STATISTICAL METHODS IN GEAR SELECTIVITY AND GEAR EFFICIENCY STUDIES

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This is to certify that the thesis entitled "Statistical Methods in Gear Selectivity and Gear Efficiency Studies" embodies the result of original work conducted by Shri A.K.Kesavan Nair under my supervision and guidance. I further certify that no part of this thesis has previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar titles of this or any other University or Society. He has also passed the Ph.D. qualifying examination of University of Cochin, held in January, 1985.

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(DR. K.ALAGARAJA)

DECLARATION

I hereby declare that this thesis is a record of bonafide research carried out by me under the supervision of Dr. K.Alagaraja, my supervising teacher, and it has not previously formed the basis of award of any degree, diploma, associateship, fellowship or other similar titles or recognition to me, from this or any other University or Society.

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CONTENTS

INTRODUCTION

For a fishing operation to be successful, it must be economically viable. Fishing industry, for that matter any industry, cannot continue its activity unless it gets sufficient financial reward. Fishermen would use only such technological development which are of benefit to them. Thus there arises the need for proper choice of fishing methods.

The catch obtained by a gear is governed by fishery dependent and fishery independent factors. Fishing mortality inflicted by a gear is the main fishery dependent factor. Rounsefell & Everhart (1953) have enumerated factors limiting abundance such as fecundity, critical stages in life history, salinity, oxygen, hydrogen sulphide, temperature, space, total productivity, competition, predation, diseases, parasites and the red tide.

Intelligent fishery management requires a body of knowledge concerning the dynamics of fish population like understanding of the mechanisms by which fish stocks are governed, their numbers regulated, the effect of fishing on a stock and the quantities and size of fish that can be taken on a continuous basis by different amounts or kinds of fishing (Ricker, 1977). These aspects have received the attention of many workers like De Lury (1947), Beverton and Holt (1957), Ricker (1958), MC Combie and Fry (1960), Pycha (1962), Holt (1963), Olsen (1959 & 1963), Cucin and Regier (1966), Regier and Robson (1966), Gulland (1969), Mc Combie and Berst (1969), Hamley (1972, 1975), Collins (1979), Jones (1984), Thompson and Ben-Yani (1984), Pauly (1980, 1984) and Alagaraja (1984).

Focussing attention on fishing mortality, the investigation centres round the methods of fishing, chief among them being the craft and gear combination. Fishing power of the vessel and gear as a combination has received some attention by workers like Beverton and Holt (1957), Gulland (1969) and Fridman et al. (1979).

In the tropical countries like India, fishing with non-mechanized country crafts contributed to about 65% of the total catch. Majority of them are even without outboard or inboard engines. Another 34% of the catch came from small mechanised boats and only 1% from large deep sea fishing boats.

Different types of fishing gear are in use. The main types are as follows:

1. Purse seine (Encircling gear)

A purse seine is a form of encircling net having a line at the bottom passing through rings attached to the net, which can be drawn or "pursed". In general, the net is set from a boat or pair of boats around the school of fish. The bottom of the net is pulled closed with the purse line. The net is then pulled aboard the fishing boat, or boats, until the fish are concentrated in the front or "fish bag". The fish are then removed from the fish bag aboard the fishing vessel or an accompanying fish-carrying vessel (Peter G. Schmidt, Jr., 1960).

2. Trawl net (Towed or dragged gear)

The trawl net is basically a large bag made of netting which is drawn along the sea bed to scoop up fish on or near the bottom. Depending upon the manner in which the gear is constructed and rigged, its operating characteristic can be altered to permit use on various types of bottom and for species of fish. The speed at which the trawl is towed over the bottom varies, depending on the species being saught from about 1½ to 2 knots upto 4½ to 5 knots for fast swimming fish. Both vessel and gear must be designed and arranged to suit the species being caught. The size of trawls operated by small fishing vessels depends on the engine power and towing pull available, the design and construction of the gear, the vessel's size and the handling space and arrangements aboard (Sainsbury, J.C., 1971).

3. Gill nets (Static Gear)

Gill net is one of the most common among static gears whose effectiveness depends on the fish moving to the gear which is set out in a particular manner by the vessel and left for a period of time in one place, the vessel will return later to retrieve the gear and take aboard the catch. The gill net is a large wall of netting which may be set either just above the sea bed when fishing for demersal species, or anywhere from midwater to the surface when pelagic fish are being saught. When working inshore in relatively shallow water, the nets are usually set and anchored in position, but an alternative is the drift net which is free to move according to tide and wind conditions (Sainsbury, J.C., 1971).

4. Traps (Another important static gear)

This method is often used in areas through which fish regularly move or congregate. Traps of many sizes and configurations, as the name implies, rely for their effectiveness on preventing fish from leaving once they have been induced to enter (Sainsbury, J.C., 1971). Traps are used in India, mainly to catch lobsters.

5. Long lines (Another static gear)

Long lining may be applied to the capture of demersal or pelagic fish, the gear being rigged to suit the species being sought and the area being fished, it is of particular importance in harvesting high individual value fish. The basic method involves setting out a long length of line, often several miles, to which short lengths of line carrying baited hooks are attached every two to six feet. The fish are attracted by the bait, hooked and held by the mouth until they are brought aboard the operating vessel which periodically hauls the gear (Sainsbury, J.C., 1971).

6. Pots

This method is particularly applicable to the capture of crustaceans, such as lobster and crabs whose principal movement is by legs on the sea bed. Pots of many differing sizes and configurations are set out and attract the species being fished by means of bait, either cut up fish or other sea creatures or in a prepared packaged form. The trap is constructed so that once the animal enter through a specially designed entrance, it is unable to escape again. It is then removed when the operating vessel retrieves the pot (Sainsbury, J.C., 1971).

Whatever be the method of fishing, fish catch at a given place and time depends on a number of factors. First, the fish should be available at the exploited area. This again depends on factors like growth of the fish in the exploited area, mortality and migration. Finally, even if fish is available in the exploited area unless the gear is efficient, the catch will be poor. Thus the choice of efficient gear became very important.

As trawl and gill nets are being widely used, the present study leading to the choice of efficient gear is confined to these two classes of gear. As already described, the former type of gear is hauled for about one hour to catch the fish. The latter types are stationary nets. The fish swims towards these nets and get caught while trying to swim trough it.

While designing trawl nets one or more of the various parameters of the net are altered and its performance compared with the reference gear. Understanding the effect of any alteration in a parameter like the nature of otter board used, shape of the net, nature and material of the twine used, mesh size at codend or on the body of the trawl, speed of tow, tension of the rope is usually the main purpose of experimentation. The performance of the modified gear is compared with a reference gear or among themselves when there are more than two gear by statistically designed experiments.

A detailed discussion on the methods of testing the trawl system has been described by Fridman et al. (1979). They have categorized the method broadly into parallel and non-parallel trawlings. Non parallel trawling operations include successive trawling operations also. Successive trawling operations are made from the same vessel using the trawl system to be compared one by one in a given sequence. All attempts are made to maintain identical field conditions as far as possible for the experiment. Then after every trawling operation with the experimental trawl system alternate trawling with the standard trawl system may be arranged. Successive trawling may not affect the result if both the trawls are working under identical conditions in stable fish shoals for the whole duration of the test programme. These authors suggest that a situation with a built in periodic variation of conditions at a definite time interval may be considered as truly typical. In such a situation, it may so happen that the experimental trawls will be systematically under conditions that always differ from those encountered by the standard trawl system. To eliminate the effect of this systematic error from the results, it would be worthwhile to choose the trawling sequence using table of random numbers.

Parallel trawling operations are conducted simultaneously with two trawl system on parallel courses and with maximum possible coincidence of the traverse of fishing regions. These limitations are necessary to provide identical fishing conditions to the extent possible. In this way each twin trawling can be considered as a separate experiment under identical conditions. Otherwise a comparison between pairs of trawling test results may not be possible to be justified.

This system enables to conduct a relatively larger number of experiments in a short time and to obtain reliable results. Further, comparison of trawling system and operation in pairs will automatically eliminate the distortions caused by changes in test conditions over the passage of time. However, it can be successfully employed only when the fishes are uniformly distributed in (water) space. Also this area must be somewhat greater than the minimum area required for the operation of two fishing vessels. These conditions are best obtained for bottom (sea bed) fish formations. For these reasons the method of parallel trawling is the most effective for the testing of bottom trawls. The distributions of pelagic fish in the open sea are non-homogeneous. For these conditions the more practical and acceptable method would be successive (alternate) trawling.

Next, for a proper appraisal of the effects on catches of various factors such as different codend mesh sizes, a small mesh cover over the codend, sweeps etc., a carefully planned experimental design and a sound statistical analysis of the results are necessary. Pope (1963) has discussed the use of randomization test and students t-test in the problem of comparison of two trawls differing in construction in some clearly defined way. Sreekrishna (1970) has used t-test to compare the efficiency of two trawl designs. When more than two gear are involved, the use of randomized block designs, Latin squares and split plot designs for different purposes have also been described by Pope (1963). Difficulties in changing the order of operation of nets cause limitations on the use of Latin Squares and other types of designs. The difficulty of application of randomisation test when the number of replicates (comparative hauls) are large has also been mentioned by this author. When the comparison of the catches by more than two gear are involved, the technique of analysis of variance (ANOVA) as applied to a randomised block design or two-way ANOVA is employed for comparing the effect of the gear, that is, the average catches. This method has found its place in a number of experiments conducted till date. To cite a few are George et al. (1975a, b), Naidu et al. (1976), Kartha et al. (1977), Narayanappa et al. (1977), Satyanarayana et al. (1978), George et al. (1979), Kunjipalu, Kuttappan and Mathai (1979), Kunjipalu, Mathai and Kuttappan (1979), Pillai et al. (1979), Khan et al. (1980), Mhalathkar et al. (1982) and Kunjipalu et al. (1984). Gulland's method of working out a ratio of the total catch of the two gear compared, with a confidence interval based on the logarithm of the ratio of comparable catches was adopted by Dickson (1971). The same has been used by Vijayan and Rama Rao (1982). Trawl efficiency has been described by Dickson

(1981). Larkin (1963, 1964), Washington (1973) and Collins (1979) compared the efficiency of two gill nets by forming catch ratios of catch per unit effort. Shelton and Hall (1981) have compared the efficiency of the Scottish creel and the inkwell pot in the capture of crabs and lobsters.

As a number of fishery dependent and independent factors, which vary over space and time affect the fish catch, usual analysis of variance (ANOVA) procedure may not be suitable for all purposes of testing. Commonly used tests depend on the distribution of the data and can be applied straight when the distribution is normal or nearly so. If there exists a normalizing transformation, still these tests can be employed after an appropriate transformation. But fish catch vary over space and time and fishery is multispecied in the tropics and as such the catch data are far from normal when confined to an area over a given time interval. Also, a general transformation is not known. Under these circumstances the common 't' and F-test in ANOVA are to be applied with caution. As another approach the possibility of applying nonparametric or distribution free methods is to be explored.

The practical utility of developing sensitive test procedures is immense as can be seen from the following arguement. Suppose that the test is able to detect a 20%

difference and that on an average 10 kg of prawns is caught per haul. Then by using a sufficiently sensitive test, the gear which catches 2 kg more can be recommended. Fish stocks which are underexploited can sustain further increase in effort and as such, the replacement of the existing units by the more efficient gear, will increase the yield without appreciable increase in the investment. This, on one hand, lifts up the economic status of those involved in fishing and on the other, helps the fishing industry to proceed one step further towards attaining a goal in proper fishery management, namely, maintaining the optimum sustainable yield. In regard to fisheries which have already reached the sustainable yield, like the prawn fishery of our country, introduction of a more efficient gear will make fishing more profitable and convenient. As the catch per unit effort (CPUE) of the new gear is more than that of the existing one, lesser number of hauls will be sufficient to produce the present yield, which leads to a reduction in the time spent for fishing and saving in fuel consumption. The present investigation is directed towards evolving a suitable test procedure considering the number of trials required for randomized block designs, the minimum size of the catch required to discern the efficiency of the gear, the problem of nonadditivity in randomized blocks and distinction between gear efficiency, fishing power and gear selectivity. These investigations cover two categories of gear namely, trawl nets and the passive gill nets as already mentioned.

The term 'gear efficiency' and 'gear selectivity' have appeared a number of times in literature on the relative performance of two or more fishing gear. The term efficiency seems to have been used to convey the idea of 'selectivity' also, perhaps to mean efficiency in selection. The use of these terms both synonimously and differently in the work relating to performance of fishing gear has prompted to examine various phrases used to convey 'the ability for size selection of a gear' and the 'ability to catch a maximum quantity of fish from those available in the fished area'. Most of the work on gear selectivity deal with size selection, that is, a study on how variations in mesh sizes of the gear affect the catch in relation to various sizes of a given fish species. The selectivity of bag nets like trawls and seines occurs in the codend to a great extent. Thus to study selectivity fishing can be conducted alternatively with the test codend and one having a much smaller mesh attached to the gear, or other devices such as a cover that will retain small fish and give a catch having a size composition more or less the same as that of the population being fished, can be arranged. But this may not be possible with other kinds of gear like hook and line, traps and gill nets because their selectivity may be altered by changing the dimensions of parts of the gear such as the size of the hook or the mesh of the gill net (Holt, 1963). The typical selection curve was believed to be similar to the normal distribution from general inspection of the size-frequency distribution in catches taken by gill nets of different mesh sizes. The fraction of the number of fish which encounter the net and are retained by it is thus the highest at a certain central length of the fish, and decreases symmetrically to zero both above and below that length. Beverton and Holt (1957) have shown that catches of two trawls having slightly different codend mesh sizes can be used to determine the selection curves for both trawls by a simple ratio method. Holt (1963) showed that a similar procedure is possible for gill nets assuming that the length selection curve of a gill net unit can be represented by a normal curve. Olson (1959) used an exponential model bearing some resemblance to the normal. Regier and Robson (1966) have reexamined the methods previously described for estimating the selectivity of gill nets as influenced by mesh sizes and have introduced four more methods. The gamma model which depends on the gamma distribution, which has a variety of shapes has been suggested by them when the length selection curve is not normal. They have discussed in detail various methods of determining selectivity curves like the graphical method of Mc Combie and Fry (1960) their own graphical 'variance' constant method and computational method, skew-normal model and Ishida's (1962) and Gulland and Harding's (1961) methods. Lucas et al. (1960) have defined selection as any process that causes the probability of capture to vary with the characteristics of the fish and selectivity as a quantitative expression of selection and traditionally means selection by size. Lagler (1968) defines selectivity of a gear by a curve giving for each size of fish the proportion of the total population of that size which is caught and retained by a unit operation of the gear. Important contributions to the definitions and estimation of gill net selectivity have been made by Barnov (1914, 1948), Buchanan-Wollaston (1927), De Lury (1947); Ricker (1949, 1969), Rolefson (1953), Olsen (1959), Mc Combie and Fry (1969), Gulland and Harding (1961), Holt (1963), Olsen and Tjemsland (1963), Parrish (1963), Treschev (1963), Steinberg (1964), Mohr (1965), Regier and Robson (1966), Kennedy and Sprules (1967) Lagler (1968), Fridman (1969), Ishida (1962, 1963, 1964 a,b , 1967, 1969 a,b) Ishida et al. (1966) Lander (1969), Mc Combie and Berst (1969), Panicker and Sivan (1965), Panicker et al. (1978), Regier et al. (1969), Sechin (1969 a,b) Andreev (1955, 1971), Kitahara (1968, 1971), Todd and Larkin (1971), Kawamura (1972), Sreekrishna et al. (1972), Hamley and

Regier (1973), Sulochanan et al. (1975), Hamley (1972, 1975), Alagaraja (1977) and Varghese et al. (1983).

Other than mesh size, the most important factors governing the selectivity of a gill net are its visibility, stretchability of meshes and tangling capacity and also the elasticity and flexibility of net twines.

To estimate selection curves, the general assumptions are that fishing powers of the two gears are equal and that the optimum length is proportional to mesh size. Gulland (1969) describes the fishing power of a particular gear as the catch it takes from a given density of fish per unit fishing time and devides this into two parts as (i) the extent (area or volume of water) over which the influence of the gear extends and within which fish are liable to be caught (= a, say) and (ii) the proportion of fish within this area which are in fact caught (= p, say). If fish or fishing were randomly distributed, then the proportion of the total stock within the area of influence would be a/A, and the catch would be (pa/A) x N, where N is the total number of fish. Thus the products $p \times \frac{a}{A}$ measures the fishing mortality. Improvements to fishing techniques can affect either 'p' or '$\frac{a}{A}$'. For instance, for purse-seiners, the area of influence can be increased by better searching, faster ships, use of advanced detection equipments etc., while the proportion of the population in this area that can be taken may be increased by the use of a larger net, or by some of the sonar equipment as pointed out by the author. As far as gill nets operating in the same area are concerned, a/A would be the same for all the gear. Therefore an attempt was made to estimate the relative proportion of fish (p) caught by two gill nets of equal area.

The preceding discussion and review of literature show that studies on gear selectivity have received great attention, while gear efficiency studies do not seem to have received equal consideration. In temperate waters, fishing industry is well organised and relatively large and well equipped vessels and gear are used for commercial fishing and the number of species are less; whereas in tropics particularly in India, small scale fishery dominates the scene and the fishery is multispecies operated upon by multigear. Therefore many of the problems faced in India may not exist in developed countries. Perhaps this would be the reason for the paucity of literature on the problems in estimation of relative efficiency. Much work has been carried out in estimating relative efficiency (Pycha, 1962; Pope, 1963; Gulland, 1967; Dickson, 1971 and Collins, 1979). The main subject of interest in the present thesis is an investigation into the problems in the comparison of fishing gears, especially in using classical test procedures with special reference to the prevailing fishing practices (that is, with reference to the catch data generated by the existing system). This has been taken up with a view to standardizing an approach for comparing the efficiency of fishing gear. Besides this, the implications of the terms 'gear efficiency' and 'gear selectivity' have been examined and based on the commonly used selectivity model (Holt, 1963), estimation of the ratio of fishing power of two gear has been considered. An attempt to determine the size of fish for which a gear is most efficient has also been made. The work has been presented in eight chapters dealing with

(i) the minimum number of trials required for comparison of trawl nets when the classical F-test relevant to two-way ANOVA is applied;

(ii) a simulation study to trace the problems faced in the classical approach along with consideration of nonparametric and other methods;

(iii) the problem of nonadditivity in the relevant two-way ANOVA and steps to overcome the same;

(iv) efficiency comparison of gill nets;

(v) comparison of gill net catches using a test based on the distribution of the catches;

(iv) an approach for the efficiency comparison within the trawl nets and within the gill nets for comparisons involving two and more gear;

(vii) the distinction between gear efficiency and gear selectivity and

(viii) estimation of the ratio of fishing power associated with gear selectivity model and determination of the size of fish for which a gear is most efficient.

The first six chapters are on gear efficiency and the last two on gear selectivity. The suitability of the classical test normally used, has been considered. It is found that the data is not suitable for direct application of this test. One of the major problems was found to be nonadditivity. This has been considered in chapters one and two. Gear efficiency studies lead to determination of superiority of one gear over the other when the gear have different efficiencies. There are two cases when the difference may not be discernible. The obvious case is one when the efficiencies of the gear are more or less equal. There is another case which is normally overlooked where inspite of the existence of differences in the gear efficieincies, the experimental results are not able to bring them out. This has been studied in chapter three. In the earlier chapters data from trawl nets were considered. To extend this work on gill net further work has been done and the same has been presented in chapters four and five. Combining the results of the earlier chapters a general guideline is indicated to compare the efficiencies of trawl and gill nets separately in chapter six. In the last two chapters the distinction between gear efficiency and gear selectivity has been brought out. In addition, estimation of the ratio of fishing power associated with gear selectivity model and determination of the size of fish for which a gear is most efficient have also been considered.

CHAPTER 1

CLASSICAL F-test IN TWO-WAY ANOVA AND THE NUMBER OF TRIALS (REPLICATIONS) REQUIRED FOR EFFICIENCY COMPARISON

1.1 Introduction

As already mentioned in the general introduction, the procedure followed to compare the efficiencies of gear in this country is mainly on the basis of the approaches suggested by Pope (1963) and Fridman et al. (1979). The standard gear and the experimental gear are operated in the same area on the same day following the principle of successive trawling as defined by Fridman et al. (1979), which has already been explained in the general introduction. A randomised block design is generally used as the experimental design, where a block is constituted by consecutive hauls made in the same area on the same day. By this the effect of those factors whose disturbance do not change over the period of a day are eliminated in the difference between the catches (Pope, 1963). The fishing gear tested form the treatments.

Fridman et al. (1979) have enumerated the care to be taken while selecting the area for technical trials of trawls to ensure maximum possible stability of the experimental condition. Experiments conducted in bad and unstable conditions necessitates more experimental trawlings which in turn increases the total duration of the trial programme and hence the cost. But some instability is bound to be present in the experimental condition especially when the duration of the experiment is longer. Thus working out the optimum number of trials is important from the cost, quickness of results and accuracy points of view.

Fridman _et al_. (1979) have suggested estimation of the number of fishing trials for technical testing of trawls, which is not efficiency comparison of gear through catch data. To study selectivity, Garrod (1976) found that in a series of 15 pairs of alternate hauls, a standard error of 77% in the fishing power occurred. From this be concluded that to detect a difference of 10% in fishing power, more than 500 hauls would be required. As this was not practical he suggested that parallel haul method was most valid to study selectivity. On this, Briggs (1986) commented that how the parallel haul method is more practical has not been demonstrated. However for statistical comparison of efficiency of fishing gear, no attempt seems to have been made to work out the number of fishing trials required when the experiment is conducted in randomized block experiments.

Solution on the number of trials require information on the estimate of variance (σ^2) in the population and a specification of the largest confidence interval to be tolerated or the smallest mean difference. Simple estimates of the sample size as well as estimates specifying the probability of success are given by Panse and Sukhatme (1957). Snedecor (1961), Cochran and Cox (1963) and Kempthorne (1967). Information on the variance is normally obtained from a previous experiment or from a knowledge of the range. In the absence of information on the variability, the number of replications should be sufficient to ensure at least about 12 degrees of freedom (d.f) for error (Panse and Sukhame, 1957). Tables on the number of replications required for a given probability of obtaining a significant result have been presented by Cochran and Cox (1963). These numbers correspond to a range of 2 to 20 in the standard error per unit expressed as percentage of the mean. For larger values of standard error as percent of the mean, the number of replicates are to be worked out. Formula to work out the number of blocks relevant to randomized block experiments has been given by Snedecor (1961). The same has been used here to estimate the optimum number of trials using actual data resulting from fishing experiments.

1.2 Materials and Methods

Three sets of data resulting from three fishing experiments were used for the investigation. The number of blocks were estimated using the formula (Snedecor, 1961),

$$b = \frac{(Q_{a,f})^2 \ (S_o^2) \ F_{f, f_o}}{\delta^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where 'a' is the number of treatments tested, f = (a-1) (b-1) corresponding to a large value of 'b', S_o, the standard error per unit (an estimate of σ), f_o, d.f corresponding to the mean square S_o^2 and δ , the least population difference in the mean, the proposed experiment is expected to detect with p = 0.75. The values of $Q_{a, f}$, originally tabulated by May (1952) and F_{f, f_o} were taken from Snedecor (1961). The number of blocks 'b' was estimated successively using 10, 15, 20, 25, 30 and 35 days' (blocks) data. For a given number of blocks b, the lowest difference in the mean which the experiment would detect were worked out from

$$\delta = \frac{Q_{a,f} \ (S_o) \ \sqrt{F_{f, f_o}}}{\sqrt{b}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The variation in the estimates of parameters with the increasing number of days (blocks) from which these were estimated were studied graphically.

1.3 Results and Discussion

The mean (m), S_o^2, standard error per unit as percent of the mean $\left(\frac{S_o}{m} \times 100\right)$ and b, as estimated from consecutive trials of 10, 15, 20, 25, 30 and 35 days after logarithmic transformation for the three sets are given in Table 1. The b's were estimated for detecting 20% or more differences in the means (δ = 20% of the mean) with p = 0.75. The standard error per unit as percent of the mean ranged between 17 to 40% for the first set, 14 to 24% for the second and 53 to 74% for the third. Thus the experimental material appeared to be heterogeneous. From its relationship with the number of blocks used to estimate, the estimated number of blocks were found to be more stable and realistic for sets 1 and 2 (Fig.1). Set 3, for which the estimated number of blocks are larger, the estimates do not stabilize but increase with increasing number of blocks from which the estimates were made. Thus the large sample property of estimates was not found to be satisfied for this set within the available range of values. This is because the estimated number of blocks increases with increase in standard error per unit and as found from Fig.2, the estimated standard error as percent of the mean increases when the number of blocks (days) from which this is estimated, increases. The standard error per unit as percent of the mean are also relatively larger (above 50%) for this set. To know how much larger the estimated number of blocks should be for larger increase in standard error per unit as percent of the mean, figure 3 is employed. A common curve

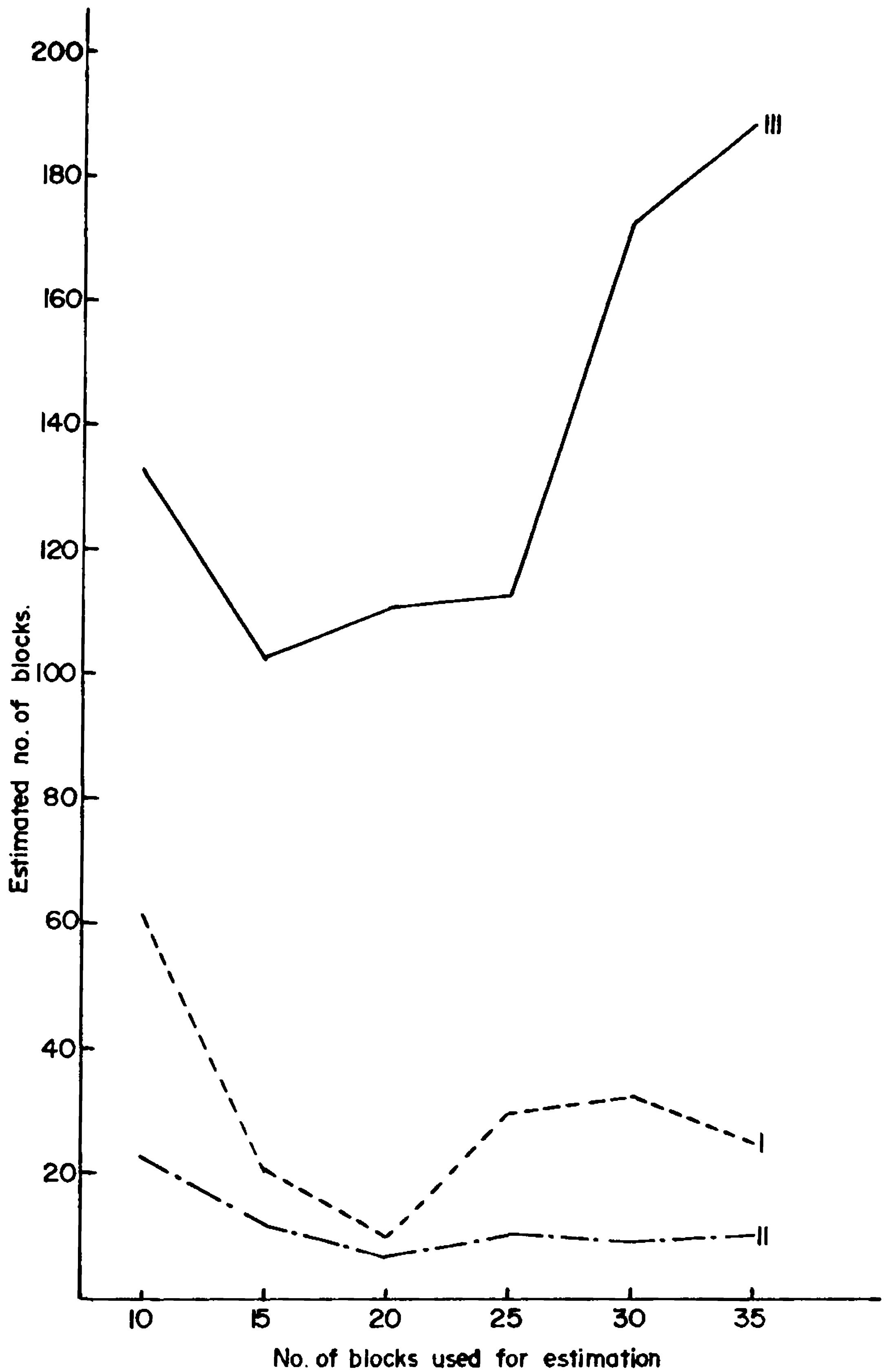


Fig.1. RELATION BETWEEN ESTIMATED NUMBER OF BLOCKS AND NUMBER OF BLOCKS USED FOR ESTIMATION.

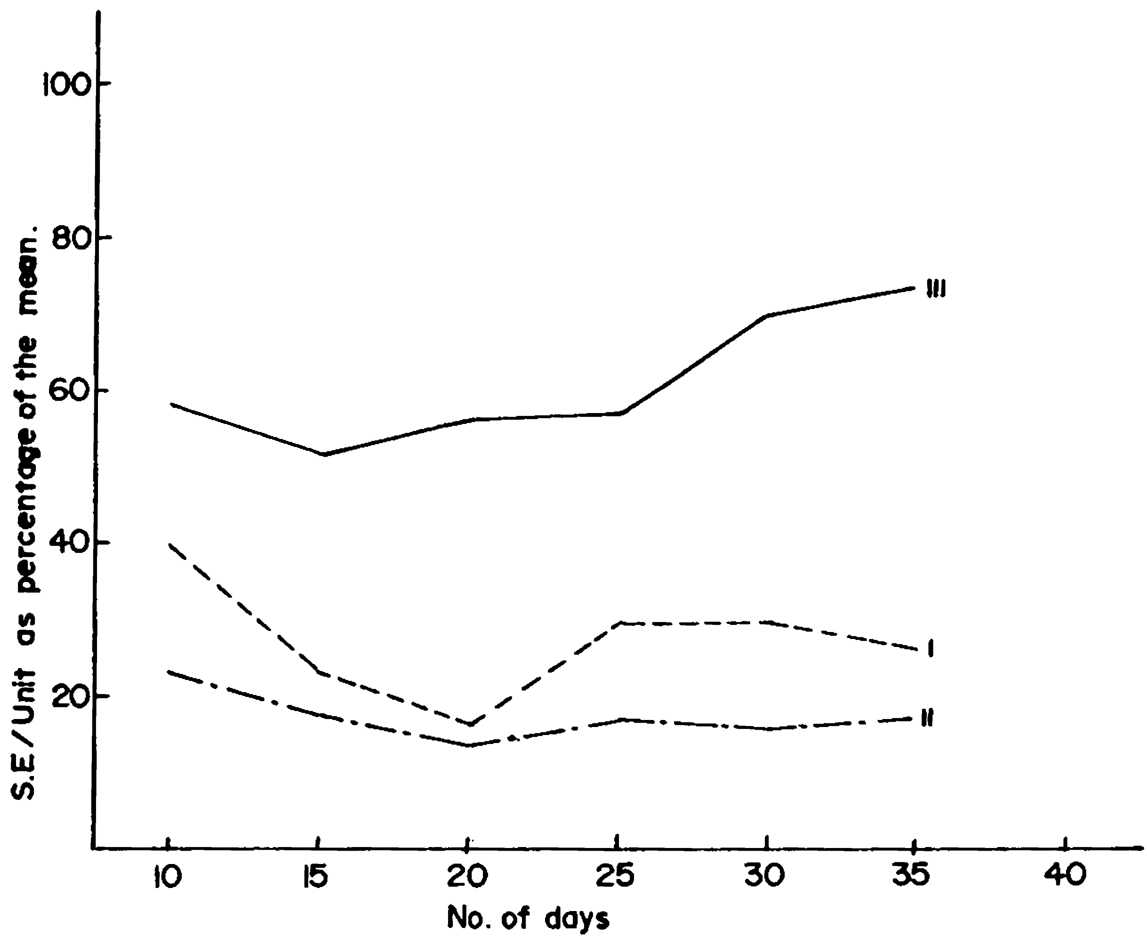


Fig. 2. RELATION BETWEEN STANDARD ERROR PER UNIT AS PERCENTAGE OF THE MEAN AND NUMBER OF DAYS.

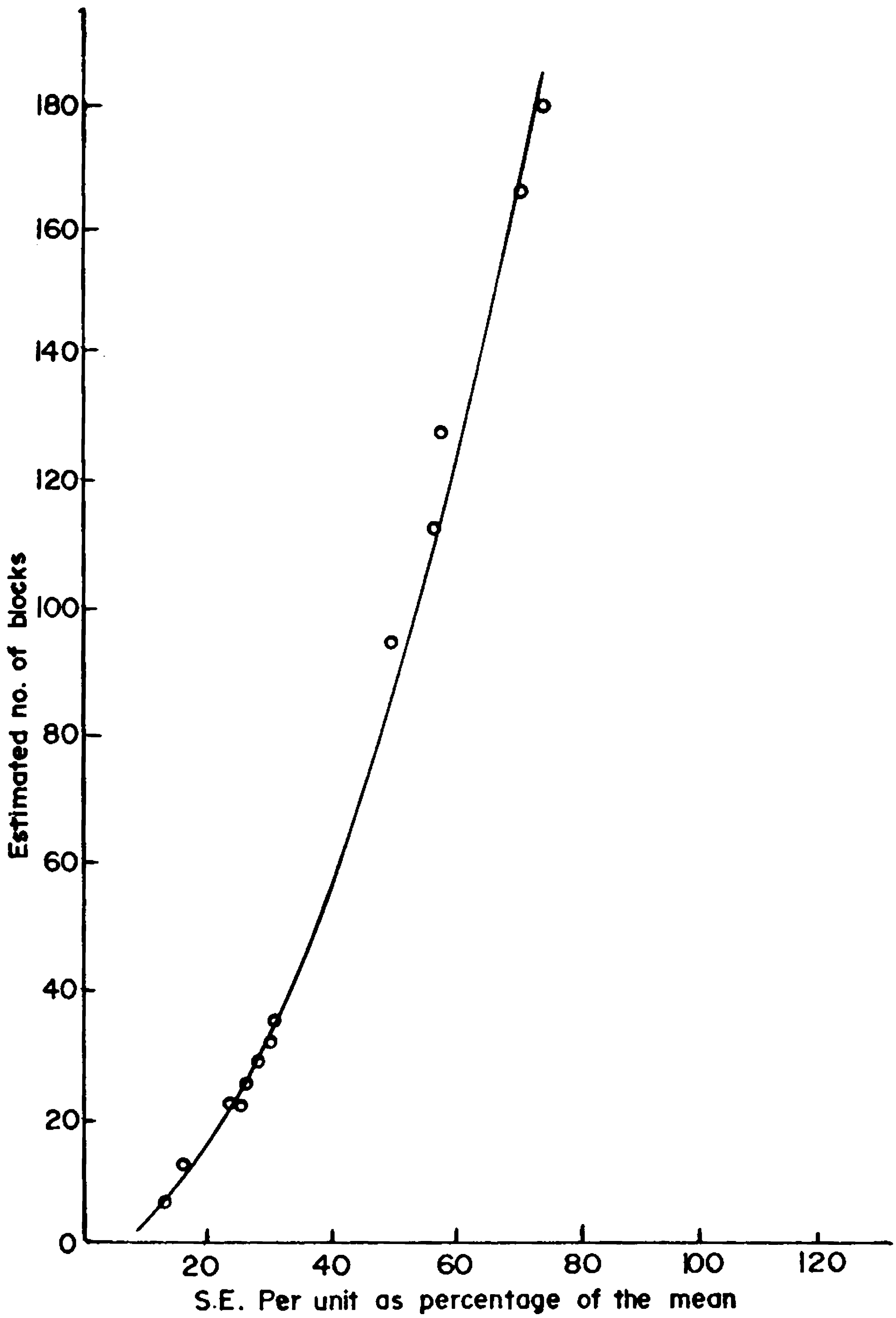


Fig. 3. RELATION BETWEEN ESTIMATED NUMBER OF BLOCKS AND STANDARD ERROR PER UNIT AS PERCENTAGE OF THE MEAN

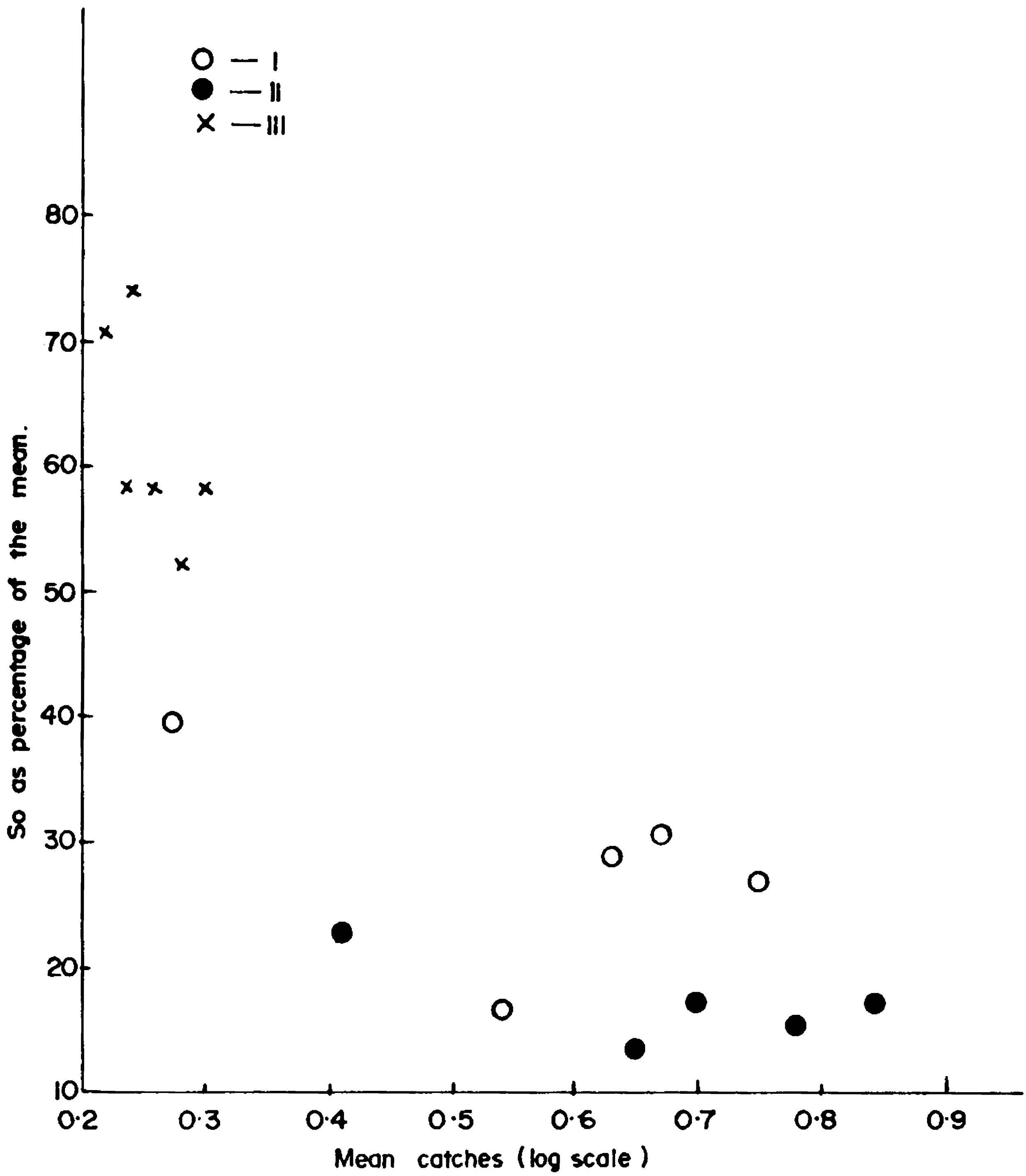


Fig. 4. RELATION BETWEEN MEAN CATCH AND So AS PERCENT OF THE MEAN.

appears to adequately represent the three sets of data. The figure shows that for standard error larger than about 30% of the mean, large number of blocks are required. For such sets of data (as in set 3), the estimation of number of blocks do not seem to be useful, because experiments requiring very large number of replications are not desirable from practical and economic points of view. Such data calls for other methods of handling. As found from Fig.4, larger standard error per unit as per cent of the mean are associated with smaller mean catches, the rate of increase in the former being rapid for decrease in the latter below a certain level. For instance, for the mean catch less than 0.4 (1.5 kg in original scale), the standard error as percent goes above 40. Thus, when the catch is very poor, standard error as percent of the mean and consequently the number of blocks required becomes very large making the analysis of variance less meaningful. The fact that when the availability of fish in the exploited area is very poor, catches will not reflect the efficiency of gear supports this conclusion.

With variations in the number of blocks, changes in the level of significance of the differences in treatment effects could be observed (Table 1). For set 3, though the significance level was very high ($p < 0.001$), the δ- value computed from equation (2) for 35 blocks was 46.1% of the mean showing that the experiment would detect only treatment effects as large as 46.1%. But the corresponding δ - values for set 1 and 2 were 16.7 and 11.0% of the mean respectively, which agree with the originally set δ -value of 20% or less. These results also support the observations made in the preceding paragraph.

In conclusion, as a practical procedure, the accumulated data can be analysed successively at the end of 10, 15, 20, ... days and depending on the standard error as percent of the mean, a decision on the number of trials can be made with 35 days' trial. If the standard error per unit as per cent of the mean stabilizes at about 30% or below, the experiment can be stopped and the decision at this stage can be taken as conclusive. The population which gives rise to such sets of data is probably less affected by fluctuations in the availability of fish because the replenishment and removal balance the subpopulations in the exploited area. For such data analysis of variance F-test as applied to randomised block design can be reasonably attempted. But when the catches are poor, say, with a mean catch less than 1.5 kg, standard error per unit will increase necessitating experimentation in very large number of blocks which would be impractical as well as uneconomical and analysis of variance approach would not be useful for such data.

For technical testing of trawls (which is not efficiency comparison of gear through catch data) Fridman *et al.* (1979) has pointed out that the number of trawling operations to be conducted may be different from the preliminary estimate for any one of the trawl characteristic. They have recommended conducting trawling experiments in half the number of trawling operations determined preliminarily. If the accuracy of the results is within the specified limits the tests are discontinued. Otherwise an equal number of trials are carried out and the accumulated experimental data are again processed. The tests are continued until the specified accuracy level is reached.

Cochran and Cox (1963) and Tippet (1952) have discussed the usefulness of sequential experimentation when the treatments can be applied to a unit in definite time sequence and when the process of measurement is very rapid so that the yield or response on unit is known before the experimenter treats the next unit in the time sequence. It can be seen that these conditions are fully satisfied for fishing experiments. The sequential experimentation has also the advantage that the experimenter can stop the experiment and examine the accumulated results before deciding whether to continue the experiment or not.

Table 1. Showing the mean, standard error per unit, standard error per unit as percent of the mean and b, computed from 10, 15, 20, 25, 30 and 35 days of fishing trials

No. of days	Mean (m)	Standard error per unit (S_o)	Standard error per unit as percent of the mean ($\frac{S_o}{m} \times 100$)	b	Significance of difference between treatments
A Set 1					
10	0.2756	0.10984	39.8	62	NS
15	0.4063	0.09651	23.5	21	*
20	0.5435	0.09103	16.7	10	*
25	0.6293	0.18425	29.3	30	NS
30	0.6699	0.20201	30.1	32	NS
35	0.7475	0.20059	26.8	25	NS
B Set 2					
10	0.4084	0.09767	23.9	23	*
15	0.5401	0.09735	18.0	12	*
20	0.6505	0.08962	13.8	7	**
25	0.6889	0.11922	17.3	11	**
30	0.7845	0.12506	15.9	9	*
35	0.8471	0.14996	17.7	11	**

Table contd.

C Set 3

10	0.3008	0.17570	58.4	133	*
15	0.2880	0.15193	52.7	103	**
20	0.2578	0.14743	57.2	116	*** ($p < 0.001$)
25	0.2375	0.13764	57.9	117	*** ($p < 0.001$)
30	0.2285	0.16174	70.8	173	*** ($p < 0.001$)
35	0.2391	0.17717	74.1	188	*** ($p < 0.001$)

NS = not significant; * = significant at 5% level

** = significant at 1% level, *** = significant at 0.1% level

CHAPTER 2

ON THE FURTHER PROBLEM OF NONADDITIVITY IN TWO WAY-ANOVA

2.1 Introduction

The difficulties in using analysis of variance (ANOVA) F-test for comparing the efficiency of fishing gear have been discussed by Nair (1982) and Nair & Alagaraja (1982). Broadly, these problems arose from the lack of satisfaction of the assumptions underlying analysis of variance. The importance of each assumption has been clearly discussed by Eisenhart (1947). Kempthorne (1967) has indicated that the main requirements on the usefulness of a model are the additivity of treatment effects and homogeneity of errors and that of these two additivity is more important. Treatment of nonadditivity in two-way classification has received much attention (Tukey, 1949; Mandel, 1961; Daniel, 1976; Johnson and Graybill, 1972a, b; Krishnaiah and Yochmowitz, 1980; Marasinghe and Johnson, 1981, 1982; Bradu and Gabriel, 1978 and Snee, 1982). Snedecor and Cochran (1968) describe the usefulness of Tukey's (1949) test of additivity "(i) to help decide if a transformation is necessary (ii) to suggest a suitable transformation and (iii) to learn if a transformation has been successful in producing additivity". Federer (1967) has observed that

Tukey's sum of squares for nonadditivity is increased when one or more observations are usually discrepant and when the row and column effects are not additive and that nonadditivity could arise from more than one source. Johnson and Graybill's (1972b) and Rao's (1974) methods of derivation and interpretation of Tukey's test show that when the above type of nonadditivity is present, the model is:

$$x_{ij} = \mu + \alpha_i + \beta_j + \lambda\alpha_i\beta_j + \epsilon_{ij}$$

and that Tukey's test correspond to testing $\lambda = 0$. x_{ij} stands for catch on the i^{th} day for the j^{th} gear, μ is the overall mean catch, α_i and β_j are the effects due to the i^{th} day and j^{th} gear respectively, λ a constant and ϵ_{ij} is the error team. Mandel, as quoted by Krishnaiah and Yochmowitz (1980), identified this model as the concurrent model and the concurrent model can be tested effectively by using Tukey's test for nonadditivity. Johnson and Graybill (1972b) and Hegemann and Johnson (1976b) have discussed that when Tukey's test shows significant nonadditivity, that is when the model given above describes the data, then the best way to analyse the data may be to find a transformation that will restore additivity. Bartlett (1947) gives a number of transformations suitable for various forms of relationship between the variance in terms of the mean and the distribution for which those are appropriate. He recommended logarithmic transformation for certain type of data with considerable heterogeneity. Nair (1982) has found that for data on fishing experiments with trawl nets logarithmic transformation did not stabilize the variance. Also application of Tukey's test to the data after logarithmic transformation showed highly significant nonadditivity ($p < 0.001$). Cochran (1947) has observed that nonadditivity tends to produce heterogeneity of the error variance. Snee (1982) discusses procedures to examine whether nonadditivity is caused due to nonhomogeneous variance or interaction between row and column factors. These show the relative importance of the assumption of additivity and this chapter presents the results of an investigation on nonadditivity in trawl net-catch data on comparative fishing efficiency studies and procedures to tackle the problem using graphical analysis and transformation.

2.2 Materials and Methods

To decide whether a transformation is necessary and if required what would be the appropriate one, Tukey's (1949) test of additivity was applied to the four sets of data given in Nair (1982). Graphical analysis of nonadditivity (Tukey, 1949) was applied to these data to check whether the nonadditivity was due to analysis in the wrong form or due to one or more usually discrepant values. Tukey's test of additivity leads to transformation of the form $Y = X^p$ in which X is the original scale. The procedure followed in Snedecor and Cochran (1968) was applied to determine 'p' to which X, the observation must be raised to produce additivity. 'p' is estimated by $(1-B\bar{X}..)$, where B is the regression coefficient in the linear regression of the residual $(X_{ij}-\hat{X}_{ij})$ on the variate $(\bar{X}_{i}.-\bar{X}..)\ (\bar{X}_{.j}-\bar{X}..)$. An estimate of B is obtained from $B = \frac{N}{D}$, where $N = \sum w_i d_i$, $w_i = \sum X_{ij}\ d_j$, $d_i = (\bar{X}_i.-\bar{X}..)$, $d_j = (\bar{X}._j-\bar{X}..)$ and $D = (\sum d_i^2)\ (\sum d_j^2)$; $\bar{X}_i.$, $\bar{X}._j$ and $\bar{X}..$ refer to the row (block) means, column (treatment) means and grand mean respectively. Tests for nonadditivity is given by F, where F follows Snedecor's F distribution with 1 and $[(r-1\ (c-1)-1]$ degrees of freedom, r and c indicating numbers of rows and columns, respectively. Tukey (1949) discusses transformations which are additive for $0 \leq p < 1$, $P = 1$ and $1 < p$ and $\log (x+a)$ corresponding to none of these. Snedecor and Cochran (1968) stated that when $p = -1$, it is a reciprocal transformation analysing $1/X$, instead of X. ($p = o$ corresponds to logarithmic transformation because for p very small X^p behaves like $\log X$).

2.3 Results and Discussion

Application of Tukey's test of additivity for the four sets of data on trawl catch (Nair, 1982) showed that there was significant nonadditivity in all the sets (Table For sets 1-3 (that is for the actual data), nonadditivity was found to be very highly significant with $p < 0.001$.

Table 1. Test for nonadditivity of the four sets of data

	F for nonadditivity	Degrees of freedom
Set 1	38.64***	1,67
Set 2	63.87***	1,67
Set 3	87.70***	1,67
Set 4	4.80*	1,18

Tukey's (1949) procedure was followed to check whether nonadditivity was caused by the presence of one or more discrepant observations or due to the need for a transformation. His method of graphical analysis for detecting the discrepant observations (outliers) was applied to the four sets of data. The method involves in plotting W_i against the block means. According to Tukey, "a usually discrepant observation will tend to be reflected by one point high or low and the others distributed around a nearly horizontal line. An analysis in the wrong terms will tend to be reflected by a slanting regression line". To determine the points high or low Tukey provided a 2s limit, namely,

$$\text{(Average cross product)} \; (= \Sigma w_i/\text{no. of rows}) \pm 2 \left\{ \begin{matrix} \text{sums of squares} \\ \text{of deviations} \\ \text{of column} \\ \text{means } (= \Sigma d_j^2) \end{matrix} \right\}^{\frac{1}{2}} \left\{ \begin{matrix} \text{Means square} \\ \text{for balance} \end{matrix} \right\}^{\frac{1}{2}}$$

The plots of w_i against the row means with the 2s limits for sets 1–4 are presented in Figs. 1–4. The figures show the presence of outliers in all the four sets ranging from 1 to 5 in number. It is clear from the figures that the points excluding the outliers are distributed on a nearly horizontal line for set 1 and on a slanting regression line for sets 2 to 4. This shows that no transformation is required for set 1 after removing the outliers while it is required for the other sets. This was confirmed by applying Tukey's test to the outlier-eliminated data (Table 1). Sets 2–4 showed the presence of nonadditivity indicating the need for a transformation for these sets.

The power transformation $Y = X^P$, suggested by Tukey's test of additivity were worked out for sets 2–4. These have been presented in Table 3 along with the estimated values of B and P. For set 2, the transformation worked out to $Y = X^{-0.31}$, which is a reciprocal transformation.

Table 2. Test for nonadditivity of the outlier-eliminated data

	F for nonadditivity	Degrees of freedom
Set 1	0.02 (not significant)	1,59
Set 2	9.90**	1,61
Set 3	34.37***	1,57
Set 4	15.23**	1,17

* Significant at 5% level; ** Significant at 1% level;

*** Significant at 0.1% level

Table 3. Tukey's transformation after eliminating the outliers

	B	P	$Y = X^P$
Set 1	Data additive after exclusion of outliers		
Set 2	0.1594	-0.31	$X^{-0.31}$
Set 3	1.0335	0.0618	$X^{0.0618}$
Set 4	0.0166	0.1594	$X^{0.1594}$

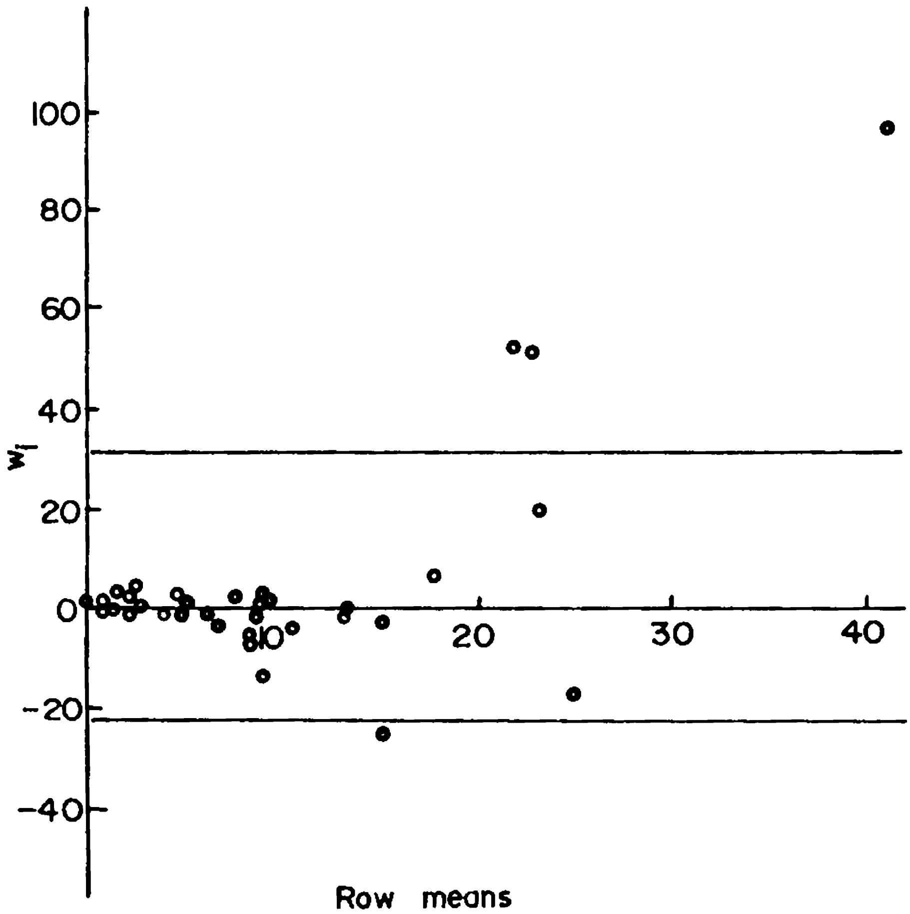


Fig.1. PLOT OF w_i ON ROW MEANS WITH THE 2S LIMITS FOR SET I.

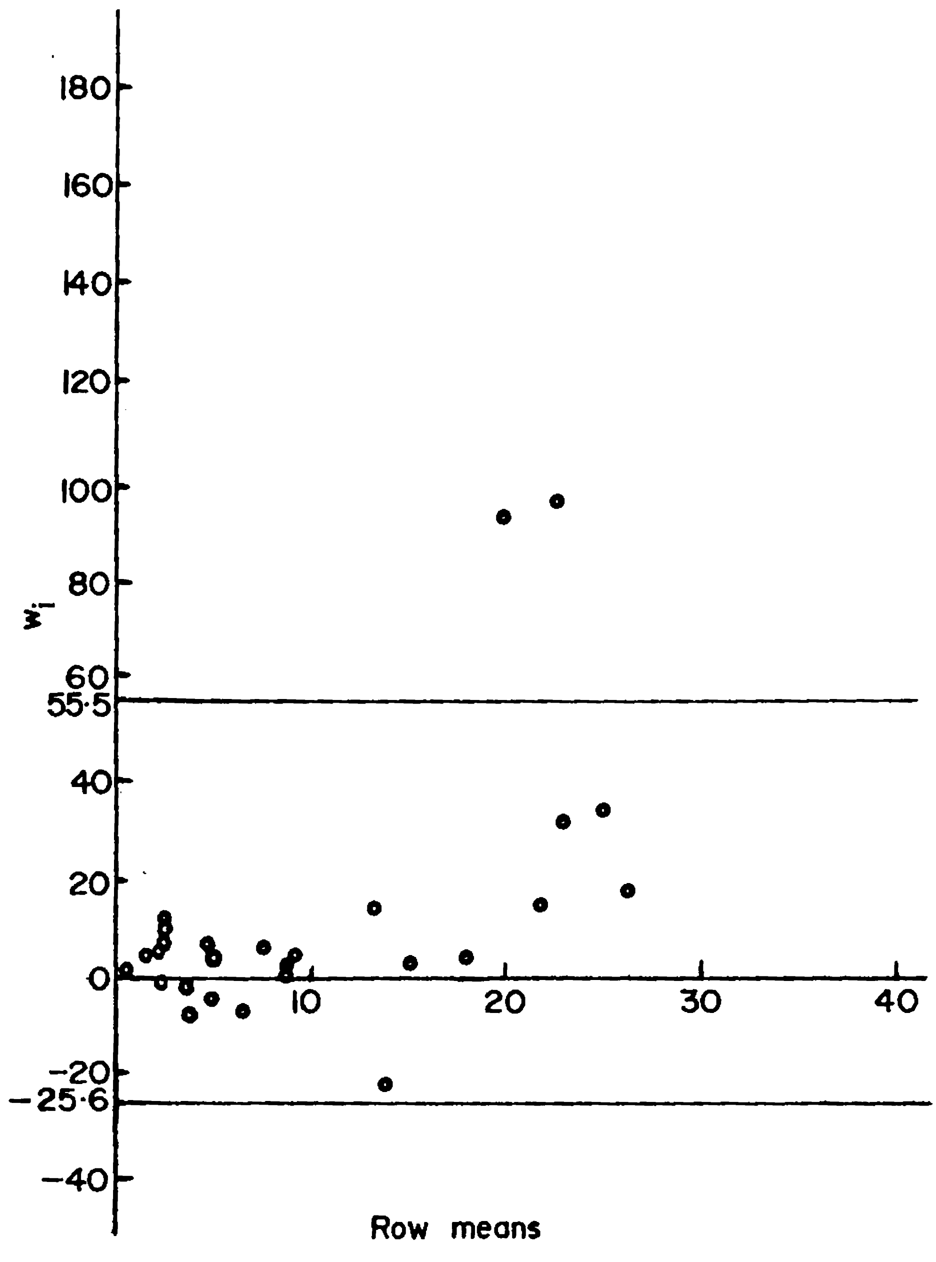
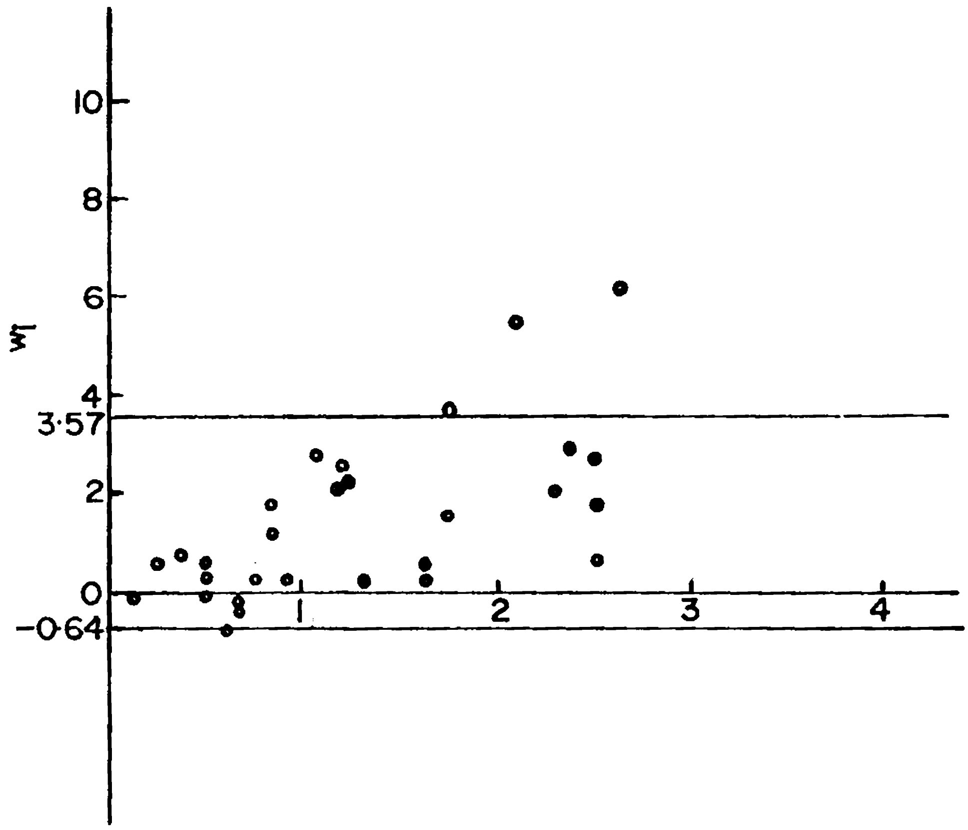


Fig.2. PLOT OF w_i ON ROW MEANS WITH THE 2S LIMITS FOR SET 2.



Row means

Fig.3. PLOT OF w_i ON ROW MEANS WITH 2S LIMITS FOR SET 3.

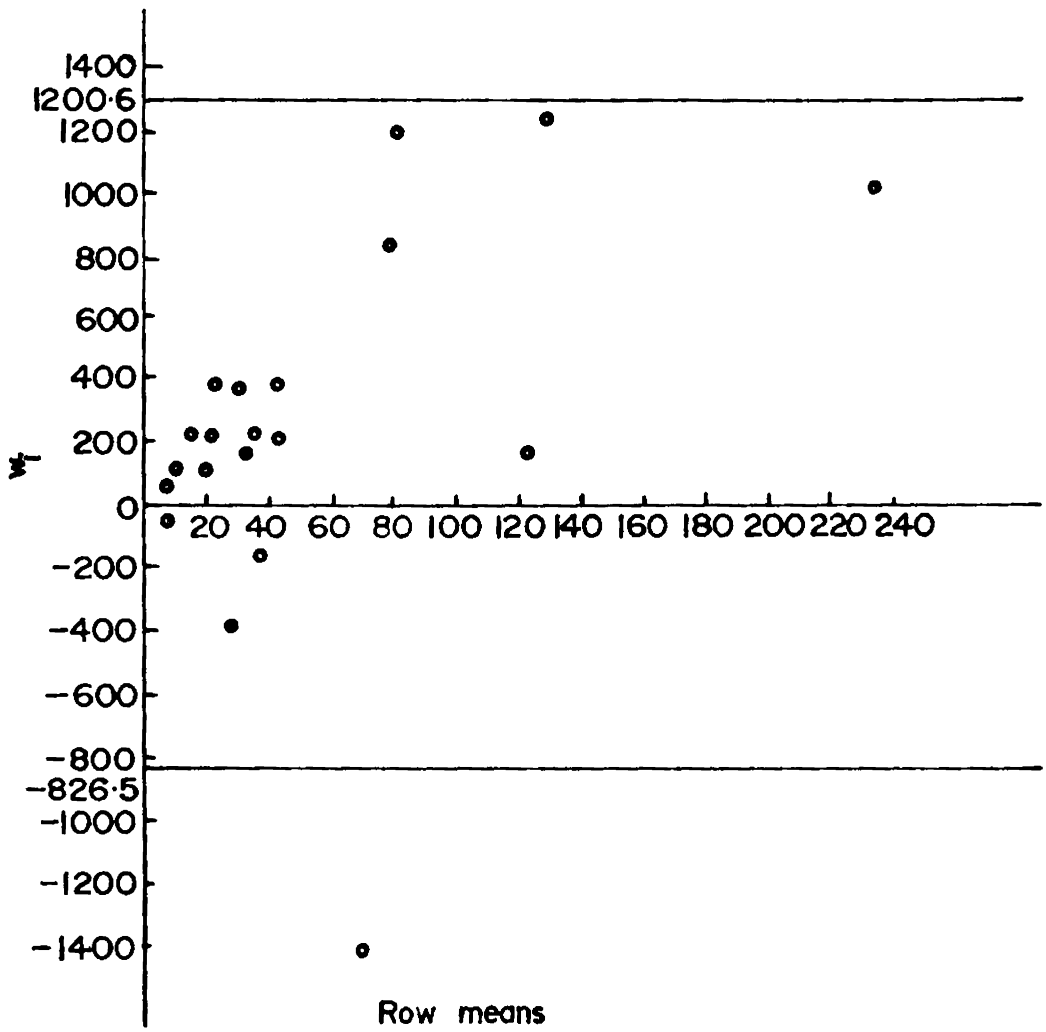


Fig. 4. PLOT OF w_i ON ROW MEANS WITH 2S LIMITS FOR SET 4.

For set 3, the transformation obtained was $Y = X^{0.0618}$ and for set 4, $Y = X^{0.1594}$.

The data were analysed after carrying out these transformations. Tukey's test of additivity now showed, nonadditivity to be insignificant for all the sets (Table 4). The reduction by 4 in the lower d.f.

Table 4. Test for nonadditivity of the outlier-eliminated and transformed data

	F for nonadditivity	Degrees of freedom
Set 1	Not applicable as data is additive after exclusion of outliers	
Set 2	2.55 Not significant	1,57
Set 3	0.05 "	1,57
Set 4	0.13 "	1,17

for set 2 is due to omission of two rows where one observation each was zero. Though p was as small as 0.0618 for set 3, logarithmic transformation did not remove nonadditivity, F for nonadditivity being 12.97***, which is highly significant for 1 and 57 degrees of freedom. Thus application of the power transformation suggested by Tukey's test to the data after eliminating the outliers has been found to be effective in making the data additive. In case where nonadditivity is not accounted for by Tukey's transformation and outlier elimination by graphical analysis or in other words where the concurrent model does not describe the data, there are other methods for testing the structure of interaction and testing the main effects, for instance, methods mentioned by Marasinghe and Johnson (1982) (for a multiplicative interaction structure) and Krishnaiah and Yochmowitz (1980).

Daniel (1976) points out that nonadditivity is often associated with a few rows or columns of the two-way table. Snee (1982) states that nonadditivity in a two-way classification with one observation per cell may be either due to nonhomogeneous variance or interaction and the data may not be sufficient to distinguish between these two. However, ways and means for interpretation of the observed nonadditivity has been discussed by this author. Federer (1967) states that the sum of squares associated with Tukey's one degree of freedom for nonadditivity gives the linear row by linear column interaction. Nair (1982) reported the dependence of standard error per unit on the average catch. A look at the model considered in this paper will show that when the availability of fish changes over period of days, the α_i's may change, for different periods causing this situation. (The dependence of variance on the mean also suggests nonnormality).

Apart from graphical procedure, much work has been done on the rejection of outliers. Rules for rejection has been discussed by Anscombe (1960), Anscombe and Tukey (1963) and Snedecor and Cochran (1968). Lately, Gaplin and Hawkins (1981) have presented bounds for the fractiles of maximum normed residuals (MNR). The present procedure is convenient to apply along with additivity test because the steps involved in testing provide the material for graphical analysis.

The present study shows that elimination of the outliers by graphical analysis and application of Tukey's test of additivity can be adopted to tackle the problem of nonadditivity in the analysis of catch data. Nair and Alagaraja (1982) suggested Wilcoxon matched-pairs signed-rank test as an appropriate procedure for comparing the efficiency of two fishing gear and illustrated with a set of data the superiority of this method over usual ANOVA. (Ordinary ANOVA was less sensitive in this case). The same set of data was analysed using the above procedure (that is outlier-elimination and application of Tukey's test of additivity and the consequent transformation as introduced and discussed in this chapter) and the same result as that given by

Wilcoxon test was obtained. This shows the usefulness of this combination of procedures in statistical comparison of the efficiency of fishing gear.

CHAPTER 3

A SIMULATION TO TRACE THE PROBLEMS FACED IN THE CLASSICAL APPROACH

3.1 Introduction

Gear efficiency studies normally lead to determination of superiority of one gear over other when the gear have different efficiencies or in other words different catchabilities. There are two cases when the differencesmay not be discernible. The obvious case is one when the efficiencies of the gear are more or less equal. There is another case which is normally overlooked where inspite of the existence of differences in the gear efficiencies, the experiment is not able to bring them out.

This chapter attempts to analyse the latter case, perhaps for the first time in the literature, when two gear are involved. Let the catchability coefficients of two gear be q_1 and q_2 respectively. For given q_1 and q_2, there exists a Nc, the level of the stock such that when the stock level N is less than Nc, the catches of the two gear are not able to show wide differences to indicate the efficiency of one over the other. However, whenever N is greater than Nc, there is every likelihood of finding out the relative efficiencies of the gear. When N is sufficiently large such that the successive removals by the gear do not affect the stock, then this case does not arise. But present day methods of exploitation affect the stock in such a way, for instance in intensive trawling, the assumption that N is sufficiently large may not hold good. Hence it is necessary to study the relationship between Nc and the catchability coefficients of the gear.

In order to find the relation between Nc, q_1 and q_2 different models have been proposed and one is selected with maximum 'R^2' (coefficient of multiple determination) and minimum variance on the basis of data simulated. The selected model is

$$\text{Log Nc} = a_o + a_1 q_1 + a_2 q_2 + \frac{a_3}{q_2 - q_1}$$

Suitable test procedures for comparing the efficiencies when N exceeds Nc have also been pointed out.

3.2 Materials and Methods

To gain information on the critical number of fish (Nc) which should be present in the area of experimentation, for discerning the efficiencies for gear, models involving the catchability coefficients of the gear and the numbers of fish caught were considered. A simple case for two gear under the assumption that there was no recruitment during the fishing activities was considered by simulating the catches. From the simulated catches, various functions of f (Nc, q_1, q_2) involving the critical number Nc and the catchability coefficients q_1 and q_2 were considered and the best fit was determined by the well known multiple regression method. The response curves were used to study the relationship between the catchability coefficients and the critical numbers. Application of Wilcoxon matched-pairs signed-rank test as given in Siegel (1956) was illustrated with simulated data and worked out for examples given in Nair (1982). Gulland's (1967) method was used to estimate the efficiency ratios.

3.3 Results and Discussion

The fish catch in terms of the efficiency of gear component is given by

$$C = \rho A \; (\sum li \; \mathcal{E} i) \; vt$$

where C = catch, ρA = density of fish in fishing area, li length of gear component i (calculated as the projected length perpendicular to the direction of motion), V = fishing gear speed, t = effective fishing time and $\mathcal{E}i$, the efficiency of the gear component (Foster, 1969; Foster *et al.*, 1977). Homogenising all conditions except the difference in the design of the gear, the above equation simplifies to

$$C_i = q_i N$$

for unit effort, where C_i is the catch of the i^{th} gear, q_i is the proportion of fish removed by the gear (that is the catchability coefficient) and N, the number of fish in the area of exploitation. The catches were simulated using the relationship

$$C_{i1} = q_i N$$

where C_{i1} is the initial catch of the i^{th} gear with catchability coefficient q_i and N is the number of fish in the exploited area present at the first operation. Assuming there was no recruitment during the subsequent days of fishing,

$$C_{ij} = q_i (N-k_{ij})$$

where $k_{ij} = \sum_{r=1}^{j-i} C_{ir}$, with $k_{i1} = 0$, holds good for the catch of i^{th} gear at the j^{th} operation when the i^{th} gear alone is operated. To illustrate the procedure the simulated catches for two gear with catchability coefficients $q_1 = 0.1$ and $q_2 = 0.2$ for an initial population of 100 fish are presented in Table 1. As the gear are operated simultaneously in the same area $q_1 + q_2 = 0.3$ is the proportion of fish caught by the two gear and $q_2/q_1 = 2$ is the ratio of the efficiencies, that is, the second gear is twice as efficient as the first one. The table shows that the 9th and subsequent operations give equal catches for the two gear, though the

Table 1. Simulated catches obtained at successive operations by two gear 1 and 2, taking the initial number of fish at the exploited area to be 100

Sl. no. of operation	Removed by		Total removal by the two gear	N$_\varphi$ of fish at the time of fishing
	Gear 1	Gear 2		
1	10	20	30	100
2	7	14	21	70
3	5	10	15	49
4	3	7	10	34
5	2	5	7	24
6	2	3	5	17
7	1	2	3	12
8	1	2	3	9
9	1	1	2	6
10	1	1	2	4
11	1	1	2	2

second is twice more efficient than the first. The sizes of initial populations were taken as 100, 1000 and 10000 and it was found that variations in the sizes of initial populations did not affect the critical number for given q_1 and q_2. When the initial size is large, the size of the population will approach the critical number only after a large number of operations, as can be visualized from the model. If N were known, the catchability coefficients and hence the efficiency ratios could have been determined directly.

As the critical number depends on how much apart are q_1 and q_2 and the strength of available stock at that instant, the catches were first simulated for $\frac{q_1}{q_2}$ ranging between 0.1 and 0.9, taking q_1 to be the smaller coefficient of the two at different stock strengths. The actual ratios corresponding to different efficiency ratios q_2/q_1 and different totals $(q_1 + q_2)$ on the first and subsequent operations are given in Fig. 1. It can be seen that in the initial stages, that is corresponding to large initial populations, the catch ratios and the efficiency ratios coincide and subsequently when the numbers of fish in the exploited areas become small, the catch ratios vary widely from the efficiency ratios. For example, when the efficiency ratio is 2.5 or less the catch ratios show equal efficiency as the stock becomes small as seen in Fig.1. This shows that the catches become ineffective to show efficiency when the number of fish in the exploited area is reduced below Nc.

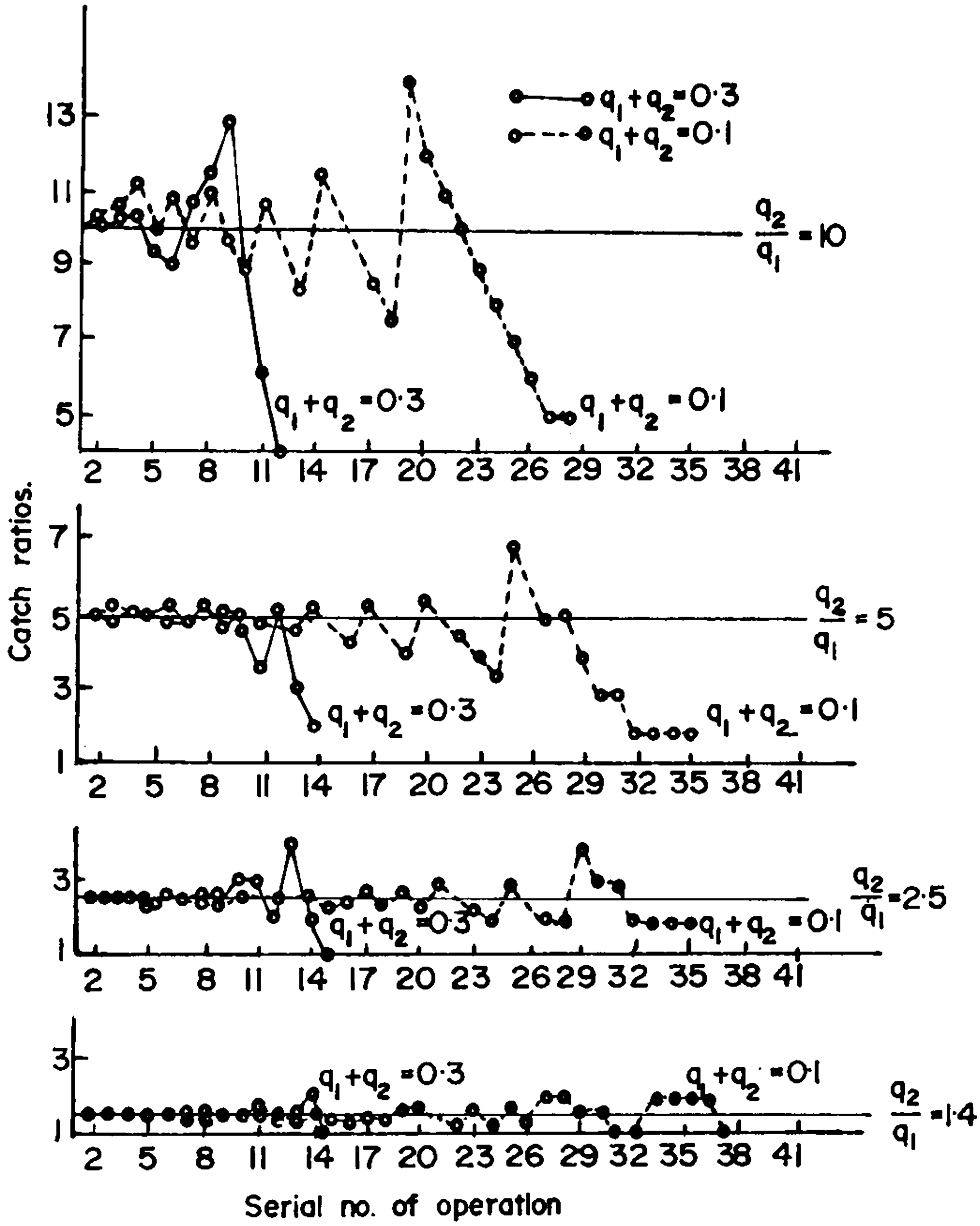


Fig.1. CATCH RATIOS CORRESPONDING TO EFFICIENCY RATIOS, 10, 5, 2·5 AND 1·4.

Now as Nc depends on q_1 and q_2, some models were tried for f (Nc, q_1, q_2). Log Nc gave increased R^2 values when multiple regression of log Nc on q_1, q_2 and f (q_2-q_1) were tried. Table 2 shows the goodness of fit of some of the models

Table 2. The regression planes and the multiple coefficients of determination (R^2) and the standard errors of the estimate (S.E.E.)

Sl.No.	Fit	R^2	S.E.E.
1	$\text{Log Nc} = a_0+a_1\frac{(q_1)}{q_2}+a_2(q_1+q_2)$	0.8969	0.2874
2	$\text{Log Nc} = a_0+a_1(q_1+q_2)+a_2(q_1q_2)$	0.6931	0.4958
3	$\text{Log Nc} = a_0+a_1q_1+a_2q_2$	0.8025	0.3977
4	$\text{Log Nc} = a_0+a_1q_1+a_2q_2+a_3(q_1/q_2)$	0.9038	0.2842
5	$\text{Log Nc} = a_0+a_1q_1+a_2q_2+a_3(q_1/q_2)$	0.8176	0.3912
6	$\text{Log Nc} = a_0+a_1q_1+a_2q_2+a_3(q_1/q_2)+ a_4\left(\frac{q_1q_2}{q_2-q_1}\right)$	0.9041	0.2906
7	$\text{Log Nc} = a_0+a_1q_1+a_2q_2+\frac{a_3}{q_2-q_1}$	0.9090	0.2763

tried for q_1/q_2 ranging from 0.4 to 0.9 and $(q_1 + q_2)$, from 0.1 to 0.5. Table 2 shows that the last model (No.7), given by

$$\text{Log Nc} = a_0 + a_1q_1 + a_2q_2 + \frac{a_3}{q_2-q_1}$$

gives the maximum R^2 and minimum standard error of the estimate (S.E.E.). Compared with equation (6) which also gives an almost equally high value of R^2, equation (7) has the advantage that it is simpler being one less in the number of terms on R.H.S. and gives as much information on Nc as equation (6) does. Similarly when compared with equation (4) which also gives an almost equal value of R^2, equation (7) has the advantage that it fits better by also including the condition that when $q_2 = q_1$, Nc becomes indeterminate. Thus equation (7) was taken to describe $f(Nc, q_1, q_2)$. To cover a wide range of values, log Nc values were simulated for $(q_1 + q_2)$ ranging between 0.0001 and 0.5 and q_1/q_2 between 0.3 and 0.9 (or correspondingly q_1 ranging between 0.0000231 and 0.2368421 and q_2 between 0.0000526 and 0.3846154). An equation fitted using 140 sets of simulated values of log Nc, q_1 and q_2 in the above range is

$$\text{Log Nc} = 6.85710+21.59985q_1-34.31757q_2+\frac{0.0000562}{q_2 - q_1}$$

with $R^2 = 0.7116$ and S.E.E. = 1.3770. The inclusion of a large number of observations reduced the value of R^2 as is expected. As there is interrelationship between the predictor variables, the significance of individual regression co-efficients is not important and it is only the significance of overall relationship that is important (Mendenhall and Reinmuth, 1978).

The response curves of log Nc on q_1 and q_2 are shown in Fig.2. As q_1 increases log Nc increases linearly at first and as q_1 approaches q_2, the lines take a vertical turn (Fig. 2A). On the other hand the response curves of q_2 are such that as q_2 decreases log Nc increases lineraly until q_2 approaches q_1. When q_2 approaches q_1, the line takes a vertical turn (Fig.2B). The isopleths of log Nc are presented in Fig. 2C. The isopleths are almost straight lines until they approach the 45° line and turns asymptotic to this line. When q_1 and q_2 are almost equal, the isopleths become very close to one another but however, they never meet. At this stage Fig.2 is not sensitive enough to identify the different isopleths. The smaller the values of log Nc, the more the scope for larger difference in q_1 and q_2. The foregoing account shows that there is a critical number such that when the number of fish in the exploited area falls short of this number, it may not be possible to discern the efficiencies by comparing the catches. The critical number depends on the efficiencies of the gear. The 'null region' is termed to refer to the region where the number of fish in the exploited area is less

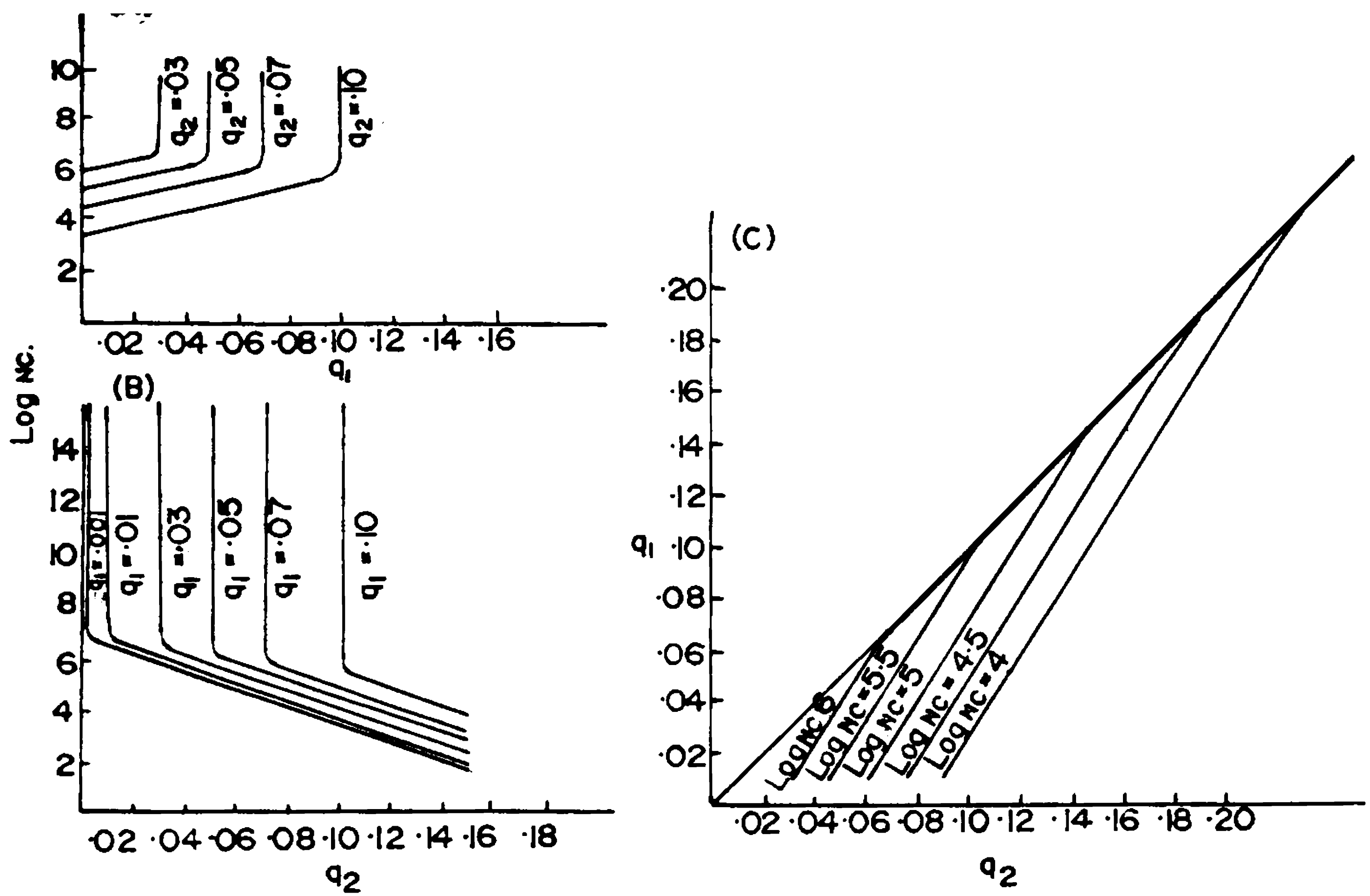


Fig.2. RESPONSE CURVE AND ISOPLETHS

than Nc and where comparison of the efficiencies is not possible by means of catches. The other region where comparison is possible is termed the effective region.

Tests for comparing the efficiencies in the effective region:

In the effective region when N > Nc two cases arise. (i) N is sufficiently large and the removal at each instant is relatively small, so that the successive removals do not affect the stock (ii) N is not large so that the successive removals decrease the stock at each instant. In case (i) ANOVA F-test may be applied to compare the efficiency of gear. In case (ii) as the availability of fish decreases subsequently, the size of the block also decreases. Therefore ANOVA F-test may not be useful. Cochran and Cox (1957) observes: "As a rule, the failure of an assumption will affect both the significance levels and the sensitivity of F- and t-tests. When the experimenter thinks that he is testing at the 5% level, he may actually be testing at the 8% level. Usually though not invariably, the true significance probability is larger than the apparent one; that is too many significant results are obtained. Also, there is usually a loss of sensitivity, in the sense that a more powerful test than the analysis of variance F-test could be constructed if the correct mathematical model were known". In this situation, a nonparametric test which do not require strong assumptions appears to be more appropriate. When two gear are involved, Wilcoxon matched-pairs signed-rank test which takes into account both the ranks and the magnitude of the difference (Siegel, 1956) may be applied. In addition to the magnitude of the difference, this test would be sensitive to consistent but small differences in the catches of the two gear. As Wilcoxon test does not appear to have been used in comparative efficiency studies of fishing gear, it is briefly described here. It consists in forming the difference d, between the pairs of catches. The differences are then ranked ignoring the sign, attributing rank 1, to the smallest d. The signs of d are then affixed to the corresponding ranks. When catches by the two gear are the same, the corresponding d's will be zero. Such pairs are dropped and the total number of pairs, N is taken excluding the pairs for which d = 0. When two or more d's are the same the average rank is assigned to the tied d's. The test criterion is defined as T = the smaller sum of like signed ranks. That is, T is either the sum of the positive ranks or the sum of the negative ranks whichever sum is smaller. The critical value of T, presented in Table 1 of Wilcoxon (1949) has been adapted and given in Table G of Siegel (1956). When T is less than or equal to the tabulated value at a given significance level, the null hypothesis may be rejected. When $N > 25$, $Z = \frac{T - \mu_T}{\sigma_T}$, where $\mu_T = \frac{N(N+1)}{4}$ and $\sigma_T = N \frac{(N+1)\ (2N+1)}{24}$ is approximately normally distributed with zero mean and unit variance.

The method is illustrated with a set of simulated data (Table 3). The simulated catch for two gear for 20 pairs of hauls are given in columns (2) and (3). The difference d, that is, A-B is given in column (4), and the ranks of d (ranking being done ignoring the sign) in column (5). T, the smaller sum of the like signed ranks is 42.5 that is $T = 7 + 13.5 + 20 + 2 = 42.5$. Since this is less than 43 at 2% level from the table of critical values of T, the null hypothesis that the gear are equal in efficiency is rejected. On the basis of ANOVA F-test carried out for the same set of data with and without logarithmic transformation, the null hypothesis was not rejected, F (for difference between gear) being 2.97 and 3.30 respectively with 1 and 19 d.f. This clearly indicated the sensitivity of Wilcoxon matched-pairs signed-rank test. In the light of this, Wilcoxon test was applied to the examples given in Nair (1982). However, the results were not contradicted by Wilcoxon test (Table 4). For the simulated data, where the superiority of one gear is consistently found, ANOVA F-test failed to show significant differences whereas Wilcoxon test did not.

Table 3. Wilcoxon matched-pairs signed-rank test applied to simulated data

Paired haul (1)	Catch by gear A (2)	Catch by gear B (3)	d (4)	Rank of d (5)
1	280	185	95	17
2	185	70	115	19
3	135	25	110	18
4	130	115	15	7
5	115	40	75	16
6	60	25	35	13.5
7	60	25	35	13.5
8	45	25	20	10
9	40	25	15	7
10	40	5	35	13.5
11	30	45	-15	-7
12	25	15	10	4.5
13	25	5	20	10
14	25	5	20	10
15	15	5	10	4.5
16	10	45	-35	-13.5
17	10	5	5	2
18	10	5	5	2
19	5	135	-130	-20
20	5	10	-5	-2

Table 4. Wilcoxon's test, ANOVA F-test and Gulland's method applied to examples in Nair (1982)

Wilcoxon matched-pairs signed-rank test

Pairs	n	$Z = \frac{T - \mu_T}{\sigma_T}$	Significant or not
A, B	27	-3.63	Significant ($p = 0.00016$)
B, C	28	-3.06	" ($p = 0.0022$)
C, A	26	-4.19	" ($p < 0.00006$)

ANOVA F-test

Pairs	n	F	Significant or not
A, B	35	21.39	Significant ($p < 0.001$)
B, C	35	8.97	" ($p < 0.01$)
C, A	35	28.99	" ($p < 0.001$)

Gulland's method

Pairs	n	Ratio	Confidence interval
A, B	15	2.11	(1.39, 3.19)
B, C	21	2.32	(1.45, 3.38)
C, A	17	4.45	(2.48, 7.99)

The differences in the sample sizes (n) are due to dropping observations giving d = 0 for Wilcoxon test and observations with '0' for Gulland's ratio.

As an estimate of the relative efficiency of the two gear is desirable, a ratio of the total catch by all hauls of the two gear (Pycha, 1962; Gulland, 1967; Dickson, 1971 and Vijayan and Rao, 1982), would be useful. Pycha (1962) estimated the ratio for different months and the whole season. Gulland's (1967) method provides a confidence interval for this ratio. For the simulated data (Table 3) the ratio obtained by Gulland's method was 1.53 with a confidence interval (0.89, 2.65). When the ratios are not consistent, the confidence interval becomes wide as the standard error increases The intervals being sensitive to outliers, the consistent performance of one gear over the other may not be reflected in the intervals. For the other sets (Table 4), the rejection of the null hypothesis was also evident from the confidence intervals as the lower limit of the confidence intervals exceeded unity in all the cases.

CHAPTER 4

EFFICIENCY COMPARISON OF GILL NETS

4.1 Introduction

Statistical comparison of the efficiency of fishing gear becomes necessary in the process of recommending new or modified fishing gear. Owing to the typical nature of the catch data in comparison with other production data resulting from more controlled conditions, there are problems in applying some of the parametric methods straight away for comparison of the catches of the competing gear. The problems involved in the application of Analysis of variance F-test have already been discussed in the previous chapters. Uses of alternate methods and combination of procedures for comparison of trawl catches have been discribed in the last two chapters. Gill nets are passive where the effort to get entangled in the net is predominantly depending on the movements and other behaviour of the fish. Trawl nets exploit a wider range of the population when compared to gill nets. In trawl nets size selection has only a lower limit. That is fishes below a minimum length only will escape through the net. In gill nets, there are minimum and maximum limits so that fish below the minimum size and those above the maximum size escape. Due to these differences the nature of catch data yielded by gill nets are different from those of the trawl nets. Therefore an examination of the data to suggest a suitable procedure becomes necessary. This chapter reports the details of an investigation conducted on this line.

4.2 Materials and Methods

Three sets of gill net catch data have been used for the purpose of this investigation. The data yielded from randomised block experiments with gear as treatments and days as blocks as described in chapter 1 have been analysed. Ordinary analysis of variance, the combination of procedures involving Tukey's test of additivity, transformation and outlier detection method as suggested by Nair and Alagaraja (1984) and the Non parametric Friedman test were applied to the data.

4.3 Results and Discussion

Tukey's test was applied to the three sets of gill net catch data. Nonadditivity was found to be highly significant (Table 1) as in the case of trawl catches (Nair and Alagaraja, 1984) for all the sets. A plot of W_i on block means for the first set showed the points as lying along a sloping line necessitating a transformation. The 2S limits showed the presence of 3 points outside the limit for the

Table 1. Tukey's test of nonadditivity applied to sets of gill net catch data

	Source	S.S.	D.F	M.S	F
Set 1	Total	414.996	263		
	Gear	8.973	5	1.7947	
	Days	239.163	43	5.5619	
	Nonadditivity	72.511	1	72.511	156.2**
	Remainder	99.348	214	0.464	
Set 2	Total	1885.530	461		
	Gear	97.494	5	19.499	
	Days	1035.773	76	13.629	
	Nonadditivity	89.044	1	89.044	50.88**
	Remainder	663.219	379	1.7499	
Set 3	Total	708.0976	81		
	Gear	14.0976	1	14.0976	
	Days	563.0976	40	14.0774	
	Nonadditivity	36.8872	1	36.8872	15.30**
	Remainder	94.0152	39	2.4106	

first set. As these points lay along a sloping line (Fig.1), the question arises whether these are to be treated as outliers or not. Here a transformation would be sufficient to correct the nonadditivity as all the points lie along a sloping line regardless of whether the point lies outside the 2S limit or not. Tukey (1949) has commented that in cases like this it was not always possible to distinguish between discrepant observations and wrong terms from the graph. At this stage an examination of the experimental material seems useful. It may be noted that though the nets operated on each day may have the same area so that catches of different nets operated on any day is comparable, over the days, the areas may differ. The effect of this may be shown as nonadditivity because of the relatively huge catches corresponding to days when nets with larger areas are operated. Further, as already stated, the gill net catches are affected by less number of extraneous factors compared to trawl catches which are further affected by factors like speed of the boat, mode of operation of the gear and the opening of the gear. Therefore the changes in the availability of fish over the days may cause a multiplicative effect leading to nonadditivity but the chances for the presence of outliers may be less. The catch ratios of pairs of gear may not differ widely in such cases.

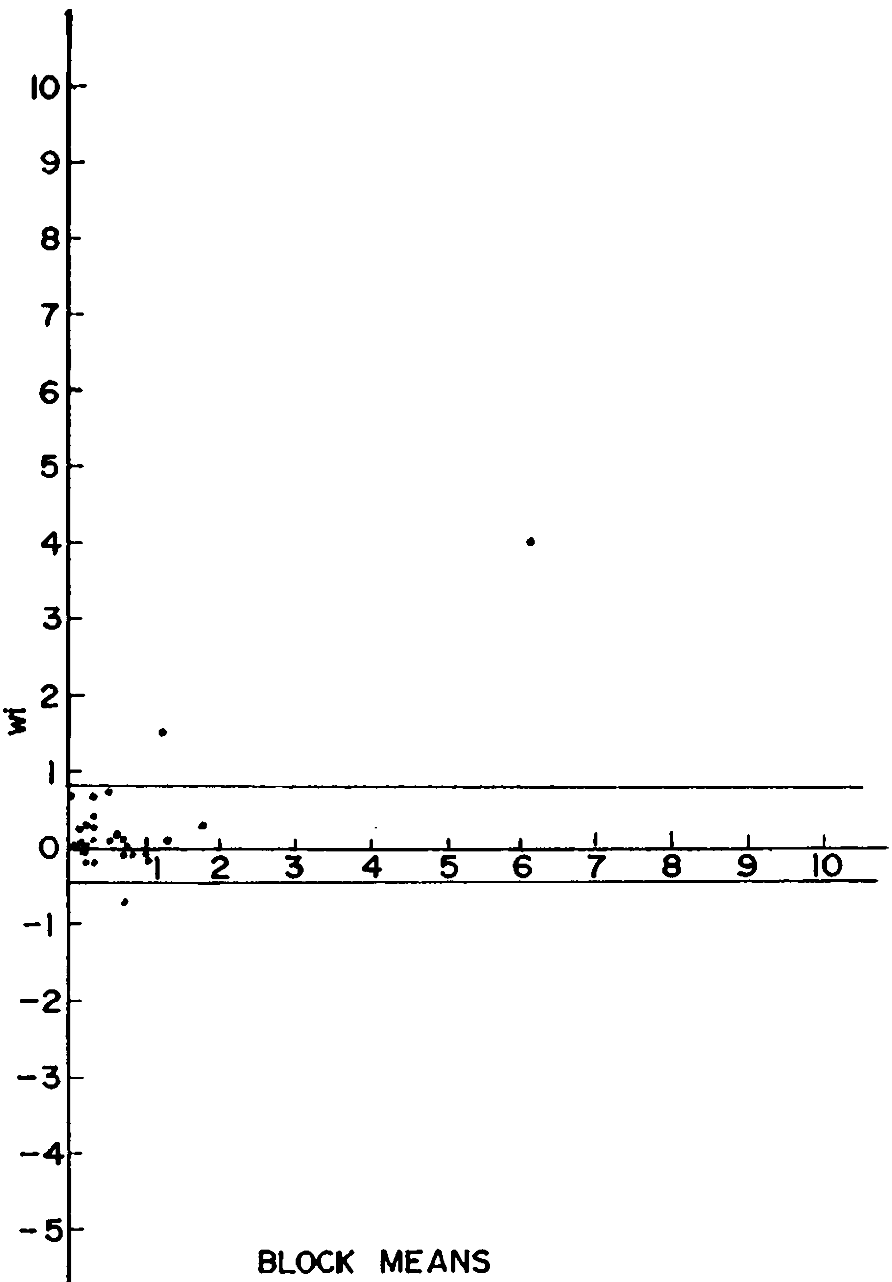


Fig.1. PLOT OF wi ON BLOCK MEANS FOR SET I DATA

Blocks (rows) with all-zero-values were found to be present in set 1. If the purpose is to gain information on the availability of fish in the area, blocks with all-zero-values are important and they should be included for calculating CPUE or average catch, but, for comparing the efficiency of fishing gear, blocks with all-zero-values do not contribute any information to the knowledge on the comparative performance of the gear because the gear are operated where there is no fish. On the other hand, inclusion of such rows may create nuisance in comparative efficiency studies because they wrongly contribute to the equality of all the gear compared and make the test less sensitive. For instance, the ANOVA of set 1 data for the whole 44 rows and excluding all-zero-values are presented in Table 2. From a comparison of (a) and (b) in the table, it can be seen that while ANOVA for the zero-blocks-included data shows an insignificant gear effect, the one for zero-blocks-excluded showed a just-significant gear effect. Thus exclusion of blocks with all-zero-values seems justified for comparative efficiency studies.

For set 1 data, fourteen all-zero-value-blocks were excluded and test for additivity was made again, which was found to be significant as in the case when all blocks were included (Table 3). The transforation to make the data additive worked out to $Y = X^{-0.55}$ for set 1. The transformation

Table 2. Analysis of variance for set 1 data

a) When all-zero-value blocks are included

Source	S.S.	D.F	M.S	F
Total	419.9962	263		
Gear	8.9735	5	1.7947	2.24 N.S
Days	239.1629	43	5.5619	6.96
Error	171.8598	215	0.7993	

b) When all-zero-value blocks are excluded

Source	S.S.	D.F	M.S	F
Total	389.6611	179		
Gear	13.1611	5	2.6322	2.28*
Days	208.8278	29	7.2009	6.23
Error	167.6722	145	1.1564	

*Tabulated value 2.27

Table 3. Tukey's test of additivity for set 1 data when the fourteen all-zero-valued blocks were excluded

Source	S.S.	D.F	M.S	F
Total	389.6611	179		
Gear	13.1611	5	2.6322	
Days	208.8278	29	7.2009	
Nonadditivity	69.4392	1	69.4392	101.79**
Remainder	98.2330	144	0.6822	

for set 1 when all the blocks were considered was also inverse ($Y = X^{-0.48}$). When the out lying points in Fig.1 are excluded, the rest of the points appear to be distributed along a nearly horizontal line. Therefore the nonadditivity of the data after simple exclusion of the outliers was tested (Table 4). Nonadditivity, now, was not found to be significant. Same result as expected was obtained for the data obtained after excluding the outliers and the all-zero-values (Table 5). Tackling 0-values, when the transformation in inverse;

Table 4. Tukeys test for additivity of set 1-data after excluding the outliers

Source	S.S	D.F	M.S	F
Total	110.9959	245		
Gear	2.0203	5	0.4641	
Days	37.1626	40	0.9291	
Nonadditivity	0.5466	1	0.5466	1.53 N.S
Remainder	71.2664	199	0.3581	

Table 5. Tukeys test for additivity of set 1-data after excluding the outliers and the all-zero-values

Source	S.S	D.F	M.S	F
Total	96.4763	161		
Gear	3.0679	5	0.6136	
Days	22.6419	26	0.8708	
Nonadditivity	0.0163	1	0.0163	<1 N.S
Remainder	70.7492	129	0.5484	

To tackle this problem, how the addition of a constant to all the observations will affect the transformation was examined. Based on Tukey's test, the transformation for additivity is given by $Y = X^p$, where $p = 1-B\bar{X}_{..}$, $B = \frac{N}{D}$, $N = \sum d_i w_i$, $d_i = (\bar{X}_{i.} - \bar{X}_{..})$, $w_i = \sum_j X_{ij} d_j$ $d_j = (\bar{X}_{.j} - \bar{X}_{..})$ and $D = (\sum d_i^2)$ $(\sum d_j^2)$. X_{ij} is the observation in the j^{th} column (that is the catch for the j^{th} gear on the i^{th} day) and $\bar{X}_{i.}$, $\bar{X}_{.j}$ and $\bar{X}_{..}$ are respectively the row mean, column mean and grand mean. X_{ij} was replaced by $(X_{ij} + 1)$, to know the effect of adding unity to all observations. It can be easily seen that d_i, d_j, w_i and therefore, D, N and B all remain the same. But $\bar{X}_{..}$ will be increased by unity, so that p becomes $1-B(\bar{X}_{..} + 1)$. Thus the new p becomes p-B. If a constant k is added to all the observations, the new p will be p-kB. Thus the transformation for set 1-data becomes $Y = (X+1)^{-2.7}$ (when the observations were taken as such, p worked out to -0.55 and B to 2.13, giving the new p-value as $-2.68 \simeq 2.7$).

The transformed data was found to be additive, sum of squares for nonadditivity being nonsignificant (Table 6). In trawl catches both transformation and outlier elimination were found necessary to make the data additive (Nair and Alagaraja, 1984) but for gill nets either transformation or removal of outliers restored additivity for one set. This is because the outlying points lie along the sloping line for some sets of gill net catches.

Table 6. Tukey's test for additivity for set 1-data after the transformation $Y = (X + 1)^{-2.7}$

Source	S.S	D.F	M.S.	F
Total	34.2336	179		
Gear	1.4567	6	0.2913	
Days	9.0918	29	0.3135	
Nonadditivity	0.3074	1	0.3078	1.89 N.S
Remainder	23.3777	144	0.1624	

Nonadditivity in set 2-data was investigated by working out the 2S limits. Four w_i's were found to lie outside the limit (-1.7109, 4.2344) for this set. The w_i's were plotted against the block means (Fig.2). The points excluding the outliers were found to be distributed on a nearly horizontal line, showing that no transformation is required for this set of data. Test for additivity for the outlier-eliminated data confirmed this (Table 7).

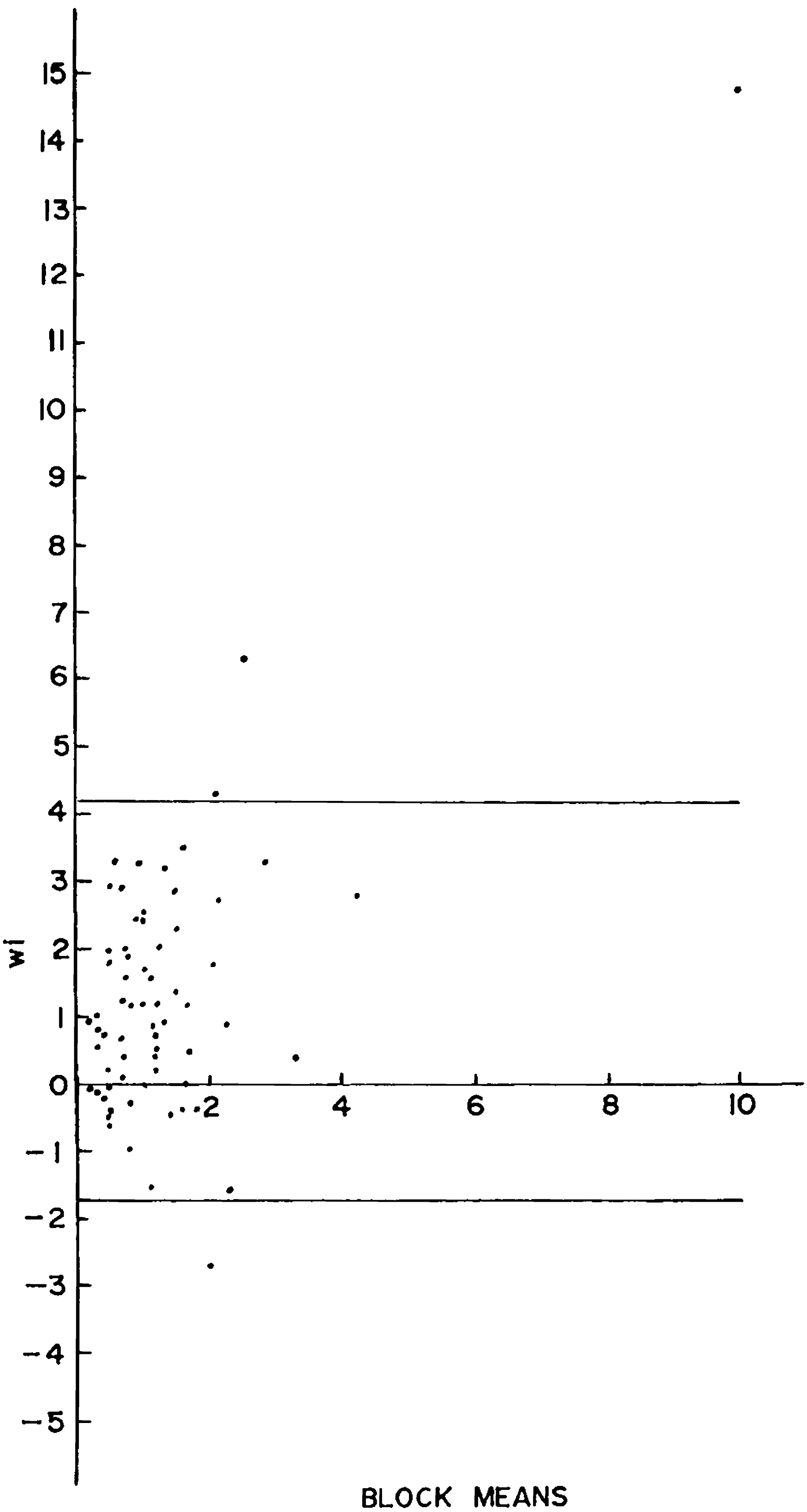


Fig.2. PLOT OF wi ON BLOCK MEANS FOR SET 2 DATA

Table 7. Test for additivity of the outlier eliminated set 2-data

Source	S.S	D.F	M.S	V. Ratio
Total	1134.1847	437		
Gear	61.4137	5	12.2827	
Days	552.4693	72	7.6732	
Nonadditivity	3.2023	1	3.2023	2.22 N.S
Remainder	516.9994	359	1.4401	

As in the case of set 1-data, whether a transformation alone without eliminating the outliers was sufficient for set 2-data also was examined. The transformation worked out to $X^{0.1689}$. But the transformed data was again found to be nonadditive (Table 8).

Table 8. Nonadditivity of transformed but outlier-included set 2 data

Source	S.S	D.F	M.S	F
Total	145.4953	461		
Gear	13.2045	5		
Days	39.2975	76	2.6409	
Nonadditivity	1.9501	1	1.9561	8.14**
Remainder	91.0372	379	0.2402	

For set 3, the correlation between w_i and $\bar{X}_{i\cdot\cdot}$, the block mean worked out to 0.5308 which is highly significant for 41 pairs. This shows the presence of a slanting regression line and therefore the necessity for a transformation. Plot of w_i on $\bar{X}_{i\cdot}$ is presented in Fig.3, which confirms the above for the points including the outliers. Therefore a transformation alone appears to be sufficient to make the data additive. The value of p was found to be negative. As some zero values are to be tackled a transformation $Y = (x+1)^p$ was made and the value of p was obtained as -1.30. The transformed data was found to be additive (Table 9).

Table 9. <u>ANOVA of the transformed set 3-data</u>

Source	S.S.	D.F	M.S	F
Total	8.3923	81		
Gear	0.00903	1	0.00903	
Days	4.6398	40	0.115996	
Nonadditivity	0.136438	1	0.136438	1.45 N.S
Remainder	3.60703	39	0.09248	

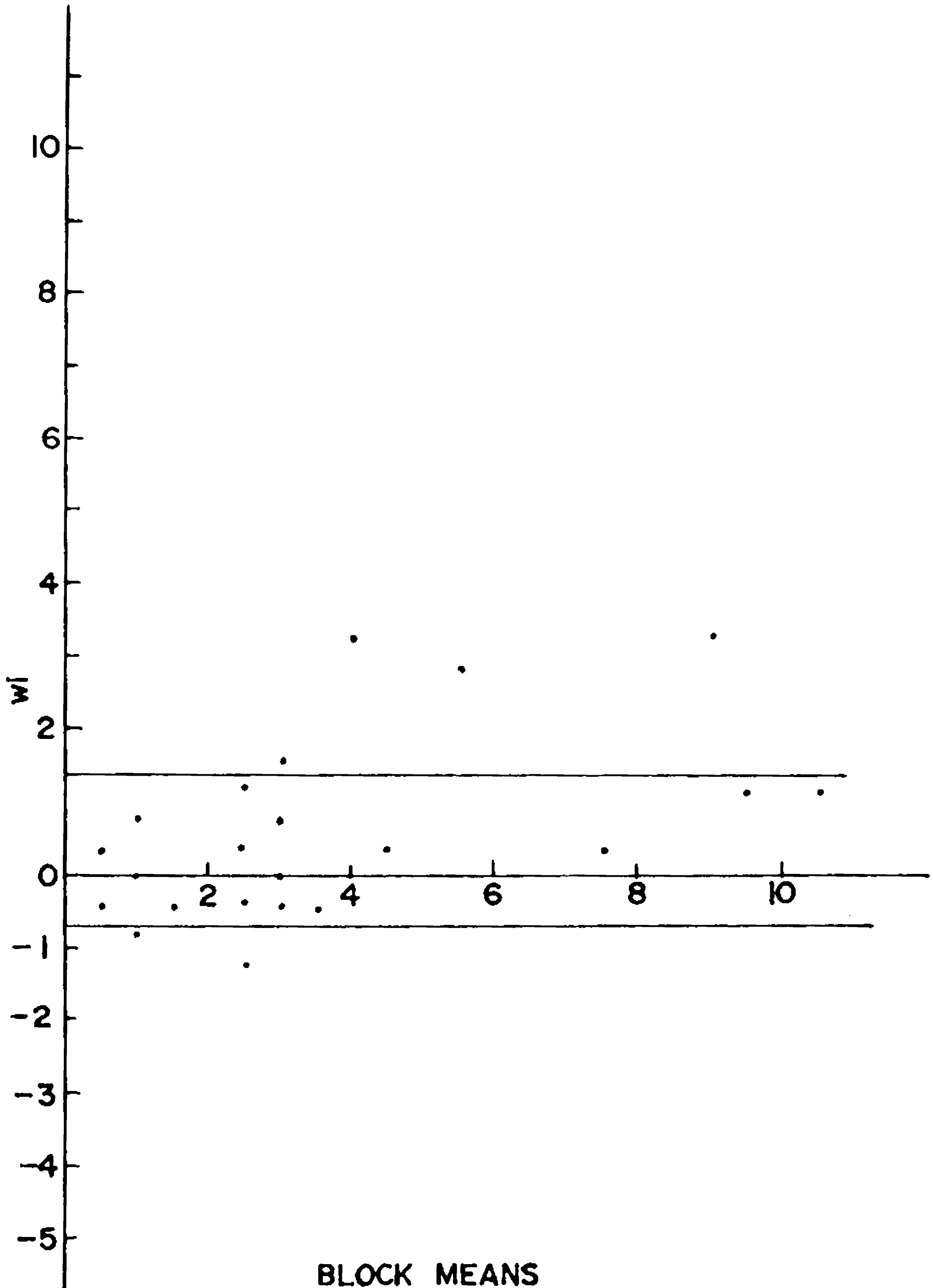


Fig.3. PLOT OF wi ON BLOCK MEANS FOR SET 3 DATA

Since the gill net catch-data is in terms of number of fish caught, square root transformation was tried to see whether it removes nonadditivity. $\sqrt{X+1}$ transformation was performed for set 3-data and the additivity was tested (Table 10). Nonadditivity was found to be significant even after the transformation, showing that the square root transformation does not make the data additive always.

Table 10. Nonadditivity of set 3-data after the transformation $\sqrt{X+1}$

Source	S.S	D.F	M.S	F
Total	38.216	81		
Gear	0.385	1	0.385	
Days	29.471	40	0.737	
Nonadditivity	1.402	1	1.402	8.28**
Remainder	6.958	39	0.169	

For the original set 3-data with nonadditivity, the treatment differences were just significant at 5% level. But when the transformation $(X_{ij} + 1)^{-1.30}$ was made and the data were made additive, the treatment differences no longer was found significant.

Since only two treatments were involved in set 3, Wilcoxon matched-pairs signed-rank test (WSR test) was tried. There were three tied observations, making N = 37. Since N > 25, the normal approximation $Z = \frac{T - \mu_T}{\sigma_T}$ was made with $\mu_T = \frac{N(N+1)}{4}$ and $\sigma_T = \frac{N(N+1)(2N+1)}{24}$. T, the smallest sum was the sum of negative ranks, which was 237.5. Thus the Z value was calculated, as -1.7198 giving a p value of 0.0854 which shows that the treatment difference is not significant at 5% level.

Further examination of the data showed that set 3 comprised of data for two seasons. In one season the catches were very poor, the number of fish caught ranging between 0 and 4 in all except one operation while in the other, the catches ranged between 0 and 12 numbers in all the operations. Thus for the first group, the catches appear to be less than the critical number as mentioned in chapter 3. Wilcoxon test when carried out for the two groups separately, showed significant result (5% level) only for the second group with T = 16 and N = 13 (There was one tied observation). This explains the nonsignificance of the transformed set 3 data.

Thus when only two gill nets are involved WSR test which is simple and valid can be applied. This test facilitates within set investigations as was done above.

When two groups with low and high catches can be identified as in the above, nonparametric tests can be applied to the two groups. If the group with higher values shows significant gear effects even if the other group does not, recommendation can be made on the basis of the result for the high-value-group, the reason for nonsignificance of the group with low catches can be attributed to the catches falling below the critical number as discussed in chapter 3. Even if a recommendation on the basis of a decision taken in the above line is made, there is nothing to lose, as in the worst case, the recommended gear can be at least equal in efficiency of the other gear.

Friedman test which is nonparametric and which do not depend on the assumptions underlying F-test, was applied to compare the efficiency of coloured gill nets to the data given by Kunjipalu et al., 1984. This test has the advantage that it can be easily applied to the two-way classification (Randomised block layout) when more than two gear are to be compared. Also the test does not depend on many assumptions as required for F-test. If Friedman test shows significance there is no need to apply any other sensitive method. If the test does not show significance then robust procedures are to be applied. The necessity can be decided by looking at the data and examining the significance levels as shown by other tests. The advantage of Friedman test is to confirm a significant result already obtained by ordinary ANOVA F-test. This is because the significance levels change in F-test from the actual level at which we are testing, when the assumptions are not satisfied, whereas in nonparametric tests, the significance levels do not change. In other words a significant result obtained by using a nonparametric test can be taken as conclusive; such results can be generalized.

CHAPTER 5

COMPARATIVE EFFICIENCY OF GILL NETS - A TEST BASED ON THE DISTRIBUTION OF CATCHES

5.1 Introduction

A study of the distribution is important in view of developing test procedures. If the form of the distribution is known, that information could be used to construct a test to compare the location. With this in view the gill net catch-data were examined. Nielsen (1983) has observed that catches followed the Poisson Distribution.

5.2 Materials and Methods

Data on catches of different types of gill nets, for instance coloured gill nets (Kunjipalu _et al_., 1984) obtained under comparable conditions for different days were used to compare the efficiencies. Frequency distributions of the numbers of fish caught according to the frequency (in terms of numbers of hauls) of occurrence of 0,1,2 etc. fish in the catch was made for different types of gill nets. The largest frequencies corresponded to occurrence of 0 or 1 fish and the frequencies decreased sharply for increasing number of fishes. Therefore the poisson, Negative binomical and Geometric distributions were considered for the data. The theoritical frequencies were calculated using the densities

$$f(x) = \frac{e^{-\lambda}\lambda^{x}}{x!} I_{(0,1,\ldots)}(x) \quad \text{(Poisson)} \tag{1}$$

$$f(x) = \binom{r+x-1}{x} p^{r} q^{x}, I_{(0,1,\ldots,)}(x);$$
$$0 < p \leq 1, \quad r > 0 \quad (q=1-p) \text{ (negative binomial)} \tag{2}$$

and

$$f(x) = pq^{x} I_{(0,1,\ldots)}(x); \; 0 < p \leq 1, \; (q=1-p) \quad \text{(Geometric)} \tag{3}$$

as given by Mood _et al_., 1974. λ ,p,q (=1-p) and r are parameters of the distributions. The goodness of fit was tested by chi-square. Further, the chi-square test (Mood _et al_., 1974),

$$Q_{2k} = \sum_{i=1}^{2} \sum_{j=1}^{k+1} \frac{(Nij-nipj)^2}{nipj} \tag{4}$$

with degrees of freedom equal to '2k minus the numbers of parameters estimated' was used to test whether two given samples are drawn from the same population such as the Poisson, the Negative binomial or the Gamma. Here k+1 refers to the number of classes and i = 1 and 2 for two samples.

5.3 Results and Discussion

The frequency distribution of the numbers of fish caught by 4 gill nets A,B,C and D (per equal area) are presented in Table 1. (The frequencies are the number of operations of equal duration). The largest frequencies correspond to the occurrence of 0 or 1 fish in the catch and the frequencies decrease as already mentioned. The comparisons made were between A and B and between C and D. The Poisson, Negative binomial and Geometric distributions fitted to these data along with the observed frequencies are presented in Table 2. The χ^2-values with the respective degrees of freedom for the goodness of fit are also presented in the table. It can be seen from Table 2 (A & B) without any test itself that the Geometric distribution does not fit any set of data. Therefore this distribution was not fitted for sets C and D. The χ^2 goodness of fit for Poisson and Negative binomial distributions as presented by Mood et al. (1974) showed Poisson and Negative binomial distributions to be a good fit (the χ^2 being non-significant) for sets A and B and Negative binomial for sets C and D (Table 2). Poisson distribution was, however, found to be satisfactory for set D, though not for set C. Negative binomial distribution fitted all the four sets of data. However, for any of these distributions, the chi-square test as given by equation (4) can be used to test whether the samples came from the same Poisson or Negative binomial populations (Mood et al. 1974).

To illustrate the application of this test for the two distributions, whether sets A and B came from the same Poisson distribution and C and D from the same Negative binomial distribution were tested, as shown below.

(i) Comparison of gear A and B:

Frequency distribution of the number of fish caught by the two nets are as under:

Number of fish	0	1	2	3	4 or more	Total
Net A	27	26	14	4	5	76
Net B	13	18	24	9	12	76
Total	40	44	38	13	17	152

Here, one parameter, namely, the mean of the Poisson population is to be estimated. The maximum likelihood estimate is the sample mean, namely,

$$\frac{0(40)+1(44)+2(38)+3(13)+4(8)+5(2)+6(4)+7(1)+9(1)+10(1)}{152}$$

$$= 1.6513$$

From (1), the expected number in each group of the population is given by

Number of fish	0	1	2	3	4 or more
Expected number	14.58	24.07	19.95	10.97	6.43

Thus the chi-square given by Mood, Graybill and Boes (1974) is

$$Q2k = \sum_{i=1}^{2} \sum_{j=1}^{k+1} \frac{(N_{ij}-n_ip_j)^2}{n_ip_j} = \frac{(27-14.58)^2}{14.58} + \ldots + \frac{(9-10.97)^2}{10.97} + \frac{(12-6.43)^2}{6.43}$$

$= 24.96^{**}$ with $2k-1 = 8-1=7$ degrees of freedom (as 1 parameter is estimated). The significance of the χ^2 shows that the two samples are not from the same population which means that the catches by the two gear are not equal. This can be generalised to several samples, that is, to catches by more than two gear also.

(ii) Comparison of gear C and D:

For data sets C and D negative binomial distribution is already found to be a good fit (Table 2). Poisson distribution turned out to be a poor fit for set C as already mentioned. Thus, assuming that the catches by nets C and D are distributed in the Negative binomial form, whether they came from the same Negative binomial distribution can be tested by the χ^2 test discussed and applied above. Frequency distributions of the number of fish caught by the two nets are as under:

Number of fish	0	1	2	3	4	5 and above	Total
Net C	9	9	6	3	5	9	41
Net D	6	12	11	4	3	5	41
Total	15	21	17	7	8	14	82

Here two parameters r and p are to be estimated from the combined data. Estimation of these parameters by the method of moments ($\hat{p} = \frac{\text{mean}}{\text{variance}}$, $\hat{r} = \text{Mean} \times \frac{\hat{p}}{\hat{q}}$, gave $\hat{p} = 0.3125$, $\hat{q} = 0.6876$ and $\hat{r} = 1.2427$. Thus from (2), the expected number in each group of the population is give by

Number of fish	0	1	2	3 and above	Total
Expected number	9.67	8.26	6.36	16.71	41

(Frequencies in the last three classes were pooled to form a single class '3 and above' to make all the expected values greater than 5, for computing χ^2)

$$Q_{2k} = \frac{(9-9.67)^2}{9.67} + \ldots + \frac{(12-16.71)^2}{16.71} = 7.94 \quad \text{(N.S)}$$

with 2k-2, that is, 4 d.f., as two parameters are estimated. Thus the hypothesis that the two catches came from the same population is not rejected.

The above illustrations have shown that a test based on the distrubtion of fish catch data (for gill nets) can be constructed. The distribution has been found to be either Poisson or Negative binomial. Negative binomial fitted three sets out of the four when all the observations were considered and the same fitted all the four sets when oneobservation in the extreme class after some discontinuity was omitted. Poisson distribution fitted 3 sets with and without the omission of the observation in the extreme class. Geographical and species difference may attribute to the difference in the distributions. However, fitting of Poisson or negative binomial is easy and can be tried for any set of gill net data. Depending on the adequacy of the fit either of these distributions may be assumed and the difference between the samples may be tested by employing χ^2 test. But it is important to test the goodness of fit, because, when the fit is not adequate, that itself will contribute to the significance of χ^2, vitiating the results of the test for difference between samples (gear).

Table 1. Distribution of fish caught by 4 gill nets A, B, C and D

A		C	
Number of fish caught	Frequency	Number of fish caught	Frequency
0	27	0	9
1	26	1	9
2	14	2	6
3	4	3	3
4	3	4	5
5	-	5	2
6	1	6	-
7	-	7	-
8	-	8	3
9	1	9	1
10	-	10	-
11	-	11	1
12	1	12	1
		13	1
Total	77	Total	41

B		D	
0	13	0	6
1	18	1	12
2	24	2	11
3	9	3	4
4	5	4	3
5	2	5	1
6	3	6	-
7	1	7	1
8	-	8	2
9	-	9	1
10	1	10	-
11	1	11	-
		12	-
		13	-
Total	77	Total	41

Table 2. Fit of Poisson, Negative binomial and Geometric distribution to the data given in Table 1

A

Number of fish caught	Observed frequency	Poisson	Negative binomial	Geometric
0	27	22	31	41
1	26	27	21	19
2	14	17	12	9
3	4	7	6	4
4	3	2	3	2
5	-	1	3	1
6	1			
7	-			
8	-			
9	1			
10	-			
Total	76	76	76	76
Test for goodness of fit (chi-square)		1.80 N.S	2.87 N.S	
d.f.		2	2	

Mean = 1.22, Variance = 2.5

(Frequencies in classes 3 and above were pooled for Poisson and 4 and above for Negative binomial, to compute chi-square)

Table contd.

B

Number of fish caught	Observed frequency	Poisson	Negative binomial	Geometric
0	13	10	15	46
1	18	20	19	18
2	24	20	16	7
3	9	14	11	3
4	5	7	7	1
5	2	3	4 }	
6	3 }		2	
7	1			
8	-	2	2	1
9	-			
10	1 }		}	
Total	76	76	76	76
Test for goodness of fit (chi-square)		5.06 N.S	5.38 N.S	
d.f.		4	3	

Mean = 2.08, Variance = 3.38

(Frequencies in classes 5 and above were pooled to compute χ^2)

Table contd.

C

Number of fish caught	Observed frequency	Poisson	Negative binomial
0	9	1.76	9.37
1	9	5.55	7.55
2	6	8.73	5.85
3	3	9.15	4.47
4	5	7.20	3.40
5	2		
6	-		
7	-		
8	3	8.61	10.36
9	1		
10	-		
11	1		
12	1		
13	1		
Total	41	41	41
Goodnes of fit (chi-square)		37.92** ($p < 0.005$)	1.71 N.S
d.f.		4	2

Mean = 3.15; Variance = 12.28

Table contd.

D

Number of fish caught	Observed frequency	Poisson	Negative binomial
0	6	8.91	4.04
1	12	9.43	9.36
2	11	7.55	10.85
3	4	5.40	8.38
4	3	3.63	4.85
5	1		
6	-		
7	1		
8	2	6.08	3.51
9	1		
10	-		
11	-		
12	-		
13	-		
Total	41	41	41
Goodness of fit (chi-square)		5.31 N.S	3.89 N.S
d.f.		4	3

Mean = 2.32; Variance = 5.07

N.S. = not significant; ** = highly significant

CHAPTER 6

AN APPROACH FOR EFFICIENCY COMPARISON OF GEAR WITH SPECIAL REFERENCE TO THE TWO CATEGORIES TRAWL AND GILL NETS

6.1 Introduction

In the last five chapters the problems involved in comparing the efficiencies of fishing gear were examined and ways and means to overcome many of them were discussed. The applicability of some tests and procedures to compare the efficiencies were also examined in these chapters. Further tests like Friedman-Type Rank Test (Mack and Skillings, 1980), Quade test (Quade, 1979) and Rank Transform test (Lemmer and Stocker, 1967; Conover and Iman, 1976; Hora and Conover, 1984) as presented in Iman et al., 1984 were also applied to data on trawl and gill net catches. Using the information gained from these applications and from the earlier chapters, an approach for the statistical comparison of efficiencies within trawl nets and within gill nets is suggested in this chapter.

6.2 Materials and Methods

Fisher randomization test for the difference, D between two treatments requires no assumption about the forms of the basic distribution of the differences. With small samples that show little overlap, the randomization test is easily calculated and recommended. Since the sample sizes are usually large, randomization test is not practicable (Pope, 1963). Snedecor & Cochran (1968) have stated that with limited numbers of values this test and the t-test show that they usually agree well enough for practical purposes. To apply the correction for continuity, they have computed t_c as

$$t_c = \frac{|\Sigma D| - 1}{n \, S_{\bar{D}}}$$

The denominator of t_c is the standard error of ΣD which may be computed either as $n \, S_{\bar{D}}$ or $\sqrt{n} \; S_D$. t_c, however tends to give too many significant results. Another test presented by these authors, namely, the t-test based on range, t_w, assumes normality.

$$t_w = \frac{\bar{D}}{w}$$

where $\bar{D}$ is the mean difference and 'w' is the range of the sample.

When more than one haul can be made with the same gear on a day, more than one observation per cell will be available. To make full use of these, Friedman-Type Rank Test (Mack and Skillings, 1980) was applied to such sets of data.

Quade test (Quade, 1979) and rank transform test (Lemmer and Stocker, 1967; Conover and Iman, 1976; Hora and Conover, 1984) as presented in Iman *et al.*, 1984 were applied to data on trawl and gill net catches. On the basis of these tests and the results obtained in the earlier chapters an approach for the statistical comparison of the efficiencies within trawl nets and within gill nets is indicated.

6.3 Results and Discussion

When continuously good catches are available even with a small sample, the application of t-test with the correction for continuity (t_c) and the t-test based on range (t_w) can be considered. For the purpose of illustration, the catches with two gear A and B and the difference d_i are given below:

A	B	d_i
13	5	8
12	9	3
8	8	0
9	2	7
11	8	3
8	7	1

$$t_c = \frac{|\Sigma D| - 1}{\sqrt{n}\, S_D}$$ worked out to 3.27, which is significant at 0.025% level showing that gear A is more efficient than gear B.

$t_w = \frac{\bar{D}}{w} = \frac{4.2857}{8} = 0.5337$ is highly significant, showing the same result as above. But as already mentioned t-test based on range assumes normality.

When more than one haul can be made with a gear, a day, the result is more than one observation per cell. Because of the problems already mentioned in the earlier chapters, ANOVA, F-test for more than one observation per cell will not be proper. Friedman-Type Rank Test as presented by Mack and Skillings (1980) is found to be convenient for application in such cases.

If the problem is that dealt with in chapter 3, that is, if a minimum discernible catch in part is not provided by the experimented gear, with the same set of data it may still be possible to find some replications with the desired level of catch. In some cases, from a frequency distribution of the number of fish caught (gear-wise) it may be possible to form two groups one with low catches and the other with high catches. As the sample size for a group would be smaller, Randomization test or tests mentioned above can be easily applied to the group with higher catches and a decision on the basis of this can be arrived at. As already mentioned in the general introduction, the economic implications of recommending even a slightly improved gear is immense and in such a context even if the improved gear is only as efficient as the standard gear, there is no risk involved, as the improved gear will be at least as efficient as the standard gear.

The results of the application of Friedman test (F_F), Quade test (F_Q) and Rank transform test (F_R) are presented below:

Specification of Data	F_F (χ_r^2)	F_Q (V)	F_R (F-test on ranks)
1) Comparison of two trawl nets	4.8* d.f = 1	(Same as WSR test significant)	0.51 N.S d.f = 1,27
2) Comparison of the effect of direction of current for Sciaenids	3.34 N.S d.f = 2	3.85 N.S (F_Q=2.01) d.f = 2	1.28 N.S d.f = 2,42
3) Comparison of three trawl nets (differing in mesh sizes)	5.25 N.S d.f = 2 (Exact test)	4.77 N.S (F_Q=2.98 d.f = 2	0.05 d.f = 2,14
4) Comparison of gill nets	6.51 N.S d.f = 5	8.07 N.S (F_Q=1.64)	1.74 N.S d.f = 5,145

Using this and the information obtained from earlier chapters, a procedure for comparing the efficiency of fishing gear is described.

An outline of approach for statistical comparison:

(i) When the efficiency of two trawl nets or two gill nets are to be compared, Wilcoxon matched-pairs signed-rank test (WSR test) may be used, as this has been found to be more efficient for the data. Also, its application is simple. For normal distributions this test is 95.5 percent as efficient as the parameteric F-or t-test (Siegel, 1956) but, for other types of distributions (for instance, some long tailed ones) this test may be more than 100% efficient compared to the F-or t-test (Snedecor and Cochran, 1968). The superiority of WSR test over F-test for trawl catches has been demonstrated by Nair and Alagaraja (1982) and the test has been applied in Narayanappa et al. (1982). Moreover, the nonnormality of the data has been indicated by Nair (1982) as revealed by the dependence of the mean on the variance. Lack of satisfaction of other assumptions like nonadditivity for ANOVA, has also been established by applying Tukey's test and the presence of outliers have been observed in the earlier chapters. Finally among the nonparametric methods for paired comparisons, except for randomization test, only Wilcoxon test seems to use interblock information. But randomization test is unwieldy for even moderately large samples (say, when the number of pairs exceeds 12) and as Siegel (1956) has observed, Wilcoxon test (WSR test) is a very efficient alternative to the randomization test because it is a randomization test on ranks.

(ii) When the efficiency of more than two trawl nets are to be compared, Friedman test and ordinary ANOVA F-test may be tried first. Applications showed Friedman test to be as sensitive as F-test, though no higher sensitivity was observed in any case. As Friedman test depends on fewer assumptions than does F-test, as a practical procedure, if the former test brings out the difference in the efficiency, there is no need to test further. If both the tests are not found to be sensitive and if the probability for an observed difference is close to the significance level, the Quade test and if still inconclusive the combination of procedures as demonstrated in chapter two may be applied. The latter, though not simple, may bring out the real difference, if any, in this case. Recently, Iman et al. (1984), while making a comparison of Friedman test, Quade test and rank transform test (Lemmer and Stoker, 1967; Conover and Iman, 1976; Hora and Conover, 1984) found Quade test to be a better choice than Friedman test for normal data for the number of treatments, $k \leq 6$ and vice versa for $k > 6$. For the nonnormal settings the result favoured the Quade test for uniform case and lognormal case (when $k = 3$), while Friedman test showed more power than the Quade test in the remaining 11 of the 16 nonnormal cases, they examined. They found Quade test to be favourable for light tailed uniform distributions while the Friedman test and the rank transform test for heavy tailed distributions. Application of Quade test and rank transform test to trawl catches showed the same result as when Friedman test was applied. However, Friedman and Quade tests showed more or less the same sensitivity but rank transform test showed a little less sensitivity.

(iii) When the efficiency of more than two gill nets are to be compared, Friedman test and ordinary ANOVA F-test may be used. Friedman test helps to confirm the result as its applicability for the data is more valid and as applications (Kunjipalu et al., 1984) have shown Friedman test to be as sensitive as F-test. The performance of Quade test, Friedman test and rank transform test were compared for gill net catches too. All the tests showed the same result. However, Quade test and rank transform test showed a little more sensitivity than Friedman test. Therefore, it is advisable to apply Quade test and rank transform test when the probability for an observed difference is close to the significance level. Another alternative to confirm the results would be the test illustrated in chapter 5. Fitting of the Poisson or Negative binomial for this purpose is simple. So also the application of chi-square test for goodness of fit and for testing equality of samples from the same Poisson or same Negative binomial populations. In fact this test can be applied to compare the efficiencies of two or more gill nets.

CHAPTER 7

GEAR EFFICIENCY AND GEAR SELECTIVITY

7.1 Introduction

The terms 'gear efficiency' and 'gear selectivity' have appeared a number of times in literature on the relative performance of two or more fishing gear. These terms appear to have been used with different implications. Especially, the term 'efficiency' seems to have been used to convey the idea of 'selectivity' also, perhaps, to mean efficiency in selection. The use of these terms both synonimously and differently in the work relating to performance of fishing gear has prompted to examine the context in which these terms are used and also to examine various phrases used to convey 'the ability for size selection of a gear' and 'the ability to catch a maximum quantity of fish from those available in the fished area'. Selection can mean any process that causes the probability of capture to vary with the characteristic of the fish, selectivity is a quantitative expression of selection and traditionality means selection by size (Lucas et al., 1966).

7.2 Materials and Methods

With this in mind, available literature on the performance of fishing gear is examined. The terms and phrases and the context in which they were used are specially noted. These are reviewed in what follows. Barnov (1976) (translated by Vilim) uses the phrase 'relative fishing efficiency of nets' and distinguishes three curves namely, 'the curve of population composition' 'the curve of relative fishing efficiency of the net' and 'the curve of result of fishing', that is the curve of the composition of the catch. The total fishing efficiency of the net has been mentioned as depending on the number of fish captured by the net and the number of fish coming into contact with the net. This absolute fishing efficiency is not constant but decreases as the number of fish entangled in the net increases and therefore Barnov says that determination of fishing efficiency must confine itself, for the time being, to determining the relative efficiency of nets. For trawl nets, the absolute fishing intensity of a given trawl for a given type of fish has been defined as the ratio of the caught fish to the total number of fish in the fished area. "If two trawls were to fish simultaneously under identical conditions, the ratio of the catch of the second trawl to that of the first would be the relative fishing efficiency of the second trawl". Barnov (1976) has also indicated approaches for the estimation of absolute fishing intensity. Much work has been done on the estimation of relative fishing efficiency as has already been referred to in the general introduction.

The relative catch rate of two gear is expressed as the ratio obtained by dividing the catch of one gear by that of the other gear when effort is equal or by the ratio of respective catch per unit efforts when effort is not equal (Collins, 1979). Seasonal variation was reported for catch comparison of pacific salmon by Washington (1973) and Larkins (1963, 1964) and the former attributes part of the variation to relationship between effort, abundance and size of fish available for capture.

Cost effectiveness of trawl system as presented by Fridman *et al.* (1979) takes into account the profitability of the trawl system by considering the cost and the price of the catch. They have defined the generalized characteristic of the trawl system performance as $W = \frac{a\, y_u\, T}{b}$ where a is the calculated price of unit mass of the catch, y_u is the amount of fish caught in unit time, T is a quantity which may be considered to represent the trawl system service life because, in this time interval, the cost of maintaining it in serviceable condition is equal to its capital cost b. Denoting the parameters of the experimental system by a suffix 'o' and the parameters of the standard trawl system by a suffix '1',

$$\frac{W_o}{W_1} = \frac{a_o}{a_1} \quad \frac{b_1}{b_o} \quad \frac{T_o}{T_1} \cdot \frac{y_{uo}}{y_{u_1}}$$

which the authors term as the index of profitability 'ω' of the trawl system. Further $\omega = \alpha \beta \tau \epsilon$, where $\alpha = \frac{a_o}{a_1}$ is the index of catch quality, $\beta = \frac{b_1}{b_o}$ is the index of the capital cost of the trawl system, $\tau = \frac{T_o}{T_1}$ is the index of the service life of the trawl system and $\epsilon = \frac{y_{uo}}{y_{u_1}}$ is the index of catch-capability of the trawl system. It may be noted that the 'index of catch-capability' of the above approach refers to the relative fishing efficiency of Barnov and other workers. It is also interesting to note that when the cost remain more or less the same and when the two nets are simultaneously operated, so that the index of quality also remains the same (or rather when the two gear are meant for the same species), then $\frac{w_o}{w_1}$, that is 'ω' becomes the 'relative fishing efficiency' of Barnov.

The size selectivity of a gear may be defined by a curve giving for each size of fish, the proportion of the total population of that size which is caught and retained by a unit operation of the gear (Lagler, 1968). This leads to the definition of selectivity as the proportionality constant s_{ij} in

$$C_{ij} = s_{ij} \times N_j$$

where C_{ij} is the catch per unit operation of a gear of fish of length j in the i^{th} mesh size, N_j is the number of fish of length j in the population and s_{ij} is the selectivity of fish of length 'j' by mesh size 'i'.

Examining the references to selectivity, one may find in Regier and Robson (1966), the terms 'selectivity', 'relative efficiency of mesh M_i to fish of size l_j' being used. They have defined standard selectivity $S_{ij} = \frac{s_{ij}}{\max_j s_{ij}}$ and total efficiency with respect to numbers of fish of mesh M_i as $L_i = \sum s_{ij}$ and with respect to weight of fish as $W_i = \sum_j S_{ij} \; W_j$. These authors have dealt with extensively, the methods of estimating gill net selectivity. Lagler (1968) as already mentioned, defines selectivity as proportionality coefficient, Briggs (1986) defines the same as the power of a fishing unit (vessel plus gear) to retain an individual of one species according to its size. According to Clark (1960), absolute selectivity gives the actual probability of capture per unit effort, relative selectivity gives values proportional to absolute selectivity and efficiency of a net is the area under its selectivity curve and the factors other than mesh size affect mainly the efficiency of the net (height of selectivity curves), but may also affect the selectivity (Shape and mode of selection curve) (Von Brandt, 1975).

Thompson and Ben-Yami (1984) deals with selectivity 'as the capacity of any method of gear type to capture certain fractions or sections of the fish population whether grouped by species, age, size or behaviour and to exclude others.' They caution that too often gear selectivity has been viewed only in the very narrow sense of mesh selectivity in the codend of trawl nets. These authors have classified the gear according to the intensity (selective type of gear and less selective gear). They have also distinguished among 'selectivity of trawls by design', 'selectivity of area swept', 'effect of tickler chains and ground ropes', 'purse seine and ring nets', 'selectivity of gill nets', 'selectivity of fish attraction methods' like light attraction, bait attraction and FADS (Fish Aggregation Devices) and artificial reefs. Among other contributions to selectivity are the work of Barnov (1976), Holt (1963), Olsen (1959 , 1963), Mc Combie and Fry (1960), Mc Combie and Berst (1969), Von Brandt (1955), Cucin and Regier (1966), Mc Combie (1961), Tester (1935), Hamley (1972), Alagaraja (1977), Jones (1984) and Thompson and Ben-Yami (1984). An excellent review of the work on gill net selectivity till date has been given by Hamley (1975). Selectivity studies are more important for mesh size regulation from conservational point of view. Mesh sizes are regulated (i) to conserve the spawning stock and (ii) to increase the long term sustainable yield (Jones, 1984). This leads to the problem of determining the best mesh size for a fishery.

7.3 Results and Discussion

Since there are 'size selection' and 'species selection', the term 'selectivity of fishing gear' appears to be incomplete unless mention is made whether what is intended is 'size selection' or 'species selection'. The ultimate objective of studies on size selection is to suggest suitable mesh sizes to catch fish of either an economically optimum size or an optimum size from conservational point of view, that is, an optimum size for the judicial exploitation of the stock. But more generally, following Thompson and Ben-Yami (1984) selectivity may be defined as the capacity of any method or gear type to capture certain fractions or sections of the fish population whether grouped by species, age, size or behaviour and to exclude others. It need not be viewed in the narrow sense of mesh selectivity alone but other forms of selectivity due to design of the trawl, area swept, specified equipments like tickler chains and ground ropes, specific nets like purse seine, ring nets, gill nets and due to fish attraction methods are to be recognized.

Efficiency of a gear may be taken as to relate to the total number or weight of fish caught regardless of a specific size. It might be possible to increase the efficiency of a net by altering the mesh size or other design parameters of the gear. Any factor which has a bearing on the total quantity of fish caught affects the efficiency of the gear. As already mentioned, the term 'total fishing efficiency' refers to the number of fish captured by the net and the number of fish coming into contact with the net. The term 'efficiency' has also been used in the same sense. It also appears that to measure the absolute efficiency there are many practical problems (Barnov, 1976) and hence attempts by large, have been to measure "relative fishing efficiency of nets". The term "comparative efficiency studies" has been very widely used in this sense. Studies on catch comparison by taking the catch ratios of the developed gear to the existing gear has been used in many of the work on 'comparative efficiency' cited elsewhere in this presentation. The connection between gear selectivity and gear efficiency as given by Clark (1960) is worth noting. He defines absolute selectivity as the actual probability of capture per unit effort, relative selectivity as values proportional to absolute selectivity and efficiency of a net as the area under its selectivity curve. In the above, the term 'selectivity' confines to size selection. When selectivity is used in this sense, it means the probability of capture per unit effort of a gi size of fish while efficiency of a net refers to the ability of the net to catch the same fish regardless of the size. In a multispecies fishery, the efficiency may be used in a much wider sense as the ability of the net to catch some specified fish species or all the fish species contributing to the total catch.

Considering s_{ij} as the proportionalty coefficient in

$$C_{ij} = s_{ij} \times N_j \qquad (1)$$

(as already mentioned), the total catch of a specified fish of all sizes caught by a gear can be written as $\sum C_{ij}$, which can be expressed as

$$\sum_j C_{ij} = \sum_j s_{ij} N_j \qquad (2)$$

Thus the relative efficiency of two gear 1 and 2 when expressed as the catch ratio, will be

$$\frac{\sum C_{ij}^{(1)}}{\sum C_{ij}^{(2)}} = \frac{\sum s_{ij}^{(1)} N_j}{\sum s_{ij}^{(2)} N_j} \qquad (3)$$

N_j, being the number of fish of length j in the population is the same in the expressions for the total catch of the individual gear. (C_{ij}'s are the catches per unit effort).

From (3), relative efficiency of two gear can be interpreted as a ratio of the weighted totals of the selectivities of all sizes, the weights being the total numbers in the respective size classes in the population.

CHAPTER 8

ESTIMATION OF THE RATIO OF FISHING POWERS AND THE SIZE OF FISH FOR WHICH THE GEAR IS MOST EFFICIENT

8.1 Introduction

Gulland (1969) observes that the fishing power of a particular gear, that is, the catch it takes from a given density of fish per unit fishing time (in the units of fishing time appropriate to the gear), can be thought of in two parts (a) The extent (area or volume of water) over which the influence of the gear extends, and within which fish are liable to be caught (= a, say) (b) The proportion of fish within this area which are in fact caught (= p, say).

Further, "if fish or fishing were randomly distributed, then the proportion of the total stock within the area of influence would be a/A, and the catch would be (pa/A) x N. That is the product p x a/A would give a direct measure of the fishing mortality.

Improvements to fishing techniques can affect either quantity. For instance, for purse-seiners the area of influence can be increased by better searching, faster ships, use of advanced detection equipment etc., while the proportion of the population in this area that can be taken may be increased by the use of a larger net, or by some of the sonar equipment".

As far as gill nets of same area are concerned a/A would be the same for all the nets. In this chapter it is proposed to estimate the ratio of proportions of fish (p) which are in fact caught by two gill nets of equal area. Assuming fish catch to be the product of the catchability coefficient and the number of fish in the exploited area, an attempt has been made to determine the size of fish for which the gear is most efficient.

8.2 Materials and Methods

By comparing catches of only two mesh sizes, the normal model

$$C_l = N_l P_M \exp -\left\{ \frac{(l-l_M)^2}{2 S_M^2} \right\}$$

where C_l = catch of fish of length l per unit fishing time

N_l = number of fish of length l liable to capture by the gear

P_M = fishing power of net of mesh size M

l_M = length of fish for which the mesh size M is most efficient

S_M = standard deviation of the mesh selection curve

(Holt, 1963; Gulland, 1969).

If two nets A and B are fished on the same population, then,

$$\frac{{}_AC_l}{{}_BC_l} = \frac{N_l\, P_A \exp\left\{ - \frac{(l-l_A)^2}{2S_A{}^2} \right\}}{N_l\, P_B \exp\left\{ - \frac{(l-l_B)^2}{2S_B{}^2} \right\}}$$

on taking logarithm to base e,

$$\log {}_AC_l - \log {}_BC_l = \log \frac{PA}{PB} - \frac{(l-l_A)^2}{2S_A{}^2} + \frac{(l-l_B)^2}{2S_B{}^2}$$

If it is assumed that the standard deviation of the selection curve is constant, that is, $S_A = S_B = S$, then,

$$\log \frac{{}_AC_l}{{}_BC_l} = \log \frac{PA}{PB} - \frac{lA^2 - lB^2}{2S^2} + \frac{l_A - l_B}{S^2}\, l$$

The right hand side is linear in l, that is, of the form a+bl

$$\text{where} \quad a = \log \frac{PA}{PB} - \frac{l_A{}^2 - l_B{}^2}{2S^2} \qquad (1)$$

$$b = \frac{l_A - l_B}{S^2} \qquad (2)$$

From the above, an attempt is made to deduce the ratio of the fishing powers of two nets. Gill net selection data presented in Holt (1963) was employed to illustrate the method.

8.3 Results and Discussion

Usually determination of the selection curves is made by using the assumption that the fishing powers of two nets are equal, and that the optimum length is proportional to mesh size. In the following derivations, the first assumption is relaxed and an attempt is made to estimate the ratio, of fishing powers PA/PB. The second assumption states that

$$l_A = k\ M_A \qquad (3)$$

$$l_B = k\ M_B \qquad (4)$$

where M_A and M_B are the mesh sizes of the two nets.

We have from (1), (2), (3) and (4),

$$a = \log \frac{PA}{PB} - \frac{(M_A^{\ 2} - M_B^{\ 2})k^2}{2S^2} \qquad (5)$$

$$b = (M_A - M_B)\ \frac{k}{S^2} \qquad (6)$$

Substituting for $\frac{k}{S^2}$ in (5) in terms of b and $(M_A - M_B)$,

$$a = \log \frac{PA}{PB} - \frac{(M_A + M_B)}{2}\ bk$$

If an estimate of k is obtained, then

$$\log \frac{PA}{PB} = a + \frac{(M_A + M_B)bk}{2} \qquad (7)$$

Generally k is estimated using a, b and M_A and M_B when fishing powers of the two gear are assumed equal. When this assumption is not made, an independent estimate of k is to be sought, to estimate the ratio PA/PB from (7).

Estimation of k:

We have from (3) and (4) li = k Mi where li is the mean size caught and Mi is the mesh size for gear 'i'. When data are available for more than 3 mesh sizes, a st line passing through the origin of li on Mi can be fitted and the slope 'k' of this line estimated. Then from (7), we have

$$\log \frac{PA}{PB} = \hat{a} + \frac{(M_A+M_B)}{2} \hat{b}\,\hat{k} \qquad -(8)$$

Illustration:

The data given by Holt (1963) were used for illustrating the estimation of relative fishing power.

On the basis of the length frequency distribution (Table 2, Holt, 1963), the mean sizes for the 8 mesh sizes were estimated as under.

	A	B	C	D	E	F	G	H
Mesh size	13.5	14.0	14.8	15.4	15.9	16.6	17.8	19.0
Mean size	58.2	58.9	60.5	61.3	62.3	63.8	66.1	67.1

The st. line passing through the origin, $\bar{I}i = kMi$ is given by

$$\bar{I}i = 3.896\ Mi$$

Assuming k to be 3.9, log $\frac{PA}{PB}$ can be estimated from equation (8). The valuesof a and b were taken from Holt (1963).

(1) Relative efficiency of mesh size B to A

$$\log_e \frac{P_B}{P_A} = -7.14 + \frac{13.5+14.0}{2} \times 0.12 \times 3.9 = -0.705$$

Ratio of fishing power, i.e., $\frac{P_B}{P_A} = 0.494$. In other words, mesh size A appears to be about two times as efficient as mesh size B.

(2) Relative efficiency of mesh size C to B

$$\log_e \frac{PC}{PB} = -12.56 + \frac{14.0+14.8}{2} \times 0.21 \times 3.9 = -0.766$$

Ratio of fishing power = 0.465. That is mesh size B is about 2.15 times more efficient than mesh size C.

(3) Relative efficiency of mesh size D to C

$$\log_e \frac{PD}{PC} = -6.23 + \frac{14.8 + 15.4}{2} \times 0.10 \times 3.9 = -0.341$$

Ratio of fishing power of D to C = 0.711 or mesh size C is about 1.4 times more efficient than mesh size D.

(4) Relative efficiency of mesh size E to D.

$$\log_e \frac{PE}{PD} = -6.70 + \frac{15.4 + 15.9}{2} \times 0.10 \times 3.9 = -0.5965$$

Ratio of fishing power of E to D = 0.551

That is, mesh size D is about 1.8 times more efficient than mesh size E.

(5) Relative efficiency of mesh size F to E.

$$\log_e \frac{PF}{PE} = -13.96 + \frac{15.9 + 16.6}{2} \times 0.22 \times 3.9 = -0.0175$$

Ratio of fishing power of F to E is 0.982. That is mesh sizes E and F are more or less equally efficient.

(6) Relative efficiency of mesh size G to F.

$$\log_e \frac{PG}{PF} = -20.41 + \frac{16.6 + 17.8}{2} \times 0.30 \times 3.9 \simeq -0.286$$

Ratio of fishing power of G to F, that is $\frac{PG}{PF}$ = 0.751. Mesh size F is almost 1.3 times more efficient than G.

(7) Relative efficiency of mesh size H to G.

$$\log_e \frac{PH}{PG} = -10.47 + \frac{17.8 + 19.0}{2} \times 0.15 \times 3.9 = 0.294$$

Ratio of fishing power of H to G = 1.342. That is, mesh size H is about 1.3 times more efficient than mesh size G.

Among the seven pair-wise comparisons gear E and F were found to have more or less the same fishing power. Estimate of k obtained by using this pair was 4.1, which is close to the 'k' (3.9) estimated from "the regression passing through the origin", namely, $Ti = k\ Mi$. This is because, the assumption of equal fishing power for the two gear appears to be satisfied for this pair only.

Relative size selectivity and determination of the size of fish, for which the gear is most efficient:

Let $N_1, N_2, .. N_t$ denote the number of fish of a specified species in the population in the t size classes. Let two comparable gear A and B of differing size selectivity be operated under identical conditions and let the number of fish caught per unit effort by the two gear be

A: $n_{11}, n_{12} \cdots n_{1t}$

B: $n_{21}, n_{22} \cdots n_{2t}$

in the t size classes

Case 1

$N_1, \ldots, N_t$ are very large, so that $N_i - nji \sim N_i$

for $j = 1$ and 2

Let $P_1, P_2, \ldots, P_t$ and $q_1, q_2, \ldots, q_t$ be the catchability coefficients of the two gear corresponding to the 't' size classes.

We, then have

$n_{1i} = p_i N_i$

$n_{2i} = q_i N_i$

so that $\frac{n_{1i}}{n_{2i}} = \frac{p_i}{q_i}$

It may be noted that if the normal model is assumed $p_i = pA \times \exp\left\{ - \frac{(l_i - l_A)^2}{2S_A^2} \right\}$ which gives the relationship between the catchability coefficient and the fishing power.

By plotting $\frac{n_{1i}}{n_{21}}$ against the size of the class 'i', l_i the relationship between $\frac{p_i}{q_i}$ and the size of the class 'i' can be determined in the form

$$\frac{n_{1i}}{n_{2i}} = f(l_i) \qquad (9)$$

Substituting for l_i, the size l_A for which the gear A is most efficient in equation (9),

$$\frac{n_1 l_A}{n_2 l_A} = f(l_A) \qquad (10)$$

and from this, an attempt can be made to determine 'l_A'

The number of fish caught in various length classes of three nets of mesh sizes A, B and C presented in Holt (1963) is reproduced below:

Length (cm)	Mesh size (cm)		
	A	B	C
	13.5	14.0	14.8
52.5	52	11	1
54.5	102	91	16
56.5	295	232	131
58.5	309	318	362
60.5	118	173	326
62.5	79	87	191
64.5	27	48	111
66.5	14	17	44
68.5	8	6	14
70.5	7	3	8
72.5	-	3	1

Taking two gear at a time to form the catch ratios and denoting by n_{1l} and n_{2l}, the number of fish caught in the length class 'l' by the two gear, the ratios

$\frac{n_{1l}}{n_{2l}}$ and log $\frac{n_{1l}}{n_{2l}}$ were formed and denoted by log (B/A) when the gear 'A' and 'B' were considered.

For the comparison of A and B and B and C, the following values were obtained.

Length (cm)	log (B/A)	log (C/B)
52.5	-0.675	-
54.5	-0.0495	-0.755
56.5	-0.104	-0.248
58.5	0.0125	0.0563
60.5	0.1662	0.275
62.5	0.0419	0.3415
64.5	0.2499	0.3641
66.5	-	0.4130
68.5	-	-
70.5	-	-

Plot of log $\frac{n_{11}}{n_{21}}$ on l is linear (Holt, 1963), showing that, the relationship is of the form

$$\log \frac{n_{11}}{n_{21}} = a + bl$$

From this, a and b can be estimated by the method of least squares. Denoting these estimates by $\hat{a}$ and $\hat{b}$,

$$\log \frac{n_{11}}{n_{21}} = \hat{a} + \hat{b}l$$

If l_A, l_B, l_C etc. denote the size (lengths) of fish for which the gear are most efficient with respect to A, B, C etc., then

$$\log \frac{n_1 l_B}{n_2 l_B} = \hat{a} + \hat{b}\, l_B$$

$$\text{or } \hat{l}_B = \frac{\log \frac{n_1 l_B}{n_2 l_B} - \hat{a}}{\hat{b}} \qquad (11)$$

But $n_1 l_B$ and $n_2 l_B$ are not known,

Regression of log (B/A) on 1, gives

$r = 0.828^*$, $\hat{b} = 0.05764$ and $a = -3.4229$ for $n = 7$

Taking $n_1 l_B$ as the maximum number of fish caught,

$$\hat{l}_B = \frac{\log \frac{318}{308} + 3.4220}{0.05764} = 59.6$$

against 56.8 when Holt model was applied.

Similarly from comparisons of gear B and C,

$r = 0.9027^{**}$, $\hat{b} = 0.08953$, $\hat{a} = -5.35242$ for $n = 7$,

so that

$$\hat{l}_C = \frac{\log \frac{362}{318} + 5.3542}{0.089525} = 60.4$$

against 60.1, when Holt model was applied.

Significance of the correlation coefficients shows the linearity of the plot of log (B/A) on 1.

On the extent of difference in the estimate owing to the replacement of $n_1 l_B$ etc., by n_{1max} etc. in the computation of l_B, l_C etc.:

From (11), the approximation leads to

$$\hat{l}_B = \frac{\log \frac{n_{1max}}{n_2} - \hat{a}}{\hat{b}}$$

where n_2 is the frequency of the other gear in the length corresponding to n_{1max}

Let $n_1 l_B = n_{1max} + r_1$

and $n_2 l_B = n_2 + r_2$

so that the actual estimate of l_B would be

$$\hat{l}_B = \frac{\log\left\{\frac{n_{1max} + r_1}{n_2 + r_2}\right\} - \hat{a}}{\hat{b}}$$

$$= \frac{\log\left\{\frac{n_{1max}}{n_2}\right\} - \hat{a}}{\hat{b}} + \frac{\log\left\{\frac{1 + \frac{r_1}{n_{1max}}}{1 + \frac{r_2}{n_2}}\right\}}{\hat{b}}$$

$$= \hat{\hat{l}}_B + \frac{\log\left\{\frac{1 + \frac{r_1}{n_{1max}}}{1 + \frac{r_2}{n_2}}\right\}}{\hat{b}} \qquad (12)$$

It follows from (12) that the difference $(\hat{l}_B - \hat{\hat{l}}_B)$, given by

$$\frac{\log\left\{\frac{1 + \frac{r_1}{n_{1max}}}{1 + \frac{r_2}{n_2}}\right\}}{\hat{b}}$$

will disappear when:

(i) r_1 and r_2 are very small compared to n_{1max} and n_2 respectively, so that $\frac{r_1}{n_{1max}}$ and $\frac{r_2}{n_2}$ become negligible

(ii) $\frac{r_1}{n_{1max}} = \frac{r_2}{n_2}$, that is when $n_2 r_1 = n_{1max}\, r_2$ or when the difference $n_2 r_1 - n_{1max}\, r_2$ is negligible.

Assuming the magnitude of r_1 and r_2 to be 10% of n_{1max} and n_2 respectively, the difference $(\hat{1}_B - \hat{1}_B)$, will be $\log \frac{1.1}{0.9}/b$ or $\log \frac{0.9}{1.1}/b$, that is $0.08715\ b^{-1}$ or $-0.08715\ b^{-1}$ when r_1 and r_2 are of opposite sign, the first when r_1 is positive and the second when r_1 is negative. Obviously, when r_1 and r_2 are of the same sign, the difference will be zero, in this case.

The difference will be negligible, in general, when the class interval is small, because, then r_1 and r_2 will be small so that $\frac{r_1}{n_{1max}}$ and $\frac{r_2}{n_{2max}}$ will be negligible

Since $\frac{n_{1i}}{n_{2i}} = \frac{p_i}{q_i}$, a relationship between the ratio of the catchability coefficients, $\frac{p_i}{q_i}$ and the size (length) for which the gear is most efficient can be tabulated for any given comparison . For $\hat{l}_B$ and $\hat{l}_C$, from the comparisons of gear 'A and B' and 'B and C' respectively, the relationship would be:

p_i/q_i	$\hat{l}_B$	$\hat{l}_C$
1	59.4	59.8
1.1	60.1	60.3
1.2	60.7	60.7
1.3	61.4	61.1
1.4	61.9	61.4
1.5	62.4	61.7
1.6	62.9	62.1
1.7	63.4	62.4
1.8	63.8	62.6
1.9	64.2	62.9
2.0	64.6	63.1

The catch ratios will be the same for different sets of values of p_i and q_i. As p_i/q_i is independent of the number of fish in the population, for certain possible values of p_i and q_i, the ratios p_i/q_i are related as per the following scheme:

$p_i > q_i$

	p_i				p_i/q_i			
$q_i = 0.1$	0.15	0.2	0.25	0.3	1.50	2.00	2.50	3.00
$q_i = 0.2$	0.25	0.3	0.35	0.4	1.25	1.50	1.75	2.00
$q_i = 0.3$	0.35	0.4	0.45	0.5	1.17	1.33	1.50	1.67
$q_i = 0.4$	0.45	0.5	0.55	0.6	1.13	1.25	1.37	1.50

From the assumptions and formulations used in this chapter, it follows that the ratio of fishing power provides with an index of the relative fishing efficiency, while the ratio of catchability coefficients provides with the size class most suitable for the gear. In determining the size class, the assumption of equal fishing powers for the two gear is not required. The method assumes a solution for 'l_A' in equation 10.

SUMMARY

Studies on gear selectivity have received great attention while gear efficiency studies do not seem to have received equal consideration. In temperate waters fishing industry in general, is well organised and relatively large and well equipped vessels and gear are used for commercial fishing and the number of species are less; whereas in tropics particularly in India, small scale fishery dominates the scene and the fishery is multispecies operated upon by multigear. Therefore many of the problems faced in India may not exist in developed countries. Moreover, there is a paucity of literature on methods of comparison of fishing gear efficiency, though much work has been carried out in assessing relative efficiencies. Hence, main subject of interest in the present thesis is an investigation into the problems in comparison of efficiency of fishing gear, especially in using classical test procedures with special reference to the prevailing fishing practices, in other words, with reference to catch data generated by the existing system. This has been taken up with a view to standardizing an approach for comparing the efficiency of fishing gear. Besides this, the implications of the terms 'gear efficiency' and 'gear selectivity' have been examined and based on the

commonly used selectivity model, estimation of the ratio of fishing power of two gear has been considered. An attempt to determine the size of fish for which a gear is most efficient has also been made. The work has been presented in eight chapters dealing with

(i) the minimum number of fishing trials required for comparison of trawl nets when the classical F-test relevant to two-way ANOVA is applied;

(ii) the problem of nonadditivity in the relevant two-way ANOVA and steps to overcome the same;

(iii) a simulation to trace the problems faced in the classical approach along with consideration of nonparametric and other methods;

(iv) problems in efficiency comparison of gill nets;

(v) comparison of gill net catches using a test based on the distribution of catches;

(vi) an approach for the efficiency comparison within the trawl nets and within the gill nets for comparisons involving two and more than two gear;

(vii) the distinction between gear efficiency and gear selectivity and

(viii) estimation of the ratio of fishing powers and the size of fish for which a gear is most efficient.

The minimum number of fishing trials required for comparison of trawl nets when the classical F-test relevant to two-way ANOVA is applied has been investigated in chapter 1. A unique solution to this problem did not appear to exist because of the heterogeneity of the experimental material. Sequential experimentation and analysis have been found to be a practical approach to this problem. By this, the experiment can be terminated utmost after 35 days' fishing for catches with standard error per unit as per cent of the mean about 30% or less (after logarithmic transformation). For data with mean catches less than 1.5 kg analysis of variance approach does not appear to be meaningful.

The important assumption of additivity in two-way ANOVA was not found satisfied for the data on trawl net catches. This has been investigated in chapter 2. As a result, to bring out the relative efficiency of fishing gear, in the analysis of catch data, a combination of Tukey's test, consequent transformation and graphical analysis for outlier elimination has been introduced, which can be advantageously used for applying ANOVA techniques. Application of these procedures to actual sets of data showed that nonadditivity in the data was caused by either the presence of outliers, or the absence of a suitable transformation or both. As a corollary, the concurrent model: $X_{ij} = \mu + \alpha_i + \beta_j + \lambda\alpha_i\beta_j + \epsilon_{ij}$ adequately fits the data.

A simulation study to trace the problems faced in the classical approach has been made in chapter 3. The study indicated that there exists a critical number above which the relative efficiencies are discernible and below which, it is not possible to indicate whether one gear is more efficient than the other. This region where indication of relative efficiency is not possible, is termed as null region. The concept of null region and evaluation of N_c, the critical number is dealt with and a mathematical model is found using simulation technique. In the case of effective region, a method of comparing efficiencies is pointed out.

The problems in the analysis of data on gill nets has been taken up in chapter 4. As in the case of trawl catches, nonadditivity was found to be present in the two-way ANOVA. However, for data on gill nets, it was found that additivity could be introduced either by elimination of outliers or by employing Tukey's power transformation. Exclusion of all-zero-value-blocks was found to be better for comparing the efficiencies.

Comparison of gill net catches using a test based on the distribution of catches has been considered in chapter 5.

The numbers of fish caught by gill nets on the basis of standard operations were found to be distributed in the Negative binomial and Poisson forms. The chi-square test presented by Mood <u>et al</u>. (1974) to test whether several given samples are drawn from the same population such as the Poisson, Negative binomial or the Gamma was found useful to compare the catches by two gill nets.

Combining the results of the earlier chapters, a general guideline for comparing the efficiencies of trawl and gill nets separately has been indicated in chapter 6. It is as follows:

(i) When the efficiency of two trawl nets or two gill nets are to be compared, Wilcoxon matched-pairs signed-rank test (WSR test) may be used, as this has been found to be more efficient for the data. Also, its application is simple. For normal distributions this test is 95.5 percent as efficient as the parametric F-or t-test (Siegel, 1956) but, for other types of distribution (for instance, some long tailed ones) this test may be more than 100% efficient compared to the F-or t-test (Snedecor and Cochran, 1968). The superiority of WSR test over F-test for trawl catches has been demonstrated earlier. The nonnormality of the data has been indicated as revealed by the dependence of the mean on the variance. Lack of satisfaction of other assumptions like nonadditivity for ANOVA, has also been established by applying Tukey's test and the presence of outliers have been observed. Finally among the nonparametric methods for paired comparisons, except for randomization test, only WSR test seems to use interblock information. But randomization test is unwieldy for even moderately large samples (say, when the number of pairs exceeds 12) and as Siegel (1956) has observed, WSR test is a very efficient alternative to the randomization test because it is a randomization test on ranks.

(ii) When the efficiency of more than two trawl nets are to be compared, Friedman test and ordinary ANOVA F-test may be tried first. Applications showed Friedman test to be as sensitive as F-test, though no higher sensitivity was observed in any case. As Friedman test depends on fewer assumptions than does F-test as a practical procedure, if either of these tests brings out the difference in the efficiency, there is no need to test further. If both the tests are not found to be sensitive and if the probability for an observed difference is close to the significance level, the Quade test and if still inconclusive the combination of procedures as demonstrated in chapter 2 may be applied. The latter, though not simple, may bring out the real difference, if any, in this case. Recently, Iman et al. (1984), while making a comparison of Friedman test, Quade test and rank transform test (Lemmer and Stoker, 1967; Conover and Iman, 1976; Hora and Conover, 1984) found Quade test to be a better choice than Friedman test for normal data for the number of treatments, $k \leq 6$ and vice versa for $k > 6$. For the nonnormal settings the result favoured the Quade test for uniform case and lognormal case (when $k = 3$), while Friedman test showed more power than the Quade test in the remaining 11 of the 16 nonnormal cases, they examined. They found Quade test to be favourable for light tailed uniform distributions while the Friedman test and the rank transform test for heavy tailed distributions. Application of Quade test and rank transform test to trawl catches showed the same result as when Friedman test was applied. However, Friedman and Quade tests showed more or less the same sensitivity but rank transform test showed a little less sensitivity.

(iii) When the efficiency of more than two gill nets are to be compared, Friedman test and ordinary ANOVA F-test may be used. Friedman test helps to confirm the result as its applicability for the data is more valid and as applications (Kunjipalu et al., 1984) have shown Friedman test to be as sensitive as F-test. The performance of Quade test, Friedman test and rank transform test were compared for gill net catches too. All the tests showed the same result. However, Quade test and rank transform test showed a little more sensitivity than Friedman test. It is advisable to apply Quade test and rank transform test when the probability for an observed difference is close to the significance level. Another alternative to confirm the results would be the test illustrated in chapter 5. Fitting of the Poisson or negative binomial for this purpose is simple. So also the application of chi-square test for goodness of fit and then for testing equality of samples from the same Poisson or same negative binomial.

The distinction between gear efficiency and gear selectivity has been brought out in chapter 7. Relative efficiency of two gear can be interpreted as the ratio of the weighted totals of the selectivities of all size of fish under consideration, the weights being the total numbers in the respective size classes in the population.

In chapter 8, a procedure to estimate the ratio of fishing powers of two gear is provided, considering the approaches in Holt (1963) and Gulland (1969). An approximate procedure to determine the size of fish for which the gear is most efficient has also been given in this chapter. In determining this size class, the assumption of equal fishing powers for the gear is not required.

To summarise, the first six chapters are on gear efficiency and the last two on gear selectivity. The suitability of the classical test normally used, has been considered. It is found that the data are not suitable for direct application of this test. One of the major problems was found to be nonadditivity. This has been considered in chapters one and two. Gear efficiency studies lead to determination of superiority of one gear over the other/others when the gear have different efficiencies. There are two cases when the difference may not be discernible. The obvious case is one when the efficiencies of the gear are more or less equal. There is another case which is normally overlooked where inspite of the existence of difference in the efficiencies, experimental results are not able to bring them out. This has been studied in chapter three. In the earlier chapters, data from trawl nets were considered. To extend this work on gill nets, further work has been done and the same has been presented in chapters four and five. Combining the results of the earlier chapters a general guideline is indicated to compare the efficiencies of trawl and gill nets separately in chapter six. In the last two chapters, the distinction between gear efficiency and gear selectivity has been brought out. In addition, estimation of the ratio of fishing power associated with gear selectivity model and determination of the size of fish for which a gear is most efficient have also been considered.

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