treat such centres as exclusive zones known as, Single Centre Zones, was initiated and is being followed till date. The secondary stage units viz. fishing boats with different gears were segregated to have separate recordings so that the estimation can be done for each landing centre day for a given gear. A marine fisheries census was conducted in 1973, which augmented the information on sampling frame. Another census was conducted in 1980 in all maritime states except Maharashtra and the information was used to update the sampling frame. In early eighties, underlining the need of an organised conglomeration of data on marine living resources, the Planning Commission had suggested strengthening of Data Centre of CMFRI. A workshop on data acquisition was conducted in 1982, which delved on all the issues flagged out by the Planning Commission and based on the deliberations, a new scheme of acquiring, processing, analysing and storing of data and dissemination of information
was charted out. The eighties witnessed significant impact of mechanisation. Motorisation of country crafts came in to existence. Hence the methodology demanded a thorough revision of gears region-wise and treated them as the domains. The selection criteria of crafts were modified. Eighties also ushered in high profile electronic computing, first through the mainframe concept and later as personal computing. This triggered development of more accurate computation methods which could be easily programmed for analysis and stored for future reference as electronic databases. After 1990, the methodology did not undergo major changes barring the deletion and addition to the existing list of landing centres. An All India Marine Fisheries Census was conducted in 2005 which facilitated updating of the sampling frame. It was a centrally sponsored scheme on Strengthening of Database and Information Networking for the Fisheries Sector under the aegis of Department of Animal Husbandry, Dairying and Fisheries (DAHD&F), Ministry of Agriculture, Government of India. Its reports on all India basis were presented to DAHD&F in July 2006. This census not only covered the details on the fish landing centres, crafts and gears but also the data on the marine fishermen population, their occupation, family status and the infrastructure available in the villages.

1.4 Marine Fisheries of Kerala

Kerala is a small state situated in the southwest corner of the Indian Peninsula between 8° 18' and 12° 48' north and 74° 52' and 77° 22' east. It is a narrow strip of lush green land bounded on the east by Western Ghats
interspersed with rivers and on the west by the Arabian Sea. Kerala has got a long and unbroken coastline of about 590 kilometres, and is only 100 kilometres across at the widest point. The area of continental shelf of this coast is about 40,000 square km and the overlying waters are considered to be one among the most productive in the Indian waters. 9 out of the 14 districts in the Kerala state have Arabian Sea as their western border.

Fishing has been the traditional occupation for generations among people living in Kerala. Among the nine maritime states in India, Kerala occupies the foremost position in marine fish production. The contribution of Kerala fisheries to the economy of the country is substantial particularly with reference to food consumption, nutrition, employment and export. Although the Kerala coastline is only about one tenth of the coastline of India, it contributes more than 30% to the country's total marine fish production. As per the latest report of the Marine Products Export Development Authority, the marine products export from Kerala during 2005-2006 was 97,311 metric tonnes valued at Rs. 1257.65 crores constituting 17% in terms of value to Indian marine products export.

The marine fisheries of Kerala have progressed tremendously during the last five decades contributing significantly to the socio-economic welfare of the coastal rural folk and to the economy of the state. Marine fishing using artisanal tackles like boat-seines, shore-seines and Chinese dip nets are an age old tradition of the state. There have been qualitative and quantitative improvements in the scale and magnitude of fishing operations
aided by scientific explorations and technological innovations as well as increasing demand for marine fish products both in domestic and international markets.

The progress of marine fisheries in the state has been quite eventful with each epoch witnessing different innovations of harvesting practices in the gears and craft. The mechanisation was experimented in the late fifties under the Indo-Norwegian Project (INP) by introducing trawlers. The INP project was undertaken under a joint agreement among the United Nations, the Government of Norway and the Government of India. (Kurien, 2000). When the INP started in 1953 there were around 38,000 active marine fishermen (Kurien 1985) and as per Marine fishery census 2005, there were 1,40,222 active fishermen in the year 2005.

The early sixties witnessed an important technological development in gear, the shift from cotton to nylon nets. For about three decades from the formation of the state of Kerala in 1956, fisheries development was associated almost totally with the catching and exporting of shrimp. The mid-sixties ushered in increased use of trawl fishing by mechanised craft targeted towards exploiting prawns, the major foreign exchange earner. Commercial purse-seining aimed at harvesting small pelagics such as oil sardine and mackerel was started during the late seventies. About two thirds of the marine fish landings of the state were accounted by the artisanal sector till 1979. In 1980 there were as many as 22 major craft-
gear combinations used by the artisanal fishermen to harvest the resources of the coastal waters (Kurien and Willmann, 1982).

One of the most significant developments in the marine fisheries of the state has been the motorisation of country craft, which was initiated in the early eighties and gained momentum in the later half of eighties. There were significant changes in the gear used by the artisanal sector. Boat seine has been converted into the mini purse-seine (ring seine) and the country craft converted into the mini trawls. The introduction of ring seine net has transformed the marine fishery scenario of the state. The impact of ring seine and mini trawlers used in the artisanal fisheries in Kerala was examined by D’cruz (1998) and reported as harmful to the fishery. The mid-nineties witnessed the phenomenon of voyage and deep-water fishing by trawlers and gill-netters.

As per the South Indian Federation for Fishermen Society (SIFFS), (1992), the Kerala coastline was distinguished by at least 14 types of fishing crafts and at least 23 types of fishing gears. Although the technological innovations introduced from time to time have helped in augmenting the total production, they have also given rise to inter sectoral conflicts among various stakeholders. Serious concern was expressed during the mid-eighties about the sustainability of the exploited resources and ecosystem degradation allegedly due to increased fishing pressure by the mechanised sector. The artisanal sector whose sustenance depended upon the small pelagic resources and other near shore resources felt threatened by the
reported incursions of the mechanised sector into their region of exploitation. This prompted the Government of Kerala instituting various committees over successive years to assess the status of the fishery and this has culminated into promulgation of Marine Fishery Regulation Act aimed at regulating and curbing fishing activity by certain gears and craft at certain clearly demarcated fishing zones. To protect the spawners from being over exploited and to safeguard the interests of the traditional fishermen, a partial ban on trawling was introduced in 1988 (Vijayan, et al. 2000). Thereafter, the ban on fishing by trawlers during the monsoon period was enforced. From the year 1994 onwards, the period of ‘Trawl-Ban’ during monsoon period was fixed for 45 days from 15th June to 29th July. The Status of marine fisheries in Kerala with reference to ban of monsoon trawling was described by Ammini (1999). There has been massive increase in ring seine operations after the implementation of the trawl ban. In addition to this, the fishing pattern also underwent changes through extension of fishing grounds to relatively deeper zones and stay over or voyage fishing aided by state-of-the-art electronic equipments for communication, position fixing and resource detection.

In Kerala, the Marine Fisheries Census 2005 was carried out in all the nine coastal districts during April-June, 2005. There were around 2,24,606 people depending on fisheries for their livelihood. Of the 222 fishing villages in Kerala, the largest number is in Trivandrum district, 42 and the least is in Kannur district, 11. There are 178 landing centres in the
state. Thiruvananthapuram district has the maximum number of landing centres, 50 and Kannur has the minimum, 11.

The total marine fishermen population in the state is about 6,02,234 of which 23% are engaged in actual fishing. Among those involved in actual fishing, 88.5% were engaged in full time fishing, 7.5% part time and 4% occasional. Full time fishermen were higher in Thiruvananthapuram district.

Trawlers (72%), ring-seiners (8%) and gill-netters (7.8%) were the main crafts of the mechanised sector. There were 29,177 crafts in the fishery of which 5,504 were mechanised; 14,151 were motorized and the rest non motorised. Kerala marine fisher folk owned 19,173 crafts out of which 7% were mechanised 44% were motorized and the remaining 49% were non-motorized crafts.

Important gears of Kerala were gillnets, hooks and lines, troll lines, drift nets, seines and trawl nets. Sharing pattern is more visible in seines, trawl nets and drift nets. Nearly 66% of the fisher folk families involved in fishing possessed neither craft nor gear. There were 414 curing yards, 320 ice factories, 153 peeling sheds, 112 boat yards and 56 freezing plants in the fishing villages of Kerala.

1.5 Objectives of the Study

The sampling methodology currently adopted by the CMFRI to estimate the marine fish landings in Kerala is based on stratified two stage
sampling scheme, the stratification is done over space and time. The Kerala coastline is divided into several geographic contiguous zones. Each zone is taken as a space stratum and they are made by combining the adjacent landing centres. The stratification over time is by calendar month. A combination of landing centre and day called as landing centre day forms the primary stage unit and the fishing boats land on a landing centre day forms the secondary stage units.

In early fifties, a three stage sampling scheme was followed for estimation of marine fish landings in which a landing centre, a time interval of 20 minutes and fishing boats were the primary, secondary and ultimate sampling units respectively. Later on there have been changes and improvements in the sampling scheme from time to time in view of practical contingencies. One of the main changes has been in the selection process of space-time units i.e., a combination of landing centre and a day forming the primary stage unit. During the last five decades the fishery sector has undergone drastic changes, but there were no significant alterations in the basic structure of the sampling design. Hence, evaluation of the sampling design is essential to determine the mode and frequency of data collection keeping in pace with the changing pattern of the fishery. Except for a study by Kutty et.al (1973) there had been no attempt to evaluate the sampling design of CMFRI in terms of the precision of the estimates and deriving optimum sample size. In this study an attempt is made to review the
existing sampling design in tune with the rapid changes in the fishery sector. The present investigation is proposed with the following objectives:

1. To evaluate the existing sampling design followed by CMFRI for estimation of marine fishery resources in Kerala.

2. To suggest improvement in the sampling design / estimate.

3. To estimate the optimum sample size to evaluate the catch and effort data.

1.6 Review of Literature

In this section, a brief review of the literature related to fishery surveys, connected sampling designs, methods of estimation are provided.

Fishery Surveys

The earliest reference to estimates of marine fish catch in India is seen in the Report on Marketing of fish in the Indian Union (Government of India, 1951) which also reports that the data were not based on any scientifically planned surveys but mostly on trade enquiries and similar other evidences (CSO, 1961). Bal and Banerji (1951) gave an account of the efforts made by the CMFRI in developing such a survey. Between 1950 and 1956 the ICAR initiated a number of pilot surveys of various designs in different regions of the country and the details are given in ICAR technical bulletin (ICAR, 1965). The estimation of yield from exploited marine stocks with reference to South East Asia was described by Banerji and Chakraborty (1972).
CMFRI conducted a workshop in 1982 to review the system of collection, collation and analysis and dissemination of data on marine living resources in the country (CMFRI, 1983). The sampling design that was followed up to 1970's was explained by Kutty et al. (1973) and evaluation of the design was done to see whether any improvement in the sampling procedure is possible by increasing the number of survey staff. The mode of collection during the late 1970's and early part of 1980's were described by Jacob et al. (1983). Later, the mode of collection underwent slight change with respect to selection of crafts and the modified scheme was given by Alagaraja (1984). Srinath et al. (2005) described in detail the existing sampling methodology followed by CMFRI for estimating marine fish landings and the expended fishing effort. The progress of the development of sampling scheme was given by Srinath and Jayasankar (2007).

Gulland (1955) discussed an analysis of samples from commercial landings of the English trawl fishery. Panse and Sastry (1960) carried out sample surveys in United Arab Republic for the improvement of fisheries statistics in that country. Tomlinson (1971) described methods for sampling commercial fisheries for small pelagic fish using two-stage sub-sampling with primary units of unequal size sampled with equal or unequal probabilities. Brander (1975) gave the guidelines for collection and compilation of fishery statistics. Statistical procedure to analyse data from the Pacific Halibut Fishery of the United States and Canada are discussed by Southward (1976) who presents a double-sampling procedure based on
time and area stratification for estimating the age and length distribution in landings. For estimating the catch at age of rockfish on the west coast of California, Sen (1986) developed a two-stage sampling plan with boat trips as first stage units post-stratified into categories and clusters sub-sampled from each category. Sen (1990) also developed a cost-effective sampling plan for obtaining reliable estimates of annual catch by recreational fishermen in Hawaii and the effort expended by fishing method for some of the important management species. Papaconstantinou et al. (2002) presents the design of an integrated sample survey system in Greece for the collection of multiple fisheries data required for fisheries management. Stamatopoulos (2002) discusses the methodological and operational concepts in fishery data collection systems. Miller et al. (2007) presented an approach for determining sampling fractions and sample sizes for each stratum within a stratified sampling design that is optimal with respect to multiple parameters that may be heterogeneous in nature.

**Sampling Designs**

Several text books such as Hansen et al. (1953), Desraj (1971), Murthy (1967), Cochran (1977), Sukhatme et al. (1997), Krishnaiah and Rao (Eds.) (1988) Särndal et al. (1992) and Thompson (2000) describe the wide variety of efficient sampling designs together with the appropriate estimation methods.

The general theory for sub-sampling from finite populations has been developed through the important contributions of Hansen and Hurwitz
(1943, 1949), Mahalanobis (1946, 1952), Sukhatme (1947, 1950), Yates (1949), Sukhatme and Panse (1951), Sukhatme and Narain (1952), Singh (1954), Durbin (1967), Sukhatme and Sukhatme (1976) and others. Procedures for estimation of various population parameters were developed for multistage design in conjunction with stratification and other sampling schemes such as selection with equal or unequal probabilities, selection with or without replacement etc.

Cochran (1946) considered a model for auto-correlated populations with a view to compare systematic sampling with stratified sampling and simple random sampling procedures. With the importance of this model in view, an attempt to deal with the problem of sampling from two dimensional populations was made by Quenouille (1949). Das (1950) gave an independent approach to the problem of two dimensional population in the context of systematic and stratified random sampling. Sukhatme et al. (1958) discussed the technique of two dimensional population for the estimation of the catch of marine sea fish in India.

Singh and Gupta (1980) estimated the production of vegetable crops where harvesting is spread over a period of about 2-3 months. They suggested that it is reasonable to assume that the number of observations made on a unit is a discrete random variable and its distribution may be assumed to be characterised by a Truncated Poisson distribution. On the basis of this, they obtained unbiased estimate of the population mean, the variance of the estimator and the estimate of variance of the estimated mean.
Kumar (1981) suggested a sampling plan for two dimensional studies using random sampling for selection of fields and systematic sampling over time. Mahajan (1984) investigated the use of successive sampling in two dimensional populations and developed suitable estimation theory for sampling on successive occasions.

Estimation of Variance

Anderson and Bancroft (1952), Gower (1962) and Gates and Shiue (1962) and Mahamunulu (1963) gave the expected mean squares for unequal sampling from infinite nested population. Bennett and Franklin (1954) considered finite nested populations, but only for balanced sampling. Gaylor and Hartwell (1969) gave a single unified procedure for obtaining the expected mean squares in nested populations, where a balanced or unbalanced random sample is taken from a finite or infinite number of levels for each classification. Khuri (2000) provides a comprehensive coverage of the literature on designs for estimating variance components, and a review of recent applications of such designs in genetics, statistical process control, and quality improvement. In addition, recent methods of estimation of variance components and model forms, other than the linear, are discussed.

Post-Stratification

Hansen et al. (1953) was the first to discuss the concept of post stratification. Williams (1962) suggested a procedure for getting approximate
variance of post-stratified estimator. This aspect has been discussed in case of uni-stage random sampling designs by Sukhatme and Sukhatme (1976), Murthy (1967) and Cochran (1977) and others.

Fuller (1966) developed small sample estimator for two post-strata and compared with pooling or collapsing procedures commonly employed in practice. Holt and Smith (1979) showed that neither the post-stratified estimator nor the sample mean is uniformly best in all situations but empirical investigations indicate that post-stratification offers protection against unfavourable sample configurations and should be viewed as a robust technique.

A post-stratified cluster sample design was proposed by Akar and Sedransk (1979). They suggested an estimator $\hat{R}$ of the finite population ratio. Post-stratification in unistage cluster sampling on the basis of the elements of selected clusters has been discussed by Mehrotra et al. (1984). They have demonstrated empirically that the suggested procedure not only provides estimates of the character under study according to the strata variable but also improves the precision of the overall estimate compared to the usual cluster sampling procedure. Sethi and Srivastava (1987) have developed ratio estimators with post-stratified design in order to overcome the constraints imposed by the assumption viz., sample mean of the auxiliary character should always be less than twice the population mean of the character on the application of ordinary ratio estimation theory. Pfeffermann and Krieger (1991) have proposed a new regression type
estimator which accounts for different regression relationships in various strata but no longer depends on the unknown strata means and sizes under post-stratification.

Mehrotra (1993) has given a scheme for post-stratification in two-stage sampling on the basis of the sample second stage units. It has been empirically demonstrated that the scheme not only provides estimates of the study character as per the strata variable but also improves the precision of the estimate pooled over the strata compared to the conventional non-stratified two-stage procedure. Kumar (1989) has extended the above schemes of post-stratification in uni-stage unequal cluster sampling and post-stratification in two stage sampling on the basis of sample second stage units to two and three stages respectively. He has also discussed post-stratification for two stage sampling with probability proportional to size. Narang (1994) has given schemes for estimation of population total in a two-stage post-stratified design.

1.7 Plan of the Thesis

The thesis consists of SIX chapters. Each chapter begins with a brief introduction highlighting the chapter contents. In the earlier sections of this chapter a brief description about the CMFRI and its efforts to collect marine fishery data, the background and objectives of this study, a brief review of the related literature are given. In the second chapter, a critical evaluation of the sampling design currently followed by CMFRI is done. Section 2.2
describes the sampling design and the procedures of estimation of total landings and its variance. Based on the CMFRI data for the years 2004-2006, the sampling fraction and the estimates of landings in each zone are described in section 2.3. Critical evaluation and the main limitations of the existing design are described in section 2.4. A few remedial measures are indicated in section 2.5.

The fluctuations and trends in the fish landings data over the years are discussed in chapter 3. Section 3.2 describes how the fisher folk population and their fishing activity varied over time. In section 3.3 the trends in the assemblage wise and sector wise landings are described by fitting suitable trends to the data. In section 3.4 the trends in the landings, boats operated and the landings per boat are discussed in detail by fitting trends for monthly data based on 2 term, 3 term, 4 term and 6 term moving averages. Comparisons of the period wise landings at the five single centre zones are made in section 3.5. Section 3.6 concludes the findings in the analysis made in the chapter.

In chapter 4, estimation of the components of variance due to each stage of sampling in the fish landing data using the nested model technique is discussed. The general linear model for ANOVA of an unbalanced nested design and its analysis are described in section 4.2. Describing the nested structure of the marine fishery data, analysis of the data using a three stage model is described in section 4.3. Zone wise estimates of variance
components for the period 2004-06 are described in section 4.4. The chapter ends with a brief conclusion of the findings.

In chapter 5 we introduce two modified sampling designs based on post stratification of the data – one applicable to single centre zones and the other for multi-centre zones. The first new design developed for single centre zones is the same as the two stage sampling currently followed by CMFRI with the only modification that the data is post-stratified according to the observed gear types is described in section 5.2. Illustration of this design is also discussed. The second new design developed is a three stage design which retains the two dimensional structure of the population over space and time and adopts post-stratification based on gear types at the third stage and is described in section 5.3. The chapter concludes by highlighting the effectiveness of the proposed designs.

A more scientific, structurally and operationally simple design is developed in chapter 6. The new design – a two stage probability proportional to size sampling design applicable to multi-centre zones is developed in section 6.2. The optimum sample sizes for estimation of the fish landing data under different sampling designs are described in section 6.3.

A final conclusion together with some recommendations on the basis of the findings of the study is given at the end. The list of references is also included.