PART 4: ALTERNATIVE INPUT BASED MEASURES

THE MEASUREMENT OF FISHING CAPACITY IN CHINESE FISHERIES AND RELATED CONTROL PRACTICES

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Abstract: In this paper, the items related to fishing capacity in the Chinese marine fisheries' statistical data are described. The key items used for monitoring and controlling fishing capacity include total number of fishing vessels, total engine power and total tonnage. The methods used by Chinese fisheries scientists for standardizing fishing effort when determining fishing capacity are described. The gray system theory is proposed as an appropriate method for standardization across different size vessels and across fisheries.

1. MEASUREMENT OF FISHING CAPACITY IN CHINESE FISHERY MANAGEMENT

China has been one of the world's top fish producing countries since 1989. In 1998, total fisheries output amounted to 39.06 million tonnes, of which the output from marine fishing was 14.98 million tonnes, 38.3 percent of the total. China's fisheries have a long history, and consist of various fishing methods in coastal waters, including trawl, purse seine, set net, longline, gill-net, etc. Furthermore, in trawling, large mid-water trawl, pair trawl, outrigger prawn trawl and beam trawl are used. Fishing enterprises consist of national and collective fishery companies, as well as joint-venture companies and private fishing units owned by individual fishermen, all of which use various types of vessels and fishing gears.

The diversity of fishing methods, numerous producers and the collapse of marine resources create difficulties in the measurement, quantification and control of fishing capacity in Chinese coastal waters. Since the late 1970s, the resources of some major economic species, such as long hair-tail fish, large yellow croaker, small yellow croaker and cutter fish, in Chinese coastal waters have fallen or collapsed. As a consequence, species with relatively low value or a low position in the food chain currently comprise the greatest proportion of total output. Given this, it is necessary to control and reduce number of fishing vessels and fishing capacity urgently. Therefore, research into the measurement and control of fishing capacity seems to be of significant in Chinese coastal waters.

In China, there are three statistic indexes currently used to indicate fishing capacity. These are the number of fishing vessel, the gross tonnage of fishing vessel and engine power. These three indexes basically represent the capacity of the Chinese coastal fishery to a certain extent and have played a role in fishery management. In addition, the number of fishing vessel and the engine power are regarded as control indexes for fishing capacity. For example, Chinese government has conducted a policy of controlling and limiting the amount of engine power since 1987.

The development of the number of fishing vessels and engine power in Chinese coastal waters from 1951 to 1997 is shown in Figures 1 and 2[2]. In 1997, China also started a 'double control' programme, aimed at controlling both the total number of fishing vessel and

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[2] Data for these figures were taken from the Yearbook of Chinese fishery statistics.

the amount of engine power. Furthermore, in early 1999, the Chinese government decided not to increase, but reduce the total number of fishing vessels and engine power in coastal waters.

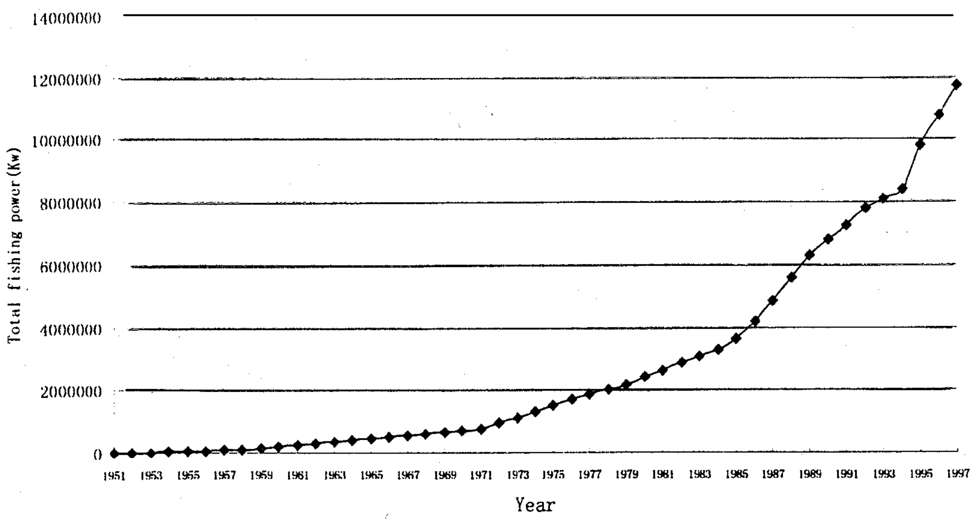

Figure 1. Total engine power, 1951-1997

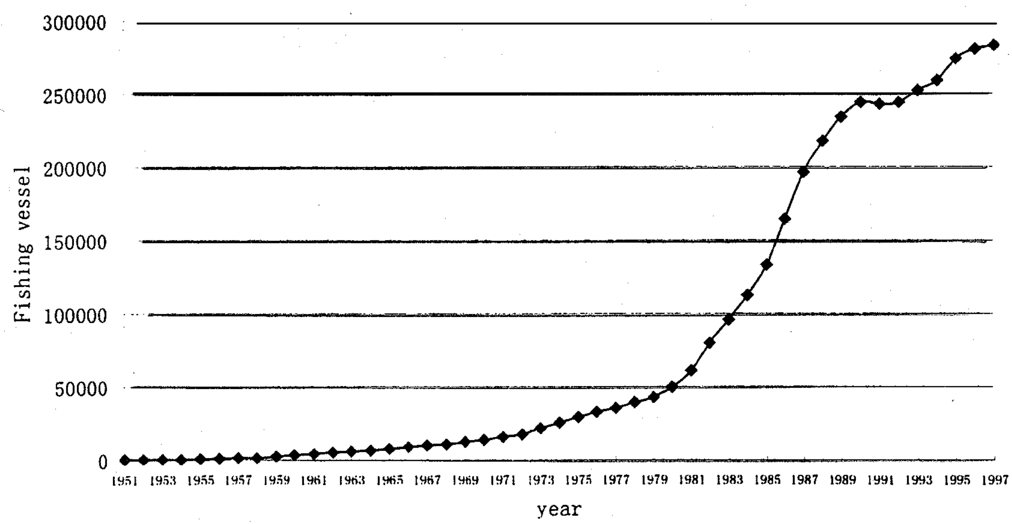

Figure 2. Total number of fishing vessels, 1951-1997

2. DEFINITION OF FISHING CAPACITY AND THE FACTORS AFFECTING FISHING CAPACITY

'Fishing capacity', which is a new concept in fishery management, has not had a standard definition and appropriate measuring method up until fairly recently. Holland and Sutinen (1998) considered that fishing capacity is usually thought of in terms of the ability to produce fishing effort per period. In FAO (1998), fishing capacity is defined as "*[t]he ability of stock of inputs (capital) to produce output (measured as either effort or catch). Fishing capacity is the ability of a vessel or a fleet of vessels to catch fish.*" However, the concept of fishing capacity originates from traditional industrial economic theory, and is based on the reasonable utilization of the fishing resources under consideration given existing ecological, economic and social aspects, and given that the various inputs (including the fishery resources) are utilized in their best combination. It should be noted that the concept of fishing capacity is different from fishing effort. It is well known that fishing effort is measured as the natural characteristics of fishing vessel (such as gross tonnage and engineer power) or fishing operation (for example, fishing days and number of hauls). However, fishing capacity should be considered as a comprehensive index, presenting or indicating all factors affecting the catches or fishing effort. Fishing capacity is also a dynamic concept that will vary with different fishing gear and method, skill, fishing area, and fishery management.

The main factors affecting fishing capacity are fishing time, fishing technology and its equipment, the biomass of the fish resources, and other inputs.

2.1 Fishing time

Fishing time consists of maximum (potential) fishing time, optimal fishing time and actual fishing time. For the purposes of macro-management, it is suitable to adopt maximum fishing time, because maximum fishing time is a relative fixed value after the period of closed fishing season and other factors affecting fishing time under a given fishery management are deducted. Optimal fishing time is the fishing time necessary to achieve the aim of fishery management, which will change as the aims of management and fish resources change. Actual fishing time may accurately reflect the pressure on fishery resources and vary with fishing vessels and marine environment. For example, a fishing vessel that stops its fishing activity may be considered as non-fishing capacity. In China, actual fishing time is usually used in the measurement of fishing capacity.

Fishing time includes productive time and non-productive time. Productive fishing time is related to detecting fish, looking for fishing ground and harvesting fish. The allocation of fishing time depends on the fishing gears and methods used. Taking whaling as an example, the time of harvesting a whale is short, but productive fishing time is mainly involved in searching for the whale. However, in the demersal trawl fishery, most of productive fishing time is spent on trawling once main fishing grounds have been found. This is also the case for longline and squid jigging. However, the harvesting time varies greatly in purse-seine fishery,

During longlining, gillnetting, trawling and squid jigging, fishing time has a positive relationship with catch. The methods for calculating fishing time should reflect the fishing feature. For example, in a trawl fishery, the catch may closely relate to the actual fishing time (e.g. per fishing hour or per haul). If the fishing time per haul is a fixed length, the number of haul may become an index of fishing capacity. However, there are many ways to measure fishing time, such as fishing hour, number of haul, fishing days, days-at-sea and number of trip, etc. Because all of these are closely related, the most suitable index needs to be selected for measuring fishing capacity.

By analyzing the distribution of fishing time to obtain a more appropriate index representing fishing effort, it is suggested that the best way to calculate the actual fishing time in the fishing ground would be by means of a unit based on either fishing days or fishing hours. For this purpose, fishing time should be recorded on the log book or catch table in detail. For instance, this would involve specifying the time spent on searching for fish and looking for fishing grounds, the time for preparing or maintaining the fishing gear, actual fishing time and clearing up the catch, etc.

2.2 Improvement of fishing technology and equipment

It is well known that science and technology will greatly influence fishing capacity, particularly for active fishing methods, such as trawling and purse seining. For these activities, fishing capacity varied with the improvement and progress of fishing vessel and fishing gear. As well as the increase in the industry in terms of boat numbers, gross tonnage and engine power of fishing vessel are increasing, the size of fishing gear is also expanding, and more advanced instruments are used. As a result of these changes, fishing efficiency improves and fishing capacity increases. For purse seining, the adoption of high speed fishing vessels and advanced detecting equipment, such as sonar, expands the detecting range and improves the efficiency of searching for fishing ground and thereby results in increased catch. In squid jigging, deep-sea temperature and salinity analyzer (e.g. VTS-300) and special designed sounder for squid are likely to strengthen the ability to find high yielding fishing grounds. Under-water lights (e.g. SWSY) made fishing not only feasible during the night, but also can be used in day time, resulting in higher catches. In contrast, in the passive fishing activities such as trap and longline fisheries, fishing capacity may mainly depend on the number of traps or lines, and their unit of capacity may be relatively stable.

2.3 Biomass of resources and their distributions

Since fish in the fishing ground are distributed unevenly, the distribution of fishing vessels is unequal also. If the fish resources are abundant, the main factors affecting actual fishing capacity may be a function of fishing vessel, fishing gear and fishing technology. In contrast, if the resource is at a low level, the major factor may be the biomass of resources. Therefore, in a fixed period, the level of resources is one of the important factors affecting total catch. However, we should note that fishermen would transform their fishing capacity from one fishing area to another. Thus the total biomass decreased in an area, the catch of a fishing vessel would still maintain a certain level.

2.4 Use of variable inputs

The variable inputs include oil, labour, ice and feed. Even if fishing time is kept constant, the level of variable inputs employed and their combination with fixed inputs may change. In a fixed fishing period, it is possible to increase catch by increasing certain variable inputs. For example, in the Chinese squid jigging fishery, in which the output from handed-jigger occupy more than 60 percent of the total catch, the number of fishermen directly influence the catch per day. In addition, some fixed capital such as refrigerator and size of storehouse also affect fishing capacity. Those fishing vessel with strong freezing and large storage facilities can support longer fishing time at sea, which can greatly affect output during the high yield period. It should be noted that while some factors come under certain restrictions, fishermen can (and do) adjust various inputs and their combination, increasing unlimited inputs. This will result in an increase in fishing capacity.

2.5 Skill of the skippers

The skill of the skippers reflects the level of fishing technology, the ability to identify the best fishing ground and the level of management. These will directly or indirectly influence the catch (output) and fishing capacity.

2.6 Sea condition and fishery management

Sea conditions in the fishing area may directly affect the available fishing time. In different fishing area, the level of biomass and management regulations are also different. However, fishing vessels move between fishing areas often, which makes fishing capacity fully utilized.

3. MEASUREMENT OF FISHING CAPACITY AND EXAMPLES

Methods of measuring capacity may be considered either 'input-based' or 'output-based'. 'Input-based' measurement, which is the traditional method, is estimated in many ways. A common practice is to select a factor positively related with fishing efficiency for the unit of fishing capacity such as labour, number of fishing vessel, quantity of fishing gear used, days-at-sea or gross engine power. But as there are so many factors, one factor could not properly reflect fishing capacity. For example, the number of fishing gear used may not be considered as a unit of measurement alone because of variations in fishing vessels, fishing gear and size. Therefore, a composite index is required. For example, in pair-trawl fisheries, an index of fishing time multiplied by engine power may be an appropriate unit for measuring fishing capacity. In gillnetting, the number of nets set per day may be used as a unit of capacity. In squid jigging fisheries, the number of sets of jigging machines and number of fishermen doing hand jigging could be considered as appropriate measurement units.

However, often several different fishing gears and fishing methods are utilized on the one fishing ground. For instance, long hairtail fish distributed over the whole East China Sea are caught by trawl, purse seine, and set nets. Consequently, the multispecies nature of the fisheries and varied factor inputs create more difficulty in measuring fishing capacity.

In the Chinese coastal fishery, the measurement of fishing capacity has not been carried out on a single fishing vessel, a single fleet or a single fishery because many factors are complicate and not easily quantified. In practice, the method adopted is based on a reference frame, using one representative fishing vessel or one fishing fleet as the standard unit of capacity. The capacity of the other fishing vessels or fleets is estimated based on a comparison with the standard vessel/fleet.

3.1 Calculation based on capacity of a single fishing method

Fishing capacity is the ability of a fishing vessel to catch fish, which depends on the size, gross tonnage and engine power, and the fishing gear used. To a certain degree, fishing capacity is positively correlated with catch per unit fishing time or catch per unit effort (CPUE), so fishing capacity may be estimated by the adoption of CPUE. For a given fishing ground, resources density and fishing time, a conversion coefficient (*K*) can be estimated as the ratio of the CPUE of one fishing vessel to that of the standard CPUE, given by:

$$K = CPUE\ of\ a\ fishing\ vessel\ /\ Standard\ CPUE \qquad (1)$$

Suppose there are three types of vessels fishing in the same fishing ground, with vessel type A being regarded as the standard fishing vessel. The conversion coefficients for type A, B and C are K_A(=1), K_B and K_C respectively. The total fishing capacity (F) in this fishing area is:

$$F = F_A + F_B K_B + F_C K_C \tag{2}$$

Where F is the total fishing capacity; F_A, F_B, and F_C are nominal measure of fishing capacity (e.g. days) of type A, B and C respectively.

3.2 Calculation of fishing capacity in multigear fisheries

If various fishing methods catch the same stock in one fishing ground, it is very difficulty for us to adopt the same unit for measuring fishing capacity and calculate total capacity. We selected a representative fishing method regarding as a standard one, for instance type A, the total capacity is:

Total fishing capacity = fishing capacity of type A×total catch / catch of type A (3)

The important step is the selection of a representative fishing method to represent the unit of capacity. If more than two fishing fleets using different fishing gears and methods catch the same stock in one fishing ground, CPUE of each fishing fleet need to be calculated first, and the differences in CPUE between the fishing fleets analyzed. If the CPUE of the two fleets are similar, either CPUE can be selected as the standard unit for measuring fishing capacity. If the CPUE of the fleets varied, there is no one fishing fleet that can be selected as the standard unit.

For example, the herring fishery in the Yellow Sea has several fishing methods, including trawling, purse seining and various set-nets. The catch from trawling dominates and makes up 50 percent of the total catch. The trawling operation covers most of area in Yellow Sea. The number of trawl nets used is quite stable and the size of trawls are identical. Ye and Huang (1980) chose 100 hauls of trawling as a unit of measuring capacity in each type of vessels, and standardized fishing capacity in the herring fishery based on the above method. In 1972, the total output of herring in the Yellow Sea reached 175 000 tonnes, and the catch from trawling per 100 hauls during January and March was 323.6 tonnes so the total fishing capacity in 1972 amount to 540 units of capacity (175 000 / 323.6). It should be mentioned that the total output, 175 000 tonnes, was caught by trawlers, seiners, and other types of fishing vessels.

3.3 Correcting fishing capacity

As fishing vessel, fishing gear, fishing time and skill have influence on fishing capacity, Gu and You (1987) proposed a correcting method for bottom trawling in the East China Sea and Yellow Sea. The method takes into account the:

(a) influence of fishing vessel and fishing gear. The engine power increased from 100-250 horse power in 1960 to 250-600 hp in 1987, the fishing gear also enlarged from 560 mesh×11.43 cm or 756 mesh×11.43 cm up to 844 mesh×11.43 cm or 1 200 mesh×11.43 cm. Since 1978, the large mesh (20×40 cm) has been adopted.

(b) changing in target species and non-target species;
(c) progress in technology and skill; and
(d) length of fishing time per haul. For example, in 1960, a pair trawling vessel made 2.59 hauls per day with each trawl towed for 2.5 hours per haul on average. In 1985, the hauls per day had fallen to 1.44, but towing time per haul increased to 4.5 hours.

Gu and You (1987) derived three correcting parameters: F_1 (corrected coefficient of fishing power and fishing vessel), F_2 (corrected coefficient of trawling time) and F_3 (corrected coefficient of fishing gear improvement), with the total corrected coefficient, F, being given by:

$$F = F1 \times F2 \times F3 \tag{4}$$

Gu and You (1987) calculated the corrected coefficient based on the data from 1960 to 1985 and estimated fishing capacity (see Figure 3), the corrected capacity is more appropriate to actual fishery.

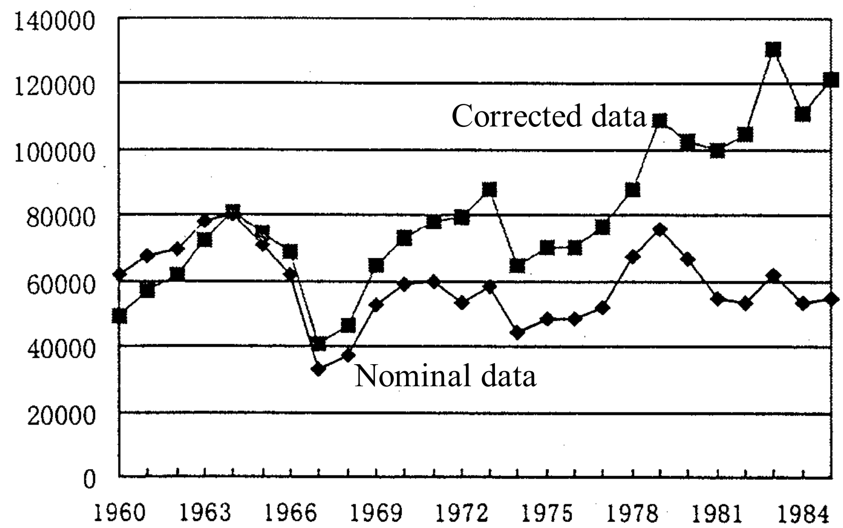

Figure 3. Comparison of nominal and corrected capacity for bottom trawlers in the East China Sea and Yellow Sea, 1960-1984

4. AN AGGREGATED WEIGHTED INDEX OF FISHING CAPACITY BASED ON GREY THEORY

From the above, there are many factors affecting fishing capacity which vary by fishing methods, so an aggregative weighted index of fishing capacity needs to be constructed. To establish such an index requires determining the main factors in each fishing methods and deriving appropriate weights to reflect their influence. Different weighted rates will be given to each main factor and an aggregative weighted index for fishing capacity can be derived. The paper intends to analyze and compare these factors through Grey theory, and build an aggregated weighted index of capacity.

4.1 Comparison factors affecting the fishing capacity

The formula for Grey correlation coefficient $L_{0\,i}(k)$ between maternal series and sub-series that have been standardized is:

$$L_{0i(k)} = \frac{\Delta_{\min} + \lambda \Delta_{\max}}{\Delta_{0i}(k) + \lambda \Delta_{\max}} \tag{5}$$

where $\Delta_{0i}(k) = |X_0(k) - X_i(k)|$ is the absolute value of difference between maternal series and sub-series at time k; Δ_{max} is the maximum value of all differences between maternal series and sub-series; Δ_{min} is the minimum value of all differences between maternal series and sub-series; and λ is the resolving rate, with a range of (0, 1). A value of $\lambda = 0.5$ is assumed in this paper.

The Grey correlation degree is given by:

$$R_{0i} = \frac{1}{N} \sum_{k=1}^{N} L_{0i}(k) \tag{6}$$

where $R_{0\,i}$ is the correlation coefficient between the maternal series and sub-series; and N is the number of compared series.

For example, the data from the Shanghai fishery company during 1981 and 1985 includes the number of hauls, fishing day and catch landing of 600 hp trawler. After analyzing these data, two factors – hauls and fishing days – are identified as the main factors affecting fishing capacity. The estimated correlation coefficients R_{01} (correlation between fishing day and catch) and R_{02} (correlation between number of hauls and catch) were 0.5162 and 0.5757 respectively, which indicates that the number of hauls is more suitable for the measurement of fishing capacity.

4.2 An aggregative weighted index for the fishing capacity

Based on the above data, an aggregative weighted index for capacity has been established by means of Factor Analysis. The formula for the aggregative weighted index (Z) is given by:

$$Z = 0.3454\, X_1 + 0.50284\, X_2 \tag{7}$$

where X_1 is the fishing time (days) and X_2 is the number of hauls.

5. DISCUSSION

The measures of fishing capacity for both single and multiple fishing methods shown above can be used as a reference index for the purposes of fisheries management. However, this measure is not perfect, as it is only based on the number of fishing vessels and their natural characteristics. There is a limitation to quantifying fishing capacity because the capacity of standard fishing vessels and fishing gear themselves vary with time. In addition, if some factors which affect fishing capacity are restricted by the fisheries regulations due to conservation of fisheries, such as set limitations on the number of fishing vessels, engine power and gross tonnage, these might result in the increased use of other inputs. Therefore, it is very important for estimation and control of fishing capacity to monitor the total catch of fleets and fully analyze and understand the function of the combination of various inputs.

The level of fish resources is the most important element in the factors. The actual fishing capacity varies based on different levels of stock. For example, one large squid jigging vessel with 50 sets of jigging machines may catch about ten tonnes squids per day only during peak fishing season in the Northern Pacific. However, the same fishing vessel may have daily catch more than 90 tonnes squid in Northwest Atlantic because of abundant squid stock. In this case, the main factors affecting the real fishing capacity may be the ability to fast-freeze and process. Similarly, the trawling duration of pair trawling for file fish in the 1950s in Chinese water was about a half hour and the catch was eight to 16 tonnes. However, in the 1990s, because of the fish resources decline, it was only about two tonnes with much longer trawling time even though more advanced facilities were used, which meant greater fishing capacity.

Among the various fishing methods, measuring capacity of trawler is the most difficult because of many factors affecting the level of output. Moreover, the total capacity of a fleet may be not equal to, and often more than the simple sum of individual capacity of fishing vessels. Since modern communication technology developed, the exchange of fishery information has become much easier than before, which has improved fishing ability. The supply of fuel, freshwater and food to the fishing vessels at sea has also lengthened the available fishing time.

It is also possible that variable inputs could become the main factors determining fishing capacity. For example, adjusting the use of fuel and labour will increase the real catching power or raise fishing efficiency. The optimal levels and combination of variable inputs depends on biological, economic and regulatory conditions in the fishery. Therefore, the levels of uncontrolled inputs will change if some inputs are regulated. Thus, both the potential and the optimal capacity of fleets may change even though the size and number of vessels do not change.

Clearly, fishing capacity is a dynamic concept, which is affected by many factors. Obviously, fishing capacity need to be corrected periodically to reflect the actual ability of the fleet.

To sum up, the aims of quantification and measurement of fishing capacity are to control and reduce the pressure on fishery resources, to achieve sustainable utilization and raise economic benefit. Therefore, from a macro-management point of view, fishing capacity of fleets is estimated on the basis of the average level rather than only on the actual capacity of one vessel. To simplify the calculation, one or several main indexes should be determined from the many factors that affect output. On the other hand, in order to correctly control and limit the increase of fishing capacity, the level of stock, sea condition and other factor have to be taken into account. Furthermore, the standardized units for measuring the fishing capacity will vary between countries, with the development of harvesting technology and with changes in stock levels. Consequently, it is suggested that capacity should be measured based on the country, fishing area or region.

In order to promote the study on the fishing capacity around the world and to carry out the international action plan of fishery management, the comparative study across countries, area and regions should be organized, and corresponding fishery data and information system should be built up with the assistance of international research groups.

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DEFINITION OF FISHING TRIP TYPES AND FLEET COMPONENTS IN THE SPANISH ARTISANAL FISHERY OF THE GULF OF CÁDIZ: A NEW APPROACH FOR STUDY OF ARTISANAL FISHERIES

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Abstract: The multigear and multispecies Spanish artisanal fishery in the Gulf of Cadiz contains a fleet of about one thousand vessels capturing more than forty commercial species. From this complexity arises the need to define fishing trip type and fleet components (i.e. groups of vessels developing the same fishing pattern through the year), which permits the monitoring of fishing effort and the design of simpler and more efficient sampling schemes.

In order to define the artisanal fleet components, the daily landings by species and vessel carried out during 1996 were considered. In a preliminary analysis, a total of 53 'fishing trip types' were objectively characterized from the species composition using hierarchical Cluster Analysis techniques (CA). A non-hierarchical k-means CA was also applied to re-classify the 1996 data and to classify 1997 landings data by trip type. The red seabream (*Pagellus bogaraveo*), red banded seabream (*Pagrus auriga*), octopus (*Octopus vulgaris*) and striped venus (*Chamaela gallina*) types stood out as important indicators of fishing trip type.

In a second stage, only those vessels with more than 50 daily landings regularly distributed through the year were selected. A new CA was applied in order to group vessels that show similar fishing annual pattern. Eleven fleet components were defined from these results. Two basic features of these components were that they were highly related to the landing (home) ports and the fishing gears used, and showed definite seasonal fluctuations according to the main fishing trip types developed.

1. INTRODUCTION

There is considerable disagreement about the definition of an artisanal fishery. Regional and national administrations categorize vessels as artisanal on the basis of criteria including administrative, socio-economic and technical aspects (i.e. vessel's characteristics, crew, fishing gears and methods, fishing time, etc). However, the thresholds selected by the various fishery administrations for such criteria may be different, even at a national scale, making difficult any comparative analysis (Camiñas, 1996).

Despite these discrepancies in cataloguing this activity, artisanal fisheries are considered to be of significant socio-economic importance. This is true also in the EU, and particularly in the Mediterranean countries and in the Atlantic waters of Spain and Portugal. Nevertheless, great difficulties arise when an attempt is made to monitor this fishing activity under the previously established national sampling schemes, which were basically designed for studying industrial or semi-industrial fisheries (e.g. see Charbonier and Caddy (1986) for a revision of this problem in Mediterranean artisanal fisheries). The artisanal fisheries are characterized by their multispecies and multigear nature, and are exploited by a high number of highly heterogeneous vessels. The fishing activities of these vessels are directly influenced by climatic factors, seasonality and economic conditions. Therefore, all of these factors limit the usefulness of such sampling programmes.

[1] Instituto Español de Oceanografía, Unidad de Cádiz, Apdo. 2609, 11006 Cádiz, Spain. E-mail: ignacio.sobrino@cd.ieo.es. A revised version of the paper has subsequently been published as Silva, L., Gil, J. and Sobrino, I (2002) Definition of fleet components in the Spanish artisanal fishery of the Gulf of Cádiz (SW Spain ICES division IXa), *Fisheries Research,* 59(1-2), 117-128.

The current procedures for fish stock assessment require adequate information on the effort and catch data by métier, as well as estimates of the relative abundance of the main fish stocks. For this to be effective, it is necessary to be able to correctly identify métiers, and to compute the effort effectively directed to each main target species as well as the corresponding catch per unit of effort (CPUE).

The Spanish artisanal fishery of the Iberian South Atlantic Coast is a multispecies, multigear fishery exploiting the demersal resources of the near shore area (Figure 1). More than 900 vessels are involved in this fishery, employing approximately 3 000 fishermen. These vessels are generally small, with average lengths of 7.7 meters, five gross tonnage register and 58 horsepower engines (Sobrino *et al*., 1994). These characteristics limit the range of activity by the fleet, although they make a great number of daily fishing trips along the year. The vessels are highly versatile, adapting to seasonal conditions and often employing complementary gear during the same fishing trip to improve their catches. This structure makes the collection of basic effort and catch data by métier, and the computation of CPUE, particularly difficult.

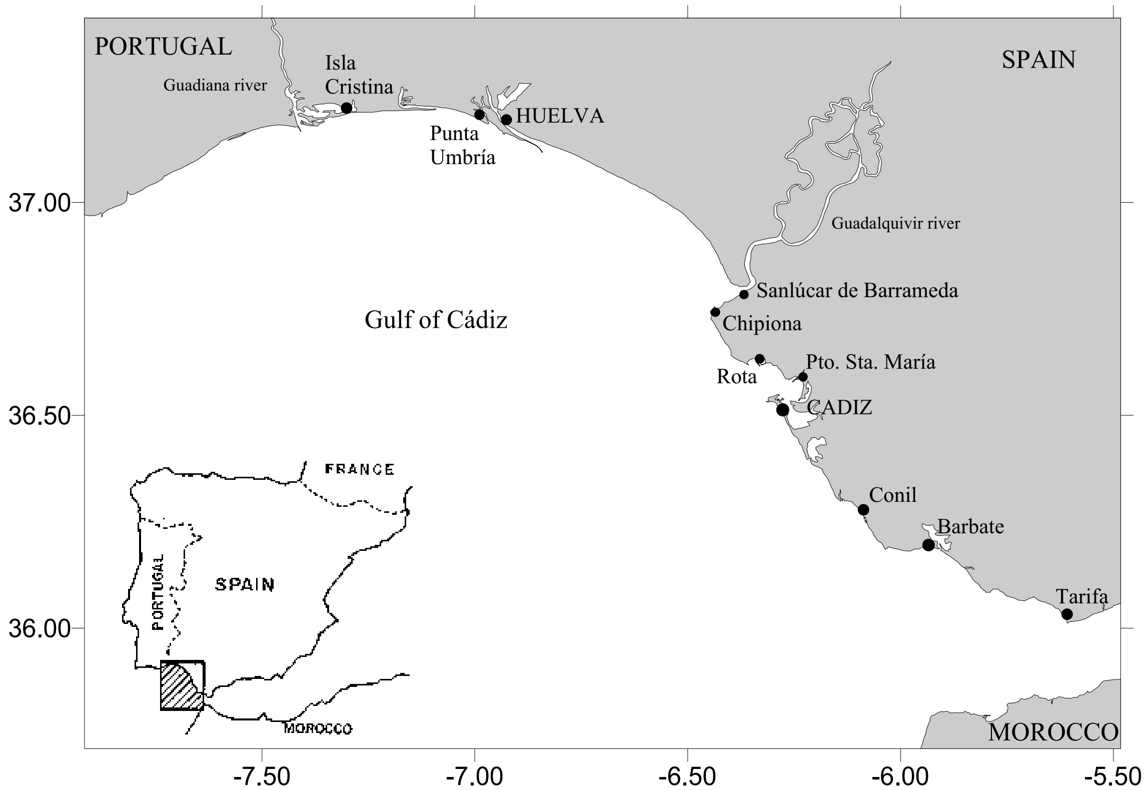

Figure 1. Gulf of Cádiz: Main landing ports of the artisanal fleet

The fishery targets a complex of high-value species, including several flatfish, *Sparids*, hake, cephalopods, crustaceans and bivalves. More than 50 different species are landed and captures are made with a great and diverse number of fishing gears like trammel nets (*trasmallos*) and gillnets (*parguera, volanta*), hand jigs (*chivos, pulperas*) and longlines (*palangres, voracera*), traps (*nasas, alcatruces*) among others (Anon., 1994). There are presently no reliable estimates of the fishing effort exerted on these stocks, nor of their abundance.

Given all this complexity, the necessity of defining different fleet components is apparent. Fleet components are defined as those groups of vessels that carry out the same exploitation pattern along the year. It is expected that consideration of the fleet component concept will allow the design of simple, more effective and beneficial sampling strategies for the artisanal fishery based on the improved knowledge of its exploitation pattern. Also, the following methodology is shown to be a very useful tool not only for monitoring the artisanal fishing activity, but also for assessing its socio-economic impacts.

2. MATERIAL AND METHODS

The daily landings of the artisanal fishery during 1996 in the main ports of the Spanish South Atlantic region were used for the definition of the fleet components. This information was derived from the daily sales returns for each vessel. A matrix was built from this database file whose rows (cases) were the daily landings and the columns (variables) were the captured species, resulting a total of 25 394 fishing trips and 53 species.

Fishing trip types were preliminary characterized using multivariate analysis techniques based on the mean specific composition of the catches. Cluster Hierarchical Analyses (CA) were carried out using the Euclidean Distance (ED) as similarity index and the Unweighted Paired-Group Mean Average (UPGMA) as clustering algorithm. Prior to undertaking the Cluster Analyses, the original matrix (expressed in Kg) was transformed into a CPUE matrix (using the number of fishing days per fishing trip as the effort unit) and then to a percentage CPUEs matrix to standardize these values. After standardization, Cluster Analyses were carried out for all landings in each month.

The resulting groups were then combined month by month for obtaining the artisanal representative fishing trip types. Afterwards, descriptive analyses were applied by trip type to obtain the mean specific composition of the landings and the vessels that integrate each group, which define each trip type.

Following this, a Non Hierarchical Cluster Analysis of K-means was applied to the matrix (which included the new variable, trip type) to reclassify the previously classified landings. The method is based on the closest centroid output, i.e. each case is assigned to a cluster based on the criteria that the distance to its center should be minimum. To calculate the centre of each trip type, the variables were standardized, obtaining the z-variables (variable mean/standard deviation), and later calculating for each group the mean of each standardized variable. These variables are the centres of each group. Once the table of centres is estimated, a K-mean Cluster Analysis with known centres was applied to the matrix of percent CPUEs to reclassify the landings, using as variables the z-variables, on the basis of the least Euclidean distance to the centres of the groups (Norusis, 1997; Visauta, 1998).

The definition of fleet components was based on the fishing pattern that each vessel exhibited each year. That is, the pattern resulting from the dispersion of their fishing trip types each month, and the combination of fishing trip types within each month, over the period of 1 year. A fleet component was then defined as groups of vessels presenting a similar fishing pattern over a year. This means that the hypothesis to be tested involves not only the similarities among vessel fishing trips grouped in fishing trip types, but also its distribution by month, over the period of one year.

The fishing trips over the period 1996 to 1997 were re-classified into 53 distinct fishing trip types, each with a distinct species catch composition. Thus, each active vessel had its own trips classified into one or more of the possible 53 fishing trip types per month over the year.

After assigning all the landings to the different fishing trip types, a frequency analysis was carried out to determine the number of fishing trips per vessel and year. Only the vessels with at least 50 fishing trips regularly distributed along the 12 months of the year were chosen. A matrix was constructed with as many variables as fishing trip types done by each vessel in every month (fishing trip types x 12 months) and as many cases as the number of selected vessels. The number of fishing trips by vessel, N_i (i=1... ..n), is given by:

$$N_i = \sum_{j=1}^{53} \sum_{k=1}^{12} (n_{ijk}) \qquad (1)$$

where the indexes j and k, ($j=1,\ldots,53$; $k=1,\ldots,12$) represent fishing trip types and month, respectively.

The raw data matrix **N**, can be defined as $\mathbf{N} = \{N_{ijk}\}$, where each row vector (case) represents a unique vessel i, and their elements N_{ijk}, are the number of trips associated with each variable (each of the possible combinations between fishing trip types and months). The Cluster Analysis method was used to identify similarities between the vessels, for a maximum of 53x12 variables.

During the aggregation phase, the UPGMA method starts with each case (vessel) in a separate cluster (fleet components), and combines them through various stages until only one cluster is left. This means that the number of groups can be analyzed at different levels of aggregation, each one representing a specific optimal number of groups.

The same methodology used to assess the 1996 fleet components was applied to the 1997 artisanal fleet landings. With regard to the 1997 data matrix, 166 vessels were analyzed from the database for that year, and which had fleet components already assigned through the cluster analysis. Once obtained, the 1997 fleet components were selected in both years to analyze the extent to which the vessels belong to one or another different fleet component.

3. RESULTS

A total of 53 fishing trip types were defined. The results obtained after the landing reclassification through the k-means procedure were very similar to those obtained from the Hierarchical Cluster Analysis. The specific composition of the three main species from the fishing trips that integrate each fishing trip type, expressed in percent CPUE, as well as the importance (in weight and number) of these landings is shown in Table 1.

VORZ-M, URT and PUL-M fishing trip types account jointly for almost a third of the total number of landings of the whole artisanal fleet. Their respective main species are the red seabream (*Pagellus bogaraveo*), red banded seabream (*Pagrus auriga*) and the octopus (*Octopus vulgaris*), respectively. Such species account for 97.7 percent, 64.8 percent and 99.8 percent of the total CPUE of each fishing trip type.

Table 1. Fishing trip types. Specific composition of the most important species (% CPUE) and their importance in weight and in number of landings

1996 Fishing Trip Type	Species in percentage decreasing importance of the total of the fishing trip type						Weight of the catch	% of the total annual catch	Nr. of landings.	% of langings
	1 st. species	2 nd. species	3 rd. species	%(1st.)	%(2 nd)	% (3rd)				
VORZ-M	Red seabream	Rockfish	Wreckfish	97.7	1.5	0.5	260 309	12.55	4412	17.37
URT	Red banded seabream	Common Seabream	Gilthead seabream	64.8	12.7	8.4	121 056	5.84	2260	8.90
PUL-M	Octopus vulgaris	Cuttlefish	Common Seabream	99.8	0.1	0.1.	168 860	8.14	1811	7.13
LANG-M	Caramote prawn	Wedge sole	Cuttlefish	98.4	0.6	0.4	22 039	1.06	1447	5.70
BOR	Common and Red pandora	Seabreams	Common and Red pandora	53.9	8.8	5.1	88 082	4.25	1059	4.17
URT-M	Red banded seabream	Common Seabream	Octopus vulgaris	90.9	3.4	1.7	45 418	2.19	970	3.82
BIV	Striped venus	Carpet shell		97.4	2.6		196 302	9.46	806	3.17
ACE-M	Wedge sole	European hake	Caramote prawn	98.6	0.4	0.3	94 337	4.55	753	2.97
BOC	Common Seabream	Red banden seabream	Seabreams	49.5	12	7.0	25 913	1.25	670	2.64
LANG	Caramote prawn	Cuttlefish	Wedge sole	45.4	13.7	9.9	39 245	1.89	576	2.27
CH	Cuttlefish	Soles	Octopus vulgaris	54.9	13.4	8.6	38 694	1.87	553	2.18
SARG	Seabreams	Rubberlip grunt	Gilthead seabream	60.6	4.1	3.9	36 018	1.74	535	2.11
CONG	European conger	Common Seabream	Rubberlip grunt	45.0	13.6	6.7	38 107	1.84	471	1.85
DOR	Gilthead seabream	Red banden seabream	Seabreams	60.5	10.8	7.3	24 438	1.18	451	1.78
LENG	Soles	Cuttlefish	Caramote prawn	57.9	14.5	5.6	21 217	1.02	445	1.75
HER	Striped seabream	Meagre	Common and Red pandora	54.1	5.2	5.2	36 684	1.77	436	1.72
CAZ	Tope shark	Rubberlip grunt	Red banden seabream	62.3	7.8	5.8	53 229	2.57	387	1.52
BRE	Common and Red pandora	Rubberlip grunt	Axillary Seabream	53.9	9.6	6.6	31 466	1.52	362	1.43
CORV	Meagre	Seabreams	Rubberlip grunt	51.5	7.2	6.0	21 501	1.04	344	1.35
PCH	Grey triggerfish	Red-banded seabream	Soles	49.9	13.6	5.5	16 725	0.81	317	1.25
LUB	Seabass	Rubberlip grunt	Seabrams	70.7	6.3	6.3	21 568	1.04	307	1.21
MER	Horse mackerels	European hake	Common and Red pandora	31.3	31.1	5.3	49 805	2.40	300	1.18
CH-M	Cuttlefish	Soles	Octopus vulgaris	92.7	3.6	0.6	15 918	0.77	295	1.16
PAR	Pargo breams	Common Seabream	Red-banded-seabream	64.7	8.2	3.7	29 446	1.42	279	1.10
LENG-M	Soles	Caramote prawn	Cuttlefish	96.7	0.7	0.5	8 093	0.39	274	1.08
ATUN-M	Atlantic bluefin tuna	Red sebream	Atlantic pomfret	98.8	1.1	0.1	65 364	3.15	270	1.06
PAJ	Two-bandad seabream	Seabreams	Rubberlip grunt	52.1	11.9	6.3	41 364	1.99	258	1.02
ACE	Wedge sole	European hake	Caramote prawn	66.0	12.9	8.7	24 574	1.18	237	0.93
RONC-BRE	Bastard grunt	Commond and Red pandora	Rubberlip grunt	410.	16.7	9.7	23 935	1.115	237	0.93
VORZ	Red seabream	Atlantic pomfret	Wreckfish	54.3	40.5	4.4	17 540	0.85	234	0.92
SAM	Common dentex	Common Seabream	Red banded seabream	37.2	19.7	11.3	7 912	0.38	234	0.92
BRE-M	Common and Red pandora	Soles	Rubberlip grunt	93.6	1.2	0.7	20 516	0.99	228	0.90
CORV-M	Meagre	Rubberlip grunt	Seabreams	93.9	0.6	0.6	12 144	0.59	224	0.88
SALMT	Surmullets	Rubberlip grunt	Common and Red pandora	59.2	9.7	7.0	6 761	0.33	220	0.87
CEN	Spinous spider crab	Rubberlip grunt	Soles	51.9	11.6	7.6	10 779	0.52	219	0.86
MER-M	European hake	Common and Red pandora	Caramote prawn	91.2	1.9	1.7	11 761	0.57	218	0.86
BES	Axillary Seabream	Common and Red pandora	Black seabream	59.9	9.0	3.9	60 009	2.89	217	0.85
RAY	Skates	Rubberlip grunt	Common Seabream	45.0	6.1	5.7	11 306	0.55	193	0.76
FER	Spurdog	Rubberlip grunt	European conger	64.6	5.2	4.7	21 140	1.02	189	0.74
PUL2	Octopus vulgaris	Cuttlefish	Red banded seabream	58.2	6.5	5.9	15 332	0.74	185	0.73
HER-M	Striped seabream	Common and Red pandora	Meagre	92.8	1.3	0.9	12 300	0.59	182	0.72
BRE-HER	Common and Red pandora	Striped seabream	Horse mackerels	52.4	20.7	11.1	23 888	1.15	178	0.70
PUL1	Octopus vulgaris	Cuttlefish	Striped seabream	28.5	20.1	8.5	21 599	1.04	164	0.65
MOR	Moray	Common Seabream	European conger	45.1	9.4	6.6	6 575	0.32	153	0.60
LIZ	G.,T. and L.grey mullet	Seabreams	Seabass	73.7	5.0	3.5	7 621	0.37	151	0.59
CHP	Black seabream	Axillary Seabream	Two-banded seabream	44.8	14.7	14.1	36 182	1.74	126	0.50
ES-CAE	Dogfish sharks	Blue shark	Pompano	70.7	21.3	1.4	51 581	2.49	122	0.48
CHV	Bluefish	Meagre	Common and Red pandora	67.1	7.1	1.3	8 086	0.39	111	0.44
MERO	Dusky grouper	Common Seabream	Seabreams	38.4	7.5	6.4	7 032	0.34	81	0.32
PUL3	Octopus vulgaris	Axillary Seabream	Seabreams	30.2	20.2	11.1	25 078	1.21	79	0.31
JAP	Atlantic pomfret	Red seabream	Rockfish	85.0	15.0	0.1	10 813	0.52	76	0.30
PLIM	Greater amberjack	Pargo breams	Common Seabream	48.7	22.1	4.8	4 639	0.22	69	0.27
ATUN	Atlantic bluefin tuna	Red sebream	Atlantic pomfret	76.1	20.4	1.9	3 804	0.18	19	0.07
Total							2074105	100	25394	100

In terms of number of landings the LANG-M, BOR, URT-M, BIV, ACE-M, BOC, LANG and CH fishing trip types are the following ones in importance. The main target species of each of these fishing trip types and their relative importance in terms of % CPUE are respectively: caramote prawn (*Maliceste kerathurus*, 98.4 percent), rubberlip grunt (*Plectorhinchus mediterraneus*, 53.9 percent), red banded seabream (*Pagrus auriga*, 90.9 percent), the striped venus (*Chamalea gallina*, 97.4 percent), wedge sole (*Dicologoglossa cuneata*, 98.6 percent), common seabream (*Pagrus pagrus*, 49.5 percent) and the cuttlefish (*Sepia officinalis*, 54.9 percent). This order changes if the fishing trip types are sorted by landed weight. Thus, BIV fishing trip type passes to the second place staying the red seabream catches in the first place (VORZ-M). Furthermore, it is observed that most of the species studied are represented by some fishing trip type and, that in 85 percent of these trip types, one target species makes up more than 50 percent of the fishing trip type total CPUE.

A total of 219 vessels were selected to obtain the fleet components. Eleven fleet components were identified after the Cluster Analysis and later frequencies analyses of the resulting groups per port and month. Landing ports of the vessels that form each component are shown in Table 2, while the relative importance of the fishing trip types for each fleet component is shown in Table 3.

Table 2. Distribution by ports of the vessels that compose the eleven fleet components in number and percentages (F.C.= Fleet Component)

	F.C.1		F.C.2		F.C.3		F.C.4		F.C.5		F.C.6		F.C.7		F.C.8		F.C.9		F.C.10		F.C.11	
Landing Ports	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Barbate	1	1.6	9	12.9	0	0	0	0	5	100.0	0	0	0	0	0	0	0	0	1	10.0	0	0
Chipiona	0	0	34	48.6	0	0	0	0	0	0	6	100.0	0	0	0	0	0	0	0	0	0	0
Conil	60	96.8	20	28.6	0	0	0	0	0	0	0	0	1	100.0	1	100.0	0	0	0	0	0	0
Huelva	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isla Cristina	0	0	4	5.7	3	100.0	6	100.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
El Puerto de Stª Mª	0	0	1	1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Punta Umbría	1	1.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	90.0	0	0
Sanlúcar de Bda.	0	0	2	2.9	0	0	0	0	0	0	0	0	0	0	0	0	3	100.0	0	0	0	0
Tarifa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	100.0
Total	62		72		3		6		5		6		1		1		3		10		50	

The 1997 fleet components were similar to those obtained for 1996. In order to test the fleet components of both years, a total of 140 vessels were selected which carried out 50 fishing trips in both years. The number of vessels that belonged to the same fleet component during the two years in the study are shown in Table 4. The degree of similarity between the two sets of results was estimated at between 88 percent and 100 percent.

4. DISCUSSION

Artisanal fisheries in the South Atlantic Spanish region, Gulf of Cádiz, as well as in the nearest areas of the Mediterranean are characterized by their multispecies nature, directionality and selectivity toward the resource (Camiñas *et al*., 1987; Camiñas, 1990). These characteristics are clearly reflected in the results obtained in this study. The high number of landed species and fishing trip types could reflect the fishery's multispecies nature and the maximum use of the catches (i.e. low discard rate). However, most of the fishing trip types (85 percent) show definite target species with mean CPUE greater than 50 percent, which indicates that effort is clearly directed in the fishery.

With regard to the fishing trip types observed, many of these are exclusive to certain ports, having a specialization toward the resource greatly influenced by the bottom features, which affect the distribution of the species. This is the case of the eastern area (Cádiz coast), where the rocky nature of the bottom favours the appearance of *Sparids* fishing trips. On the other hand, in the ports of the western area (Huelva coast) where the bottom consists of sand, mud and gravel, most fishing trips caught species such as prawns and wedge sole, among other (Ramos *et al*., 1995).

In the analysis of the fleet composition of the eleven fleet components by port (year 1996), we find that practically all, with the exception of F.C.2, belong to vessels from a single port. Within the same port, such as in the case of the ports of Conil and Isla Cristina, the determination of the fleet components is made based on the use of certain types of fishing gears during different seasons. As a consequence, an exploitation pattern based on the seasonal sequence of particular types of fishing trips could be defined.

Therefore, the directionality of the fishery and the use of the fishing gear targeting on different species at different seasons in many cases, and, moreover, influenced by certain environmental factors (hydrography), determines the different fleet components. The range of vessels that conform to a specific fleet component could vary greatly. In some cases, they comprise a great number of vessels and in other cases, they can comprise only one vessel with such a difference in activity as to justify a separate fleet component. The high selection criteria (i.e. only vessels with 50 or more landings per year) results in a certain consistency in those fleet components that are composed of a fewer number. The use the different gear types also affects the number of boats that conform each fleet component. For instance, longlines and handlines are used by a great number of boats (F.C:1: 60 and F.C.11: 50, respectively) from certain ports while clay pots and traps are used by a smaller number from the whole area (F.C.4: 6 and F.C.5: 5, respectively).

In this way, we find three fleet components in the port of Conil that are characterized by the use of diverse fishing gear. F.C.1 uses hook longline during the whole year, focusing on different target species depending on the season. F.C.7 used gillnets during the year directed principally towards the red mullet, and the F.C.10 is characterized by a seasonal combination of hook longlines and traps. Moreover, in these three cases, they all utilize hand jigs for common octopus during the season in which the resource is abundant. It was expected to have a fleet component exclusively dedicated to the octopus fishery with hand jigs, or alternating this fishing gear seasonally with others as a result of the sharp decrease of this species in the Gulf of Cadiz during 1996. This decrease was primarily a result of unfavourable environmental conditions, such as heavy rainfall (Silva *et al.,* 1998).

In the case of Isla Cristina, two clear fleet components are distinguished by the fishing gear as well as by the target species. The F.C.4 is exclusively dedicated to the octopus fishery by means of clay pots and the F.C.3 used the gillnet throughout the year for fishing striped seabream, common and red pandora, bastard grunt and meagre.

Lastly, a heterogeneous component, F.C.2, appears in a number of ports. It is characterized by the use of gillnets and trammel nets, recording similar landings throughout the year.

Table 3. Relative importance (%) of the trip types in each fleet component (1996)

	Fleet Components										
Trip Type	1	2	3	4	5	6	7	8	9	10	11
ACE	0.0	1.7	0.0	0.0	0.0	2.2	0.0	0.0	4.8	0.0	0.0
ACE-M	0.0	6.4	0.0	0.2	0.0	10.7	0.0	0.0	8.8	0.0	0.0
ATUN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
ATUN-M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
BES	0.0	1.3	1.0	0.0	16.7	0.0	1.7	10.8	0.0	0.0	0.0
BIV	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
BOC	8.1	0.9	0.0	0.0	0.0	0.0	0.0	6.5	0.0	0.0	0.0
BOR	5.7	7.5	3.0	0.0	1.1	2.1	12.8	0.5	0.0	0.0	0.0
BRE	0.6	3.4	7.8	0.0	0.2	1.4	2.6	0.0	0.8	0.0	0.0
BRE_HER	0.0	0.4	1.0	0.0	0.0	14.3	0.0	0.0	0.2	0.0	0.0
BRE-M	0.1	1.8	0.8	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0
CAZ	3.8	1.3	0.0	0.0	0.0	0.2	1.7	11.8	0.0	0.0	0.0
CEN	0.8	2.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
CH	0.8	5.1	0.0	0.0	0.0	1.0	4.3	0.0	1.4	0.0	0.0
CH-M	0.2	2.9	0.0	0.0	0.0	0.7	0.9	0.0	0.8	0.0	0.0
CHP	0.0	0.2	0.0	0.0	24.7	0.0	0.0	0.0	0.0	0.0	0.0
CHV	0.0	0.6	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0
CONG	5.2	0.8	2.0	0.2	0.0	0.1	0.0	1.6	0.0	0.0	0.0
CORV	0.3	3.0	8.3	0.0	0.0	5.9	0.9	0.0	0.5	0.0	0.0
CORV-M	0.1	1.7	1.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0
DOR	3.7	1.5	0.5	0.0	0.2	1.9	0.0	1.1	5.2	0.0	0.0
ES-CAE	0.0	0.2	0.5	0.0	0.2	1.0	0.0	0.0	0.0	0.0	0.0
FER	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HER	0.0	2.3	29.1	0.4	0.0	5.4	0.0	0.0	7.7	0.0	0.0
HER-M	0.0	1.1	8.0	0.0	0.0	3.0	0.0	0.0	1.1	0.0	0.0
JAP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
LANG	0.4	7.2	0.0	0.2	0.0	1.3	0.0	0.0	26.7	0.0	0.0
LANG-M	0.0	17.3	0.0	0.2	0.0	3.4	0.0	0.0	5.2	0.0	0.0
LENG	0.4	2.9	0.0	0.0	0.0	0.3	0.0	0.0	12.6	0.0	0.0
LENG-M	0.2	2.4	0.0	0.0	0.0	0.1	0.0	0.0	5.0	0.0	0.0
LIZ	0.0	1.3	0.0	0.0	0.0	2.8	0.0	0.0	1.9	0.0	0.0
LUB	1.3	1.8	0.3	0.0	0.0	0.7	7.7	0.0	4.3	0.0	0.0
MER	0.0	1.3	1.8	0.2	0.6	10.7	0.0	0.0	1.3	0.0	0.0
MER-M	0.0	1.8	0.3	0.0	0.0	8.2	0.0	0.0	0.2	0.0	0.0
MERO	0.4	0.2	0.0	0.0	1.3	0.0	0.0	7.5	0.0	0.0	0.0
MOR	1.4	0.2	3.5	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0
PAJ	0.0	0.4	0.0	0.0	44.6	0.0	0.0	0.0	0.0	0.0	0.0
PAR	2.4	1.0	0.5	0.0	0.2	0.4	0.0	1.6	0.0	0.0	0.0
PCH	2.2	1.7	0.0	0.0	0.9	0.9	0.0	2.7	0.8	0.0	0.0
PLIM	0.9	0.1	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0
PUL1	0.0	1.2	0.3	0.0	0.2	0.0	2.6	0.0	0.1	0.0	0.0
PUL2	1.1	1.0	0.8	0.4	1.1	0.0	0.9	5.4	0.0	0.0	0.0
PUL3	0.0	0.4	0.0	0.0	3.7	0.0	0.0	17.2	0.0	0.0	0.0
PUL-M	10.0	2.0	0.5	98.0	0.4	0.0	6.8	5.4	0.0	0.0	0.0
RAY	0.9	1.1	0.0	0.0	0.0	1.3	0.0	1.1	0.0	0.0	0.0
RONC-BRE	0.2	1.3	27.4	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0
SALMT	0.7	1.1	0.0	0.0	0.0	0.0	54.7	0.0	0.7	0.0	0.0
SAM	3.0	0.1	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0
SARG	0.9	3.6	1.3	0.0	3.9	2.9	0.0	17.2	9.3	0.0	0.0
URT	31.2	0.8	0.0	0.0	0.0	0.0	0.0	2.7	0.1	0.0	0.0
URT-M	13.1	0.3	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0
VORZ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
VORZ-M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.0

Table 4. Number of vessels belonging to the same fleet component for the years 1996 and 1997 expressed in percentage with respect to the components of 1996

	F.C. 1997										
F.C. 1996	1	2	3	4	5	6	7	8	9	10	11
1	95.2	4.7	0	0	0	0	0	100	0	0	0
2	4.8	88.4	0	50	0	0	0	0	0	0	0
3	0	0	100	0	0	0	0	0	0	0	0
4	0	0	0	50	0	0	0	0	0	0	0
5	0	0	0	0	100	0	0	0	0	0	0
6	0	0	0	0	0	100	0	0	0	0	0
7	0	0	0	0	0	0	100	0	0	0	0
8	0	2.3	0	0	0	0	0	0	0	0	0
9	0	4.7	0	0	0	0	0	0	100	0	0
10	0	0	0	0	0	0	0	0	0	100	0
11	0	0	0	0	0	0	0	0	0	0	100
total (%)	100	100	100	100	100	100	100	100	100	100	100

From the fleet components comparison of both years, based on the vessels which carried out more than 50 fishing trips per each year, it can be seen that vessels which belonged to a fleet component determined in 1996 continued to belong to the same fleet component in 1997 in a high percentage (Table 4). This indicates that most of these vessels carry out the same exploitation pattern over the whole period examined, strengthening the defined fleet components. As for those vessels that change their exploitation pattern and consequently are included in different fleet component in 1997, it is observed that these new components are similar in terms of gear type and landing port.

Therefore, this work suggests a high relationship among the fleet components, landing ports and the fishing gears with a slightly marked seasonality in function of each component target trip types. These results will be taken into account on the design of an efficient and simple sampling scheme for the artisanal fishery collection of data (biological, economic and social) under comprising the "fleet component" concept. The fleet components analysis can be used as a useful tool for sampling design in artisanal fisheries from the basis of monitoring certain vessels which belong to the estimated fleet components. Sampling could embrace biological and fishery aspects (i.e. catches, effort) and socio-economic fishery aspects (i.e. first sale prizes, staff involved, etc.). In addition, it provides an important benefit in terms of a lower effort requirement for carrying out the artisanal fishery study.

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ASSESSING FISHING CAPACITY OF THE EASTERN TROPICAL PACIFIC FLEET OF SKIPJACK TUNA

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Abstract: The impact of different fishing intensities and fleet size on the stock was analyzed, allowing the assessment of management strategies and estimation of the carrying capacity. An age-structured simulation model for the skipjack tuna fishery of the eastern tropical Pacific was developed. Population parameters, boat numbers, carrying capacity, and costs and benefits of fishing operations are required as inputs. The yield response to fishing capacity is analogous to the response to fishing effort in surplus yield models. When age of first catch is increased, and assuming catchability remains constant, significant increases in yields, profit, and carrying capacity may be obtained. Given the current age of first catch and assuming constant catchability, the model output indicates that under the economic equilibrium limit (i.e. total revenues = total costs, fishing mortality = 0.62, and a catch of 132 000 $\pm$ 2 000 tonnes) estimates of the potential yield suggest that the fishery withstands a maximum carrying capacity of 74 000 tonnes. The trend of yields from 1992 to 1998 suggests a possible reduction of the fishing intensity *F*, from near the level required to attain maximum yield, where it seems to be not profitable, towards the level required to attain the optimum economic yield. Skipjack caught within the regional Economic Exclusive Zone represents 64 percent of total biomass, implying that the countries with capacity to fully exploit the stock within their 200-mile limits may claim exclusive rights to do so.

1. INTRODUCTION

The increase in fishing intensity has become a major problem in many artisanal and industrial fisheries. It has contributed to overfishing and depletion of many commercially important fish stocks. An estimate of the world fleets states that they are 2.5 times larger than needed (Porter, 1998a; Gréboval, 1999), and up to 70 percent of world's marine stocks are considered to be depleted or fully exploited. When there is too much fishing capacity, each boat catches far less than its maximum potential (Porter, 1998b). Excessive fishing capacity has contributed to a decline in landings of many fisheries and also is considered as an economic waste (FAO, 1998). For this reason, its causes and definition, measuring and controlling fishing capacity has become a concern to be considered in the Plan of Action to be adopted internationally. Unfortunately, fishing capacity has not been considered as an issue of control in management practices of most world fisheries (Newton, 1999) even though overcapacity of the global fleet has a long history (Porter, 1998a).

The tuna fishery, in contrast with many other fisheries, records and identifies each fishing vessel operating on the high seas. This then gives us available historical records of fishing operations as well as catch and effort. The skipjack is the most highly captured tunid species, with 1 560 000 tonnes during 1995, mainly in the western and central Pacific. In the eastern Pacific, yields amounted to 240 000 tonnes in 1992 (Hinton and Ver Steeg, 1994). Important yields are obtained near Baja California, Islas Revillagigedo, Clipperton Island, Central America, northern South America, and the Cocos and Galapagos Islands. The identification of fleet overcapacity and optimum yield levels implies a potentially high significance related to the sovereignty of the countries exploiting this stock within their economic exclusive zones (EEZ). In the present analysis, other stocks exploited in the tuna fishery were implicitly ignored. For the purpose of the present paper, the skipjack was

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considered as the only stock in the fishery. Hence the results are valid specifically for this stock and any extrapolation should be made carefully.

2. METHODS

A simulated-model-age-structure was used, following the basic principles of stock assessment described by Hilborn and Walters (1992) and more specifically by Chávez (1995), Nevárez-Martínez *et al*. (1999), López-Martínez *et al*. (2000), and Ponce-Díaz *et al*. (2000). This differs from the approach adopted for the measurement of capacity from an economic viewpoint (Kirkley and Squires, 1999)

The only meaningful measure of fishing capacity is the tonnage of fish that it can catch (Porter 1998b). For the tuna fishery, to which skipjack belongs, and for the goals of this paper, the fleet tonnage capacity was used instead the number of fishing days or any other measure of effort. The analysis of fleet carrying capacity (C_a) is analogous to fishing effort and, with a fleet-dependent catchability coefficient (q_k), is a component of fishing mortality (F), such that:

$$F = q_k C_a \qquad (1)$$

Therefore, response of yield (Y) with respect to F and C_a can be described by a surplus yield parabola, given by:

$$Y = \alpha_k\ C_a \exp^{-(\beta k\ Ca)}$$

where α_k and β_k are estimated coefficients of the equation. Once estimates of F were obtained from the last fifteen years of catch records, obtained from Hinton and Ver Steeg (1994) and from the IATTC (1999), parameters of a function analogous to those of the Fox model (1970) were obtained.

The stock size and the exploited age groups are described as:

$$N_{t+1} = N_t e^{-zt} \qquad (2)$$

where N_t is the number of fish with age t, and Z is the total mortality (where $Z = M + F$, i.e. natural (M) plus fishing (F) mortalities).

The yield obtained each year is the product of F multiplied by the stock size. That is:

$$Y = F\sum_{Tc}^{tT} N_t\, w_t \qquad (3)$$

where Y is the yield (e.g. tonnes), t_c is the age of first capture, t_T is the last age group, and w_t is the mean weight of fish of age t.

Apart from tuna and a few other stocks, most fisheries lack fishing-effort data records or tonnage capacity of their fleets, making estimates of carrying capacity a difficult task. The use of catch data for the last fifteen years is desirable, however, the model can use data for only one year, assuming that these data and other information such as the von Bertalanffy growth parameters (K, L_∞, t_o), the length-weight relation coefficients, the age of first catch, age of maturity, and current data on costs and benefits of fishing operations are available or can be collected in a short term survey.

Values of the parameters L_∞, t_o, and K of the von Bertalanffy growth model (L_∞= 83.9 cm, K = 0.6811 and t_o = -0.0018), were taken from Fish-Base 98 (Froese and Pauly, 1998). The asymptotic weight (W_∞ = 12.1 Kg), and the average weight by group of age were estimated by the relation $W = aL^b$ using the values a = 0.005916 and b = 3.28, also taken from Fish-Base 98.

For the analysis of age structure, longevity of the skip jack tuna was determined initially, assuming at least 95 percent of the population survives to 95 percent of its asymptotic length, which upon transforming the equation of von Bertalanffy gives the ratio $3/K$, which is equivalent to only four annual groups. This value is considered very low, because for the long line fishery, Matsumoto and Skillman (1984) report catches of 12 year-old fish. Therefore, the criterion of considering eight age groups for this analysis was adopted. A factor adding certain complexity to the analysis is the fact that fish more than three years old are seldom found in the eastern Pacific (J. Joseph, pers. comm). Therefore, yield estimates must be based only on the age groups exploited, but estimations of recruit numbers should consider all adult stock.

The estimate of natural mortality (M) value was obtained after Pauly (1980). The age of first catch (t_c) was identified as one year, and the reconstruction of the age groups was made under the implicit assumption that it has remained constant over time.

The model, developed on a spreadsheet as an interactive user-friendly tool and accessible to non-specialists, provides the way to estimate the Beverton and Holt (1957) recruitment model (a slightly modified version is used here) β parameter, giving α as a fixed value. The estimate of recruitment is multiplied by a random number with normal distribution, whose variation coefficient (VC = 0.056) is determined by minimizing the differences between observed and estimated catch (when there is a series of catch values to match with) and by doing a fine tuning of initial number of recruits.

The fishing mortality values (F) each year were estimated through the comparison of simulated and observed catch levels. This was undertaken once the initial age structure was defined by means of a successive approximation procedure using the *solver* function in the Excel spreadsheet that fits the catch recorded for every year of data with that calculated from the catch equation. Simulations were made through 15 years after the last year of data records. The mean values of the last five years of simulation were used to evaluate the effects of fishing strategies and, therefore, the fleet size over the long term.

If a single year of catch data is used, then a single F estimate value is made. Once the series of parameter values required are put in, the model estimates the potential yield under a series of F values, which is graphically shown on the screen, often describing a parabola. This way it is possible to determine the potential yield as a function of fishing mortality. Depending upon these key variables, the fleet size required to obtain a particular yield can be determined. This yield may be the maximum sustainable yield (MSY), or the optimum economic yield (OEY), corresponding to the F value giving the highest profits. If the study case is a stock whose age of first capture is larger than age of sexual maturity, then a yield parabola is found whose maximum value is usually located at F levels higher than the former one with a fleet size which is different from that required to achieve the OEY.

The fleet carrying capacity, if seen as the simple relationship described above, may be interpreted as a simplistic linear relation. However, it implies more complexity, because it really is a dynamic function of the stock and recruit sizes, age of first catch and *F*, elements which comprise a hypothesis to be tested. The model developed enables us to choose the age of first capture during the simulation period and corresponding yields, hence fleet sizes depending upon *F* are obtained.

The fleet carrying capacity can be formally represented by combining Equations 1 and 2, giving:

$$C_a = F/q_k = (Y/\sum_{Tc}^{tT} n_t\, w_t)/q_k \tag{4}$$

Throughout the simulation process, increasing the age of first catch also increased potential yield and profits, but the number of boats remained constant, depending upon the *F* value assigned. To obtain a dynamic response of the fleet size as a function of age of first capture, the C_a originally obtained was weighted by the ratio of revenue to costs.

The analysis and other pertinent considerations were made assuming the fishery relies upon a single stock, a constancy of age of first catch, and the selection pattern over time, regardless of other species exploited by the same gear, with the intention to explore the accuracy and perspectives of a general use of the method developed here.

To test the hypothesis, and used for the skipjack fishery, validity of the model was tested by a comparison between observed and recorded yields and by a minimization of errors of the former data series.

3. RESULTS

The parameter values of the Fox model linking *F* and C_a are $\alpha_k = 2$ and $\beta_k = 0.000007$, with a relatively low correlation. This function was used to determine the fleet number weighted by the revenue/cost ratio for the simulation period, and the value of $q_k = 0.000007$.

The α parameter of the parent-recruit relation equals 0.25 and was left constant, whilst β was determined with the aid of the *solver* function (1.04). Using both parameters, the estimation of the number of one-year old recruits to the stock every year was made. Age groups were reconstructed and catch values were evaluated for the period of analysis, observing that with a $F = 0.7$ average yields above 128 000 tonnes per year can be obtained over the long term as shown in Figure 1. The fleet tonnage is a variable depending upon *F* and also describes a parabolic tendency with a maximum fleet carrying capacity of 70 000 tonnes at F = 0.7.

Using values of $F > 0.7$, the stock is overexploited. The OEY is achieved at $F = 0.2$, when total profits are US$112 000, and the revenue/cost ratio is 1.97. There is a remarkable contrast between biological and economic optimum, given that under the current selectivity pattern and age of first catch, the biological optimum (MSY) is achieved at unprofitable levels of fishing intensity. However, analysis of potential yield shows that if age of first capture is higher than two years, yields may be much higher and no values of MSY or OEY, nor a maximum carrying capacity (not shown here) are achieved. Fishing exploitation can then be as intense as possible (Figure 1).

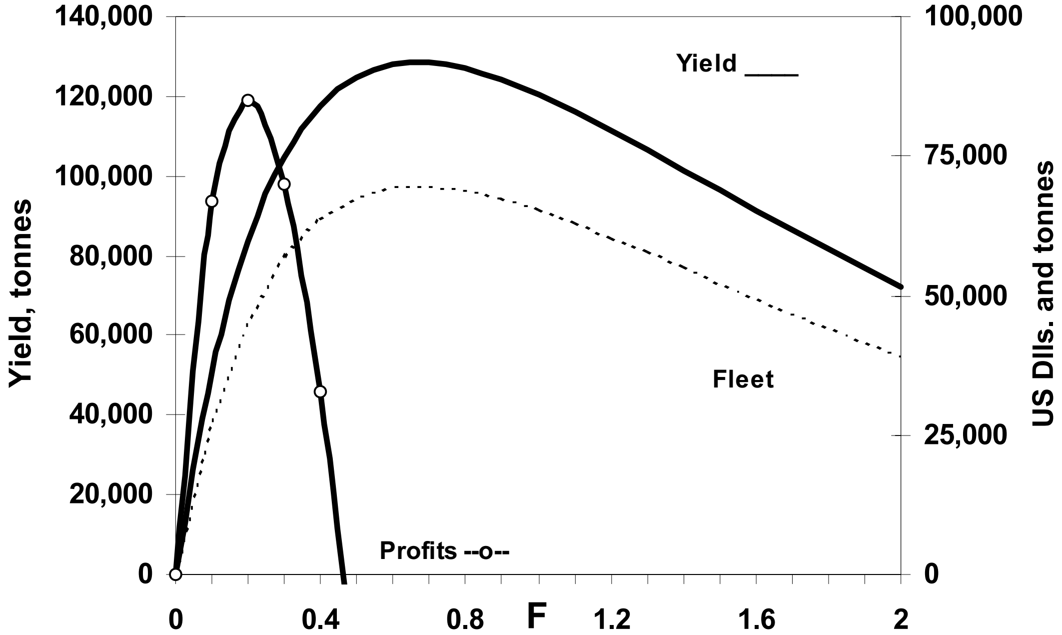
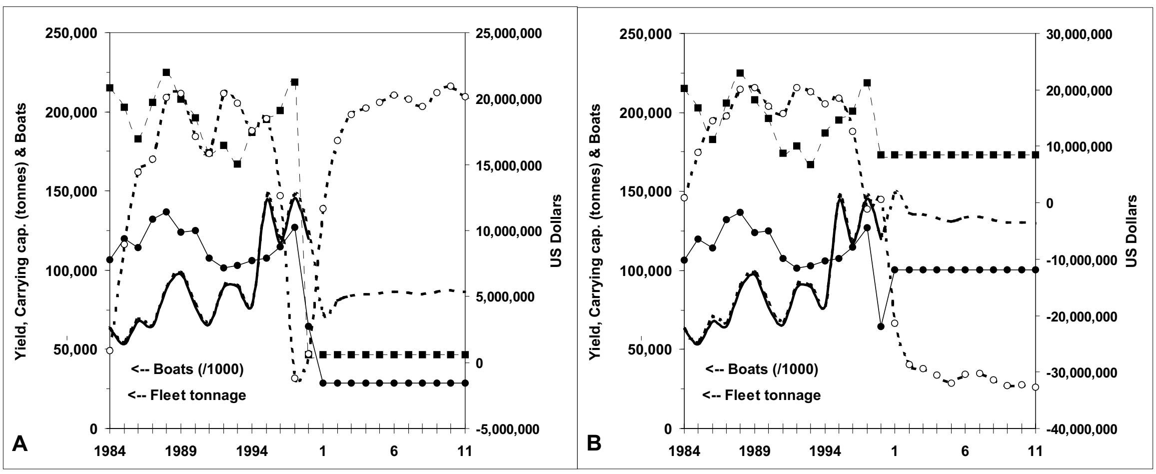


Figure 1. Potential yield of the skipjack stock exploited in the eastern Pacific

To maintain the fishery in the long-run, a good fishing strategy under the current selectivity pattern could be made with a fishing mortality of $F = 0.2$, providing the highest profits, though a significant number of boats would have to be withdrawn from the activity. Again, the estimate of potential yield obtained by simulation shows that a significant yield increase, about six times higher than the current one, could be obtained with a $t_c > 5$ and $F \geq 1.7$.



Yield ——; Simulated yield – – –; Profits – – o – –; Boats ···■···; Fleet tonnage —•—

Figure 2. Dynamic response of the model showing historic trends and simulations of biological, and economic levels, as well as boat numbers and fleet carrying capacity under two key fishing intensities a) With $F_{OEY} = 0.2$; b) With $F_{MSY} = 0.7$.

Observed and simulated catches (Figure 2a, b) show a good fit of the model. The results indicate that the stock has been progressively more exploited over time. Statistical records show that, from 1978 to 1985, there was an important drop in yields from 179 000 tonnes in 1978 to 53 000 tonnes in 1985, probably caused by overfishing. A new increase in fishing intensity began in 1991 with 66 000 tonnes caught, arriving at 145 000 tonnes in 1997 and with F values increasing from 0.149 to 0.558 (Table 1), overexploiting the stock.

Table 1. Yield data (rounded to the closest thousand), fleet sizes as number of boats and carrying capacity (after Hinton and Ver Steeg, 1994; IATTC, 1999), and estimates of fishing mortality F, adult numbers, and one-year old recruits for each year of the 1984-1998 data series.

Year	Recorded Catch, tonnes	Fishing Mortality F	Million of Age I Recruits	Million of Adults	Number of boats	Carrying capacity, tonnes
1984	63 000	0.232	13	19	215	106 701
1985	53 000	0.146	14	20	203	119 937
1986	68 000	0.166	14	21	183	114 366
1987	65 000	0.148	14	21	206	132 188
1988	88 000	0.207	14	21	225	136 616
1989	97 000	0.240	14	21	208	123 955
1990	77 000	0.184	14	21	196	124 805
1991	66 000	0.149	14	21	174	107 575
1992	89 000	0.210	14	21	179	101 348
1993	90 000	0.216	14	21	167	102 752
1994	77 000	0.182	14	21	187	105 885
1995	144 000	0.429	14	20	195	107 543
1996	117 000	0.363	14	19	201	114 957
1997	145 000	0.558	14	18	219	127 257
1998	122 000	0.451	14	18	111	53 949

The results of the simulations suggest that the OEY (84 000 tonnes) can be obtained under F = 0.2, and that the MSY = 128 000 tonnes can be achieved at F = 0.7 (Figure 1). At F = 0.2 the goal could be achieved with a carrying capacity of 29 000 tonnes in about 45 boats. If MSY is chosen as the target yield, then a carrying capacity of 761 000 tonnes in about 100 boats is required (Table 2). However this fishing intensity is below profitable levels. Uncertainty yield levels in each case approach $\pm$2 000 tonnes. Trend of yields (89 000 tonnes in 1992 and 120 000 tonnes in 1998) show the situation of a possible economic overexploitation of the stock, and the fishery seems to have switched towards the F_{OEY} point, rather than to the F_{MSY} level, where it seems to be unprofitable (here the revenue/cost ratio = 0.7). If current F values for the last year (1998) are around 0.45, annual yield is 122 000 tonnes and the fleet carrying capacity required is 50 000 tonnes (82 boats) with a B/C = 1.03. At the F_{OEY} level, the fishery is more profitable (revenue/costs = 1.59).

Under a fishing intensity exploiting the stock at the economic equilibrium limit (EEY) (revenue/cost ratio = 1, F = 0.47, and a catch of 124 000 tonnes), the fishery withstands a maximum carrying capacity of 51 000 tonnes, equivalent to 84 boats.

4. DISCUSSION

The tuna fishery contributes to impressive amounts of all high seas catch (41 percent) and total landed value (82 percent), as stated by Newton (1999). This emphasizes the need for strengthening the regional cooperation of the countries involved in this activity to provide effective control of fishing capacity. For the tuna fisheries of the eastern Pacific, the IATTC is setting up a group working on fleet capacity limits (Porter, 1998b).

Fleet capacity and its control implies technological issues rather than only the stock dynamics (Gréboval and Munro, 1999) and though this is essentially an economic issue, before taking any management action to control the excess capacity requires an accurate assessment of the exploited stocks and their dynamics on which the economic system relies and for which it is an unavoidable input. Issues regarding fleet dynamics belong to the domain of economy, however, any assessment that does not consider the stock as a variable input may give a biased estimate.

One of the aspects often implicit in the measurement of fishing capacity is the use of the Gordon-Schaeffer model. Its conception departs from the ecological consideration that the catch per unit of effort (CPUE) is a good indirect measure of the stock density and the CPUE should often be used despite the possibility of having access to more realistic and structurally correct models (Ludwig and Walters, 1985). However, when fishing capacity is in excess, a portion of the fleet remains on dock and CPUE stops being a good estimator of stock density. Therefore the available data may not behave properly to fulfill the requirements to fit the model mentioned, and an estimate of optimum level of effort or fishing capacity (number of boats, or fishing capacity) may not be obtained or may be inaccurate. For the tuna fishery, the problem of obtaining accurate estimates of fishing effort becomes an enormous task, because not only is there a variety of boat sizes and gear types, but in the last few years, the common adoption by some fleets of fish aggregating devices (FADs) located by satellite, turns fishing effort into a stereotype different from its original traditional concept and for the same reason, of doubtful validity.

The results of the simulations may appear to show some mismatches with respect to recent data records. Values chosen, as indicators of MSY and OEY levels are lower than current yields and even worst, the EEY is higher than they are (Table 2). However, these indicators correspond to the mean values of the last five out of the fifteen years of simulations, chosen as estimators of a long term behaviour of the fishery to be used as reference points if adopted for decision making in the process of managing this fishery.

Table 2. Total yields (thousand tonnes), F, fleet sizes (as boat numbers and thousand tonnes of carrying capacity), and revenue/cost levels corresponding to current values (for the years 1997 and 1998) and estimates of potential yield at the optimum biological yield (MSY), optimum economic yield (OEY), and economic equilibrium yield (EEY) fishing intensity levels.

Fishing level	*F*	Yield	Boats	Capacity	Revenue/costs
1997	0.56	145	219	127	0.86
1998	0.45	122	111	53	1.03
MSY	0.7	128	100	61	0.7
OEY	0.2	84	45	29	1.6
EEY	0.47	124	84	51	1.0

4.1 On the fleet allocation

All symptoms of the skipjack exploitation intensity and the stock dynamics point towards the need to reduce fleet carrying capacity. For this reason, the adoption of F_{OEY} as target of a management strategy addressed to the reduction of fishing intensity seems a desirable option. If a policy like this is adopted, the fleet carrying capacity should have to be reduced about 18 000 tonnes. Evidently, a reduction of fleet size should have to be made gradually to avoid severe social and economic impacts.

From the data produced by Hinton and ver Steeg (1994) and IATTC (1999), the mean catch of skipjack caught in the eastern Pacific Ocean for the years 1988 to 1992, summarized in Table 3, amounts to 95 000 tonnes, which is above the estimate of OEY (84 000 tonnes), but below the MSY level (128 000 tonnes). Total yields for the years 1997 and 1998 were 145 000 and 120 000 tonnes caught with total carrying capacities of 128 000 and 53 000 tonnes in 219 and 53 boats (Table 2). The mean catch for the 200-mile exclusive zone for the years 1988 to 1992 amounts to 61 000 tonnes and the catch by the main participant countries (Ecuador, Colombia, and Mexico) in this zone for the same period was 43 600 tonnes. The yield obtained within the EEZ of the region is 64 percent of the total. This implies that if F_{OEY} is chosen as target, which seems the most convenient option to adopt, only 36 percent (31 000 tonnes) out of a yield of 87 000 tonnes could be shared by a carrying capacity of all the fleets exploiting the stock in international waters. Under these conditions, the eastern tropical Pacific countries with capacity to fully exploit the stock within their 200-mile limits may claim exclusive rights to exploit existing biomass (56 000 tonnes) within their limits. In this respect, good care should be taken setting suitable controls of fishing effort and fleet sizes to avoid overexploitation of the stock.

Table 3. Proportion of yield (61 200 tonnes, mean of the years 1988-1992), caught within the EEZ of the countries where the skip jack stocks are exploited (64 percent of total yields) in the eastern tropical Pacific (based on table 12 by Hinton and Ver Steeg, 1994). Data on the fleet sizes for these countries correspond to the year 1997 (1996 for Costa Rica), total fleet size fishing at the eastern Pacific in 1996 was 201 ships or 115 000 tonnes (after IATTC, 1999).

Country	Yield	Fleet sizes	
	Percent	Boats	Capacity (tonnes)
Colombia	13.7	9	6 600
Costa Rica	8.2	1	n. s.
Ecuador	19.4	56	24 000
El Salvador	0.5	--	----
Guatemala	0.3	--	----
Mexico	10.5	54	41 500
Nicaragua	0.4	--	----
Peru	1.8	--	----
United States	0.1	--	----

ns. = Not specified, ---- = No data.

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TECHNICAL INDICATORS OF THE TEMPORAL DEVELOPMENT OF FISHING POWER IN THE ENGLISH DEMERSAL FISHERIES OF THE NORTH SEA

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Abstract: Fishing capacity comprises four components: (i) the number of fishing vessels, (ii) the size of each vessel, (iii) the technical efficiency of vessel operation, and (iv) the time spent fishing. Fishing power, which comprises segments (ii) and (iii), is generally not directly measurable. Both fish stock assessment and management would benefit from a better understanding of the temporal development of fishing power. Firstly, a deeper insight into the relationship between catch-per-unit-effort (CPUE) and stock abundance would enhance the accuracy of stock assessments. Secondly, refining the relationship between fishing mortality and nominal fishing effort would provide a basis to allow direct control of the fishing pressure exerted by fleets on stocks. The temporal dynamics in fishing power, however, are difficult to distinguish from stock fluctuations. The purpose of this paper is to investigate and identify such dynamics. Three independent indicators, derived using different methods are proposed. The first is an indicator of variation in catchability, derived from the relationship between fishing mortality and fishing effort. The second and the third are indicators describing variations in fishing power, based on the CPUE of a fleet of vessels, relative to the CPUE of a reference sub-fleet. The reference sub-fleet is characterized by low variation in fishing power and comprises either a set of reference vessels belonging to the fleet under examination (indicator 2) or a research vessel survey (indicator 3). The methods are illustrated using data collected from the English demersal fisheries operating in the North Sea for the time period from 1989 to 1998.

1. INTRODUCTION

The measurement and assessment of fishing capacity in fisheries with highly fluctuating stocks is by no means trivial. Fishing capacity comprises four components: (i) the number of fishing vessels, (ii) the size of each vessel, (iii) the technical efficiency of vessel operation, and (iv) the time spent fishing. Fishing power, which relates to components (ii) and (iii), is generally not directly measurable. Both fish stock assessment and management would, however, benefit from a better understanding of the development of fishing power over time.

In this paper, relationships will be developed between fishing effort and fishing mortality for a number of the main demersal fishing fleets operating in the North Sea. The results from preliminary analyses of (E&W) vessels are presented and discussed.

2 MATERIAL AND METHODS

This paper uses United Kingdom (E&W) data for the North Sea. Commercial vessel trip data on six species (cod, haddock, plaice, saithe, sole and whiting) were extracted for the years 1989-1998. Values were obtained for a number of variables including days at sea, area fished, effort, gear, vessel horse-power (hp), port of landing, weight of species (cod, haddock, plaice, saithe, sole and whiting) catch, value of catch, month and year. Eight fleets were identified from the vessel trip data – beam trawl, bottom pair trawl, fixed nets, longliners, nephrops and prawn gears, otter gears, seiners, and other gears.

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For the purpose of this paper, the North Sea is sub-divided into five regions identifying distinct fishing areas. The definition of the five regions is arbitrary but merely serves a didactic purpose. A number of stocks and fleet segments that operate in the North Sea will be considered within these regions, providing that sufficient data exist for meaningful computations to be performed. The areas considered are:

- region 1 denoting the northern part of the *plaice box* above latitude 55°;
- region 2 denoting the southern part of the *plaice box* below latitude 55°;
- region 3 denoting the Belgium and Dutch coastline;
- region 4 denoting the northern part of the North Sea above latitude 55° but excluding the *plaice box*; and
- region 5 denoting the southern part of the North Sea below latitude 55° but excluding the *plaice box*.

The *plaice box*, a protected area in the south-eastern North sea was established in 1989 (Council Regulation EEC No.4193/88) to reduce discarding of undersized plaice in the main nursery areas, and thereby enhance the recruitment to the fishery. Initially, in the *plaice box*, beam-trawlers larger than 300 hp were excluded during the second and third quarters of the year, but in 1994 the regulation was extended to the fourth quarter. Since 1995 the *plaice box* has been closed throughout the whole year (Pastoors *et al.,* 1998). The effects of the protected area have previously been evaluated using a simulation model (Anon., 1987, 1994; Rijnsdorp and van Beek, 1991).

The temporal dynamics in fishing power are difficult to distinguish from stock fluctuations and it is the purpose of this paper to investigate two methods that might assist in the identification of the (temporal) development of fishing power. The methods are illustrated using data collected from the English demersal fisheries operating in the North Sea for the time period from 1989 to 1998.

The first method is based upon an indicator of variation in catchability, derived from the relationship between total fishing mortality and fishing effort. Estimates of the total fishing mortality may be derived from the retrospective analysis that is performed by the relevant ICES Stock Assessment Working Group.

The retrospective analysis of total fishing mortality is a graphical representation of the historical time series of fishing mortality, which have been calculated in different years of assessment - one time series is represented for each year of assessment. Often, these time series follow the same trajectory for the oldest assessment years, and then diverge for the most recent assessment years. When the trajectories are merged, it may reasonably be assumed that the estimates of total fishing mortality are robust. Such estimates may gain in reliability and may hence be used to derive partial fishing mortality and log-catchability. Formulae are presented below.

2.1 Partial fishing mortality

The partial fishing mortality $\overline{F}(y,m,a,f,s)$ of fleet *f* and species *s*, in year *y*, month *m* and area *a*, averaged over appropriate age classes, may be related to total fishing mortality $\overline{F}(y,s)$ in year y, total catch $C(y,s)$ in year *y*, and partial catch $C(y,m,a,f,s)$, by the equation:

$$\overline{F}(y,m,a,f,s) = \overline{F}(y,s)\frac{C(y,m,a,f,s)}{C(y,s)}, \; y \in \left[Y_{1(s)}, Y_{n(s)}\right] \qquad (1)$$

where $Y_{1(s)}$ and $Y_{n(s)}$ denote the first and the last year, respectively, where converging estimates of $\overline{F}(y,s)$ are available from the ICES retrospective analysis for each species.

The values of annual total fishing mortality, as estimated by Extended Survivors Analysis, XSA (Darby and Flatman, 1994), and the annual total catch are taken from Anon. (1999). XSA is the *de facto* method used for the analysis of commercial catch-at-age data within the ICES area. It is an implementation of sequential population analysis (Doubleday, 1981) that relies upon either cohort analysis or virtual population analysis, VPA, to re-create a stock's historical population structure from the catch-at-age matrix. The VPA estimates of numbers-at-age are conditional upon the time series of values of the natural mortality and the population numbers alive at the oldest age in each cohort - the survivors. XSA is an iterative method of estimating the survivors using the relationship between catch-per-unit-effort, CPUE, and the VPA estimates of population abundance-at-age; the "N"s. The algorithm is initiated with an initial value of the number of survivors. Fleet catchabilities-at-age are estimated using the estimates of N and the indices of CPUE. Predictions of N by fleet, by age and by year are then made for each observed value of CPUE. The predicted values are projected forward to the final age in each cohort using the estimated fishing mortalities and the assumed natural mortalities. A weighted average of the survivors provides new estimates of the terminal N and the XSA algorithm iterates until successive estimates of the fishing mortality converge.

2.2 Partial log-catchability

The partial log-catchability time series $LQ(y,m,a,f,s)$ may then be derived from the equation:

$$LQ(y,m,a,f,s) = Ln\left[\frac{\overline{F}(y,m,a,f,s)}{E(y,m,a,f)}\right], \; y \in \left[Y_{1(s)}, Y_{n(s)}\right] \qquad (2)$$

where E denotes fishing effort measured in the number of days fishing (or hp*number of days fishing).

The second method is dependent upon indicators of variations in fishing power, based on the CPUE of a fleet of vessels, relative to the CPUE of a reference sub-fleet. The reference sub-fleet is characterized by low variation in fishing power and comprises either a set of reference vessels belonging to the fleet under examination (indicator 2) or a research vessel survey (indicator 3), if available. The reference vessels are not chosen with respect to their efficiency performances but with regards to their stability over time. Assuming that a set of steady vessels can be identified then the variations over time of catchability and relative technical efficiency should be consistent. The presence of any identifiable systematic pattern within the index is then tested statistically. The index of technical efficiency (or index of fishing power, IFP) is defined, for the present, as the difference between the log-CPUE of a fleet and the log-CPUE of its related reference sub-fleet.

3. RESULTS

Results are presented for each of the five regions and eight fleets previously defined but the analyses are restricted to six species (cod, haddock, plaice, saithe, sole and whiting) which are commercially fished in the North Sea by the United Kingdom (E&W) fleets.

3.1 Method 1

The assignment of specific year ranges [$Y_{1(s)}$, $Y_{n(s)}$] to each of the six species (cod, haddock, plaice, saithe, sole and whiting) requires a subjective judgment. In this paper, the years identified for analysis are merely given for illustration and shown in Table 1.

Table 1. Species/year ranges chosen for North Sea stocks

Species	$Y_{1(s)}$	$Y_{n(s)}$
Cod	1989	1993
Haddock	1989	1989
Plaice	1989	1997
Saithe	1989	1995
Sole	1989	1993
Whiting	1989	1993

In principle, the species and year combinations given in Table 1 may be applied to the United Kingdom (E&W) commercial fishery data for the North Sea. Unfortunately, not all species/area/fleet/year/month combinations have sufficient data to permit formal data analysis. Hence, it was further necessary to restrict attention to the year ranges shown in Table 2.

Table 2. Species/area/fleet/year combinations chosen to illustrate Method 1.

Gear	Area	Cod	Haddock	Plaice	Saithe	Sole	Whiting
Beam trawl	1	1990 - 93	1989[a]	1990 - 97	1992 - 93	1990 - 93	1990 - 93
	2			1989 - 97			
	3			1989 - 97			
	4			1989 - 97			
	5			1989 - 97			
Bottom pair trawl	2			1989 - 92			
	4			1989 - 97			
	5			1989 - 97			
Fixed nets	1			1991 - 94			
	2			1990 - 97			
	3			1989 - 97			
	4			1990 - 97			
	5			1989 - 97			
Longliners	4			1991 - 97			
	5			1989 - 97			
Nephrops and prawn gears	4			1994 - 97			
	5			1994 - 97			
Other gears	5			1989 - 97			
Otter trawl	2			1989 - 97			
	3			1989 - 97			
	4			1989 - 97			
	5			1989 -97			
Seiners	2			1989 - 97			
	4			1989 - 97			
	5			1989 - 97			

a. no data for United Kingdom E&W.

Estimates of partial fishing mortality and partial log-catchability were calculated as described earlier in the *Material and Methods* section. The tabulation and presentation of numerical estimates is neither useful nor meaningful. Instead, graphical displays were produced and assessed for evidence of a linear trend over time (i.e. month/year) in partial fishing mortality and partial log-catchability. The results are summarized in Table 3.

Table 3. Linear trend over time for selected species/area/fleet combinations

Species	Area	Fleet	linear trend over time	
			partial fishing mortality	partial log-catchability
Cod	1	beam trawl	increasing	increasing
Haddock	1	beam trawl	constant	constant
Plaice	1	beam trawl	constant	constant
		fixed nets	constant	constant
	2	beam trawl	constant	constant
		bottom pair trawl	decreasing	decreasing
		fixed nets	constant	decreasing
		otter trawl	decreasing	constant
		seiners	decreasing	constant
	3	beam trawl	constant	constant
		fixed nets	decreasing	decreasing
		otter trawl	constant	constant
	4	beam trawl	constant	decreasing
		bottom pair trawl	constant	constant
		fixed nets	constant	decreasing
		longliners	decreasing	decreasing
		nephrops and prawn gears	decreasing	constant
		otter trawl	decreasing	decreasing
		seiners	decreasing	constant
	5	beam trawl	constant	constant
		bottom pair trawl	decreasing	decreasing
		fixed nets	constant	decreasing
		longliners	constant	constant
		nephrops and prawn gears	decreasing	increasing
		other gears	constant	constant
		otter trawl	decreasing	decreasing
		seiners	decreasing	constant
Saithe	1	beam trawl	*insufficient data to comment*	*insufficient data to comment*
Sole	1	beam trawl	constant	constant
Whiting	1	beam trawl	increasing	increasing

3.2 Method 2

The basic statistics of CPUE, ln-CPUE, mean (ln-CPUE), variance (ln-CPUE) and the first-order auto-correlation of ln-CPUE were calculated for all species/area/fleet combinations. The selection of the number of observations (N) and the time series to which to apply *Method 2* were then based upon visual inspection of a number of plots. The graphs of variance (ln-CPUE) versus N and the first-order auto-correlation of ln-CPUE versus N were used to aid in the choice of the minimum number of observations required to ensure that the variance (ln-CPUE) and the first-order auto-correlation of ln-CPUE are both independent of N. For the English vessels operating in the North Sea, the threshold was chosen as 100 observations.

Graphs of variance (ln-CPUE) versus mean (ln-CPUE) and the first-order auto-correlation of ln-CPUE versus mean (ln-CPUE) were then used to determine whether variance (ln-CPUE) and the first-order auto-correlation of ln-CPUE are correlated with the mean (ln-CPUE). These plots were used to select a set of fleets and areas for each species such that variance (ln-CPUE) and the first-order auto-correlation of ln-CPUE are not correlated with the mean (ln-CPUE). For the English vessels operating in the North Sea, only beam trawls fishing in area 4 were retained for further analysis.

The selection of a reference sub-fleet from the *V* vessels operating in the North Sea proceeded along the following lines. Firstly, a selection of fishing vessels with minimum variance (ln-CPUE) amongst the pool of *V* vessels was made. The *V* fishing vessels were then sorted by decreasing variance (ln-CPUE) and only the *V/4* vessels with lowest variance (ln-CPUE) were retained for further investigation. The proportion of vessels retained is arbitrary but once again, serves a didactic purpose. Secondly, a selection consisting of choosing fishing vessels with minimum first-order auto-correlation of ln-CPUE amongst the pool of V/4 vessels initially selected was made. The *V/4* fishing vessels were sorted by decreasing values of the first-order auto-correlation of ln-CPUE, and only the *R = V/16* vessels with lowest first-order auto-correlation of ln-CPUE were retained for further investigation. The time series of ln-CPUE corresponding to the *R* reference vessels are collectively referred to as the reference sub-fleet.

All vessels not chosen to be included in the reference sub-fleet then comprise the remaining *whole* fleet. The index of technical efficiency as defined previously in the *Material and Methods* section was calculated for each of the six species and the results are displayed in the Figures 1-6 for North Sea cod, haddock, plaice, saithe, sole and whiting, respectively.

The Figures 1 through to 6 will be commented upon in the *Discussion*.

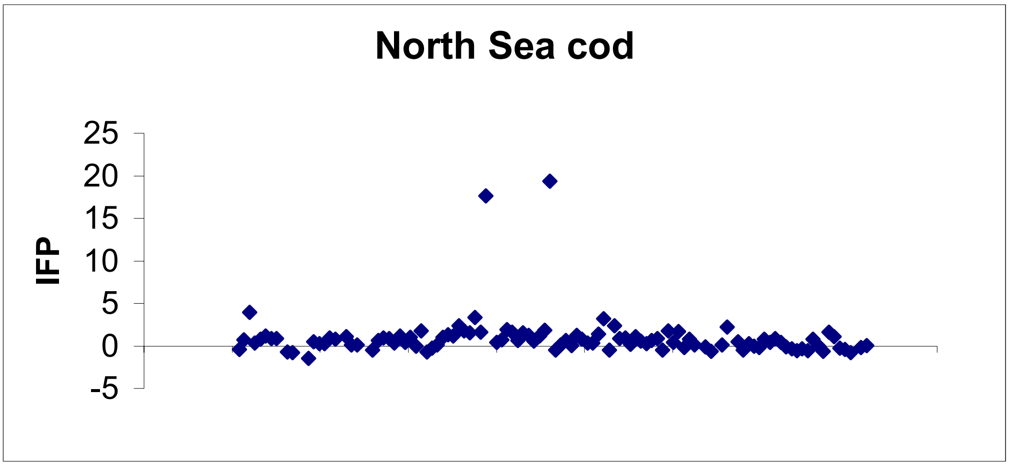

Figure 1. Index of technical efficiency for the beam trawl fleet fishing in area 4 for cod.

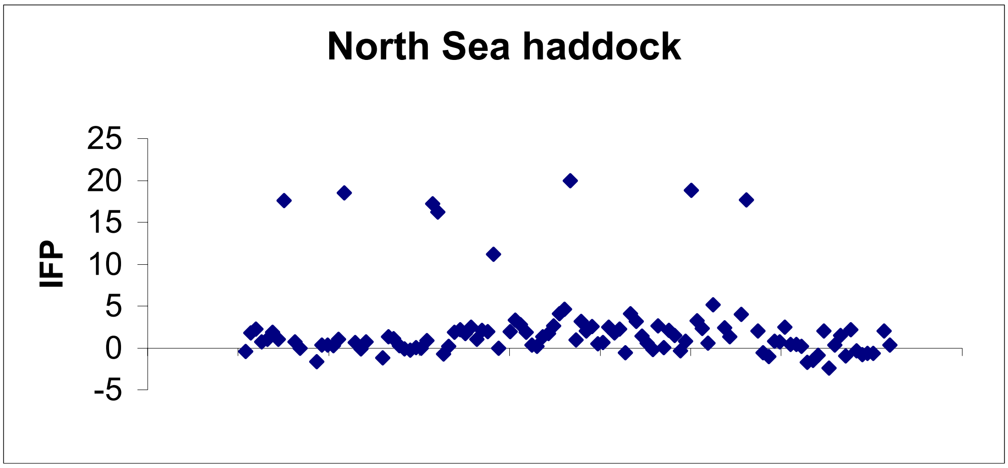

Figure 2. Index of technical efficiency for the beam trawl fleet fishing in area 4 for haddock.

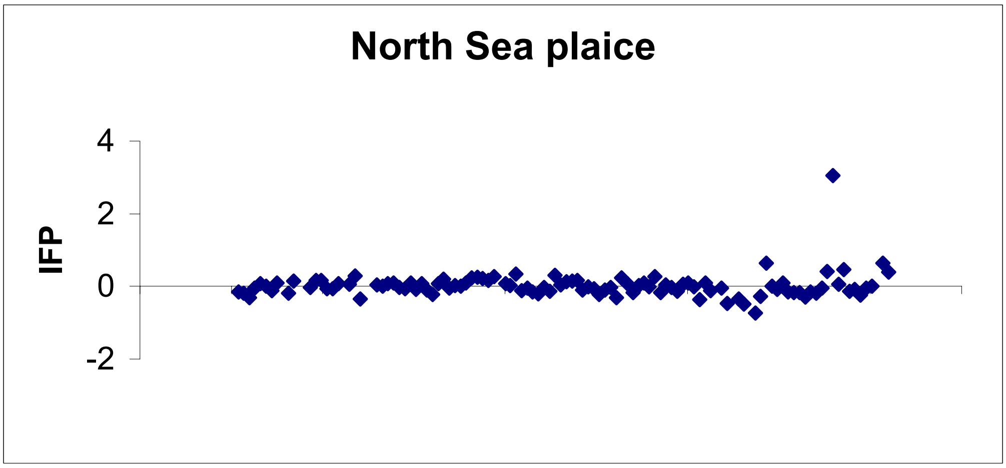

Figure 3. Index of technical efficiency for the beam trawl fleet fishing in area 4 for plaice.

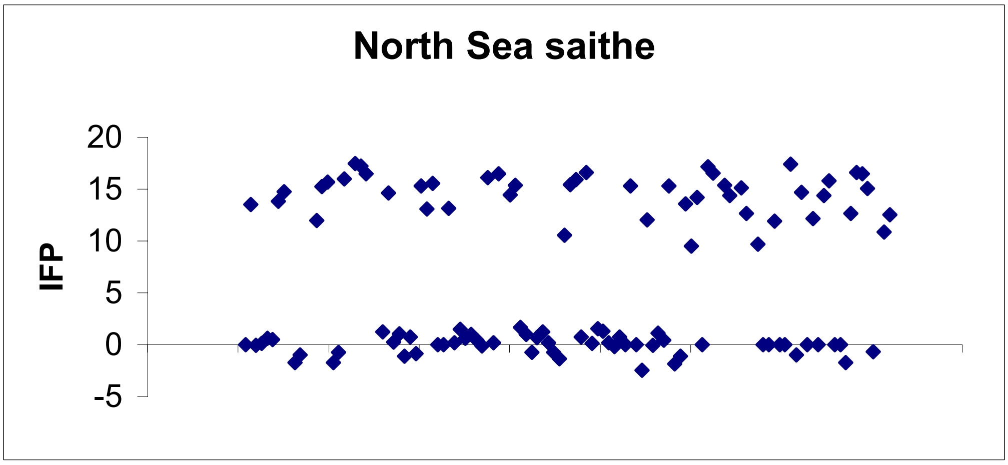

Figure 4. Index of technical efficiency for the beam trawl fleet fishing in area 4 for saithe.

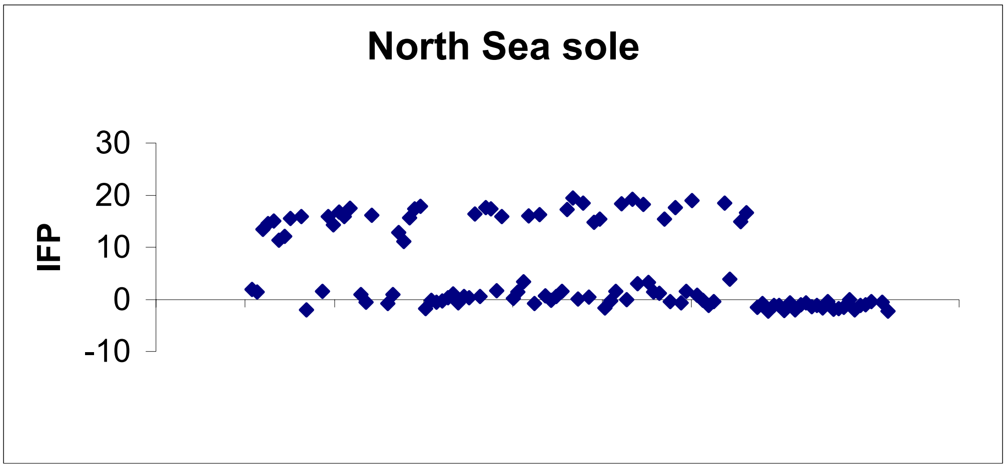

Figure 5. Index of technical efficiency for the beam trawl fleet fishing in area 4 for sole.

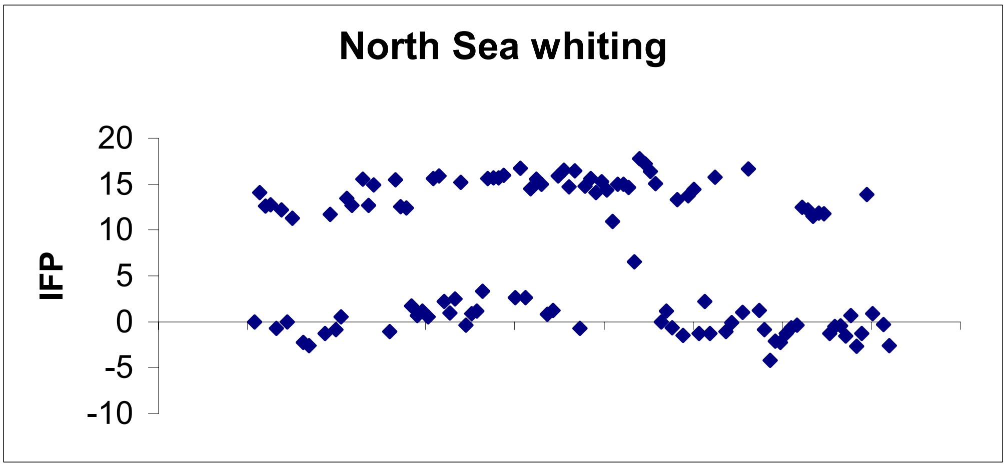

Figure 6. Index of technical efficiency for the beam trawl fleet fishing in area 4 for whiting.

4. DISCUSSION

The use of technical measures such as closed areas and seasons has become an increasingly important management tactic within the ICES area. Catch databases disaggregated by species, quarter, fleet and ICES statistical rectangle have been used in attempts to assess the effects of technical conservation methods. National data collection programmes have not, however, been generally designed to provide catch-at-age data at such a fine-grained level.

Refining the relationship between fishing mortality and nominal fishing effort would provide a basis to allow direct control of the fishing pressure exerted by fleets on stocks. The temporal dynamics in fishing power, however, are difficult to distinguish from stock fluctuations. The purpose of this paper has been to investigate and identify such dynamics.

Three independent indicators, derived using different methods have been proposed. The first is an indicator of variation in catchability, derived from the relationship between fishing mortality and fishing effort. The second and the third are indicators describing variations in fishing power, based on the CPUE of a fleet of vessels, relative to the CPUE of a reference sub-fleet. The reference sub-fleet is characterized by low variation in fishing power and comprises either a set of reference vessels belonging to the fleet under examination (indicator 2) or a research vessel survey (indicator 3), if available. The methods have been illustrated using data collected from the English demersal fisheries operating in the North Sea for the time period from 1989 to 1998.

The index of technical efficiency, as calculated, exhibits a number of features. Within area 4, the beam trawl fleet appears to have a relatively constant index of fishing power with respect to cod, haddock and plaice. The numerical values fluctuate about a value of zero and hence, do not appear to indicate a *real* difference between the reference sub-fleet and the whole fleet. The picture for saithe, sole and whiting is more intriguing with the index appearing to separate into two distinct groups – with values fluctuating about a value of zero and also about a non-zero value which appear to be approximately independent of time. One can of course speculate as to the possible causes of these differences but a more detailed investigation might reveal a likely source of the difference.

Eight fleets have been identified from the vessel trip data on the basis of their gear; namely, beam trawl, bottom pair trawl, fixed nets, longliners, nephrops and prawn gears, otter gears, seiners, and other gears. Future analyses might consider re-defining fleets in terms of specific combinations of gear/hp/mesh size. Of course, at the national level, the fleet definitions must be appropriate for the fisheries of the United Kingdom

Finally, this paper has been concerned neither with the derivation of a model for catchability-at-age nor the prediction of catchability-at-age. However, the United Kingdom (E&W) vessel trip data discussed can be used to investigate the relationship between catchability and its variance and then to assess the performance of various predictive models for catchability based on variables and factors which are controllable by management actions (Anon., 1995; O'Brien, 1995; O'Brien *et al*., 1995). Such an approach might be used for any species and fleets but is outside the scope of the present paper.

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DISTRIBUTION OF CATCH PER HAUL IN TRAWL AND PURSE SEINE FISHERIES: IMPLICATIONS FOR REDUCTION OF FISHING CAPACITY

Yoshihiro Inoue and Tatsuro Matsuoka

Abstract: The capacity catch of two fleet segments – offshore trawlers and inshore purse seiners – are estimated through consideration of the maximum observed level of catch over a given time period. The results suggest that between 80-90 percent of the current catches could still be achieved following a one third reduction in fishing capacity. The optimal level of fishing capacity reduction, however, was not estimated.

1. INTRODUCTION

The relationship among the catch (*C*), stock (*N*), fishing gear efficiency (*q*) and effort (*E*) is generalised in an equation as $C = q \cdot E \cdot N$. These factors, *q*, *E*, *N* are not constant from operation to operation in actual fisheries. The *q* and *E* are affected by various parameters, such as engine horsepower, gear size, the number and skill of crewmembers and others. These parameters are also generally combined to give a measure of fishing mortality, given by $F_c = q \cdot E$, where the maximum of F_c is also an indicator of fishing capacity, and can therefore be used to derive a capacity index. In this paper, an analysis of the statistical distribution of catches per haul in trawl and purse seine fisheries in Japan is presented. The F_c was investigated and the relationship between reduction of the fishing capacity of a boat and the expected amounts of production was simulated.

2. DATA AND METHOD FOR ANALYSIS

Five fishing boats operating in the Northern offshore trawl and one coastal purse seine fleet were examined. The Northern offshore trawl is a medium-sized sector and the trawlers operate in an area of North East off Hokkaido (Northern Island). They produce a total catch of 4,000-5,000 tonnes a boat per year. The offshore trawlers included in the analysis were very similar technically. They were all equipped with fishing gear of similar size, and used a 1,800 SP engine and a 124 GT hull. The coastal purse seine fleet that was examined operates in the Seto inland sea in Western Japan. It consists of a pair of seiners (680 PS) and two carrier boats.

The catch data including the operation information were collected for a 3-year period (from 1989 to 1992) for the trawlers, and for a 1-year period (1997) for the purse seine fleet. Each value of catch per haul was transformed into a logarithm and its frequency distributions were analyzed. The frequency distribution curves were obtained for all the boats and main fish species. The method allowed approximation of the distribution with normal distribution curves, on which the relationship between reduction of the fishing capacity and the amounts of consequent catch was simulated.

3. RESULTS

3.1 Species and quantities of target fishes caught by trawlers

No distinctive difference was found in fishing trend over the three years and between the five trawlers. The data for each species for all the boats and years were, therefore, amalgamated for the analysis of the species composition (Table 1). Walleye Pollock comprised of as much as 79 percent of all the catch in weight. Other fishes, such as Atka fish, flat fishes, red fishes and pacific cod were marginal in quantity. The total amounts of catch by the respective five fishing boats during the three years did not differ largely from each other, or ranged from 12 000 to 14 000 tonnes. The total numbers of hauls by the five boats for the three years ranged from 1 500 to 2 000, with an average of 1 778. The difference between the boats was also extremely small. The catch of walleye pollock by each boat was around 10 000 tonnes, which comprised a major proportion of the total quantity of catch. It was assumed, therefore, that the detailed analysis of walleye pollock should be representative of all catches.

Table 1. The proportion of the fish species captured by five trawlers in three years[a]

Fish species	*Scientific name*	Proportion
Walleye Pollock	*Theragra chalcogramma*	79 %
Threadfin hakeling	*Podnema longipes*	8 %
Pacific cod	*Gadus macrocephalus*	1 %
Atka fish, flat fish and red fish		1 %
Others		11 %

a). The total catch amount was 64 845 tonnes from 8 888 times of haul.

3.2 Characteristic distributions of catch per haul by offshore trawlers

The catch per haul over the three years was analysed for each fishing boat. The distributions were found to be closely similar to normal distribution curves (Figure 1). The difference among the fishing boats was extremely small. This implies that the fishing activity undertaken by the studied boats is nearly the same. The catches per haul by each boat when targeting walleye pollock ranged mainly from 0.6 to 20 tonnes. They were highly concentrated, where as many as 800 times of operations by each boat fall around the centre of the distribution and only 50 times of operations distributed peripherally in the above range.

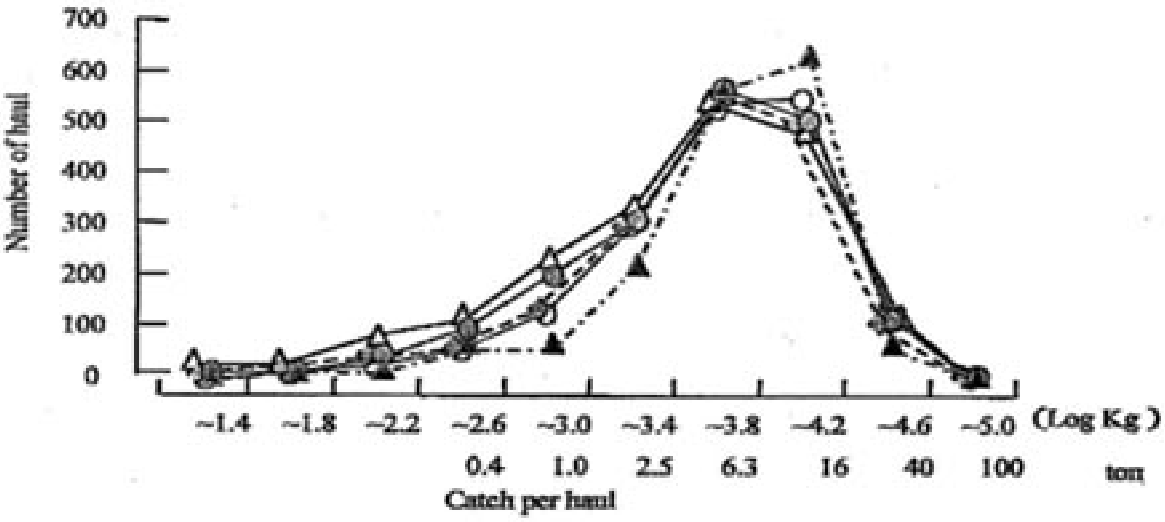

Figure 1. Distribution of catch per haul by offshore trawlers

On the basis of little difference in average catch among the boats, catches per haul from all the fishing boats for the three years were amalgamated and examined. For this purposes of the analysis, data of which the catches of walleye pollock were less than 100 kg were excluded, on the basis that they were most likely by-catch associated with the targeted catch of other species. The average catch per haul was 5.0 tonnes, and the standard deviation was as small as 2.6 kg. The 95 percent confidence interval for the average catch per haul was from 4.9 tonnes to 5.1 tonnes. It was concluded that the average catch per haul is some five tonnes when targeting walleye pollock and 3.3 tonnes in the case of operations of no particular targets in the Northern offshore trawl fishery operating in the area of North East off Hokkaido.

The largest quantities of catch per haul were, however, around 50 to 60 tonnes for all the boats in the three-year record. Those occurred only once or twice each year. This implies that the fishing capacity of the vessels is around 50 to 60 tonnes all the time, although the chance of fully utilizing such a large fishing capacity was five percent or less. According to a simulation, if fishers reduce their fishing capacity to 8.3 tonnes, as the upper limit of catch quantity per haul, they would maintain the catch equivalent to 70 percent of the current production and the loss in comparison to the current production could be 30 percent. If they limit the fishing capacity to 11.5 tonnes, they would maintain the level at 80 percent of the current production, while capacity of 17.4 tonnes would enable 90 percent of the current production. However, if they want to maintain the 95 percent of the current catch, a fishing capacity of 24.5 tonnes would be required.

3.3 Characteristic distributions of catch per haul by coastal purse seine

The target species for the examined coastal purse seine were jack mackerel, mackerel and sardine. The nets used during the studied period were some 672m in cork line length and 195m deep. The nets for respective target species were similar in size, despite the deference in mesh size. The frequency distribution of catch per haul is shown in Figure 2. For the purposes of the analysis, empty hauls (which occurred in ten percent of the cases when targeting jack mackerel and mackerel) were excluded from the analysis. The catches per haul for jack mackerel and mackerel ranged from 0.06 tonnes to 10.4 tonnes, and those of sardine from 0.8 tonnes to 130 tonnes. The largest amount of catch per haul was 173 times greater than the smallest for jack mackerel and mackerel and 163 times greater, for sardine. The largest amount of catch per haul occurred only once or twice a year. The statistical distribution patterns of the catch per haul for the three fishes were similar to those for walleye pollock from the trawlers.

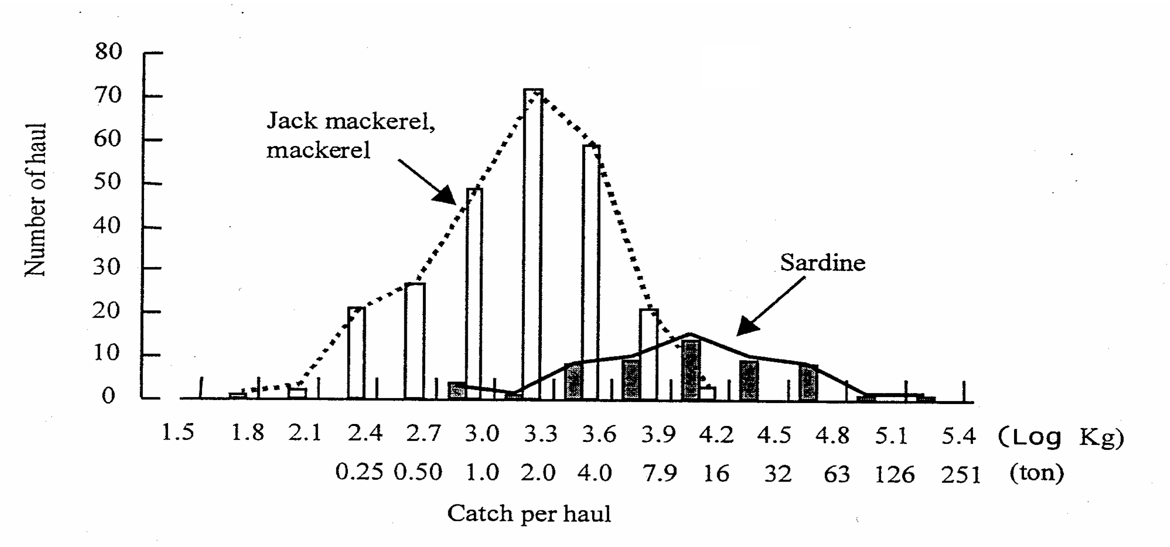

Figure 2. Distribution of catch per haul by coastal purse seine

4. DISCUSSION

The fish stock exploited by the studied fishing sectors fluctuates from year to year, as does the total allowable catch (TAC). Control of fishing capacity is necessary under such a circumstance. In other words, fishing capacity must be adjusted frequently. It is, however, not realistic to change each year the number of boats or the ability of a boat such as the size, engine horsepower, fishing devices onboard every year. These factors should be changed from the long-term viewpoint over 20 to 30 years. The realistic fishing control corresponding to the fluctuation of fish stock should be applied to fishing gear and operational methods.

The actual catch per haul with the same fishing capacity differs by a factor of 100 between the smallest and the largest. In both the studied fishing sectors, the largest catch occurred only once or twice a year. This implies that, theoretically, 80-90 percent of the current catch could still be achieved even if fishers reduce their fishing capacity by one third from the present condition. However, the appropriate rate of reduction of the fishing capacity has not been clarified yet, because there are no actual data under the condition of reduced fishing capacity. The reduction rate should be decided on the basis of a survey of current fisheries and trial operations prudently.

This study suggests that it is possible to reduce the fishing capacity in current capture fisheries. The method used demonstrates that it is possible to assess fishing capacity from catch records even if there is no detailed survey on fishing gear and fishing boat. The present fishing gear do not have the function or structure to change their fishing capacity, however, it must be possible to design such gear by a systematic approach from the beginning of the development.

A RELATIONSHIP BETWEEN FISHING EFFORT AND FISHING CAPACITY IN FLUCTUATING FISH STOCKS

Tatsu Kishida[1] **and Tokio Wada**[2]

Abstract: We define here the meaning of fishing capacity as the upper limit of fishing effort (e.g. boats*trips) for a given fleet (e.g. the number of vessels). Ideally speaking, the best measure to reduce fishing effort seems to be to reduce fishing capacity itself when fishing effort exceeds the optimal level which can be estimated from biological reference points. But when the possibility exists that the stock fluctuates widely or an uncertainty in the optimal effort level exists, it seems inevitable that a certain level of surplus in fishing capacity will be required as a buffer. If the fishing capacity was reduced to the calculated average 'optimal' fishing effort level, no potential fishing effort to utilize stocks that exceeds the 'optimal' level remains. In year when the stock is less than the optimal level, the buffer fishing effort should be removed by closure of the fishery after the quota for the year has been achieved. Using a simple stock dynamics model, it is suggested that the optimal fishing capacity to achieve the maximum yield and maximum revenue through a long-term period is about a half and a quarter of the maximum fishing capacity corresponding to bionomic equilibrium level in a high stock abundance period, respectively.

1. INTRODUCTION

Pelagic fishes such as the Japanese sardine *Sardinops melanostictus*, and chub mackerel *Scomber japonicus* fluctuate widely in their abundance with over decadal scale. While fishing capacity of purse seine vessels increases in response to a high stock abundance, an excess of fishing capacity can arise as the stock abundance begin to decline. In Japan, fisheries management based on the total allowable catch (TAC) started in 1997 for these major pelagic species. Some problems have been pointed out for the output control system using TAC, i.e. a reliability to the stock assessment, costs to update accumulated catch of the year, under report by fishermen, discards for high grading. For the chub mackerel stock around Japan, recruitment over exploitation by purse seine fishery, i.e. heavy fishing pressure for yearling and 1 year-old fish, is also pointed out and it may cause a delay of stock recovery (Wada *et al*., 1996; Kishida, 1998) under a TAC control system. An excess of fishing capacity lies behind these problems. Therefore, FAO advocates the reducing of fishing capacity before the application of any output control system in fisheries management.

In this paper, we developed a simple simulation model describing the stock dynamics of pelagic fishes fluctuating under natural and fishing conditions, and discussed the relationship between reference points for these stocks and proper size of fishing capacity.

2. MODEL AND METHODS

Assuming a Schaefer growth model (Schaefer, 1954), a convex parabolic relationship exists between fishing mortality (or fishing effort) and catch. If the price of fish can be assumed to be constant regardless of quantity of catch, the yield curve directly corresponds to the revenue curve for the industry. This revenue curve can be regarded as a production function for use in economic models.

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An assumption underlying the basic Schaefer model is that growth is affected only by the level of fishing effort, and is not susceptible to substantial environmental fluctuations. For Japanese sardine and chub mackerel, whose stock fluctuates widely with long-term cycles, several production functions can be specified to represent high stock level period and low stock abundance period as well as the standard 'average' stock conditions.

For the purposes of the analysis, the target reference point is MSY using fishing mortality F (or fishing effort X). Periods of low and high stock abundance are denoted as F_{MSY}(low)[X_{MSY}(low)] and F_{MSY}(high)[X_{MSY}(high)] respectively.

Here, fishing capacity FC is defined as the upper limit of fishing effort which can be used within a certain unit time. For example, if there are ten vessels available and each vessel can operate 50 trips per year at most, then we define $FC = 500$ (boat*trips). If the actual mean number of trips by these vessels was 30 in a year, then fishing effort in this year was 300 (boat*trips). Therefore, both fishing capacity and fishing effort are treated with the same unit.

Economic models take costs into consideration. Here, costs are assumed to be given by:

$$Cost = \alpha + \beta X \tag{1}$$

where α is fixed costs, and βX are variable costs which depend on the level of fishing effort, X. We consider fixed costs α as maintenance costs per vessel per year such as depreciation amount and fixed wages. For free access fishery, which is assumed in this model, fishing effort tends to increase to the bionomic equilibrium point X_{eq} where revenue corresponds to costs (Gordon, 1954), such that no economic profits exist in the fishery. Therefore, the maximum fishing capacity that is commercially attainable [Max (FC)] is X_{eq} (high), although this obviously corresponds to over-investment, and losses will occur when the stock is less than the present high level. On the other hand, if fishing capacity is less than X_{MSY}(low), the effective use of the fish stock cannot be achieved due to the low exploitation rate during other than low stock level periods. From the long-term point of view, the proper level of fishing capacity seems to exist between the range:

$$X_{MSY}(low) < FC < X_{MSY}(high) < X\ (high) \tag{2}$$

Since it seems reasonable to hold excess fishing capacity in low stock level period as a buffer for high stock level period, we examine how much fishing capacity is appropriate to hold.

We assume that the stock dynamics follow the Schaefer model, and carrying capacity K and intrinsic growth rate r to be a function of time $K(t)$ and $r(t)$, respectively, i.e.:

$$dN/dt = r(t)N(K(t) - N) / K(t) - FN \tag{3}$$

where N and F denotes the stock size in number and fishing mortality, respectively. At the equilibrium condition ($dN/dt = 0$), $Catch = FN$, equation (3) can be transformed as follows;

$$Catch = K\ (t)\ F(r\ (t) - F) / r(t) \tag{4}$$

Assuming constant price p, revenue Y can be given by:

$$Y = pK(t)F(r(t) - F) / r(t) \quad (5)$$

and profits, *Prof*, is expressed by subtracting cost *Cost* from *Y*, i.e.:

$$Prof = pK(t)F(r(t) - F) / r(t) - \alpha - \beta X \quad (6)$$

which can also be expressed as:

$$Prof = K(t)F(r(t) - F) / r(t) - \alpha - \beta F/q \quad (7)$$

In equation (7), the parameters of economic costs α and β are expressed as relative values divided by fish price.

The optimal size of fishing capacity for the fluctuating stock is estimated as the fishing mortality *F* (or effort *X*) which maximize the cumulative yield or revenue under long-term fluctuation of *K*(*t*) or *r*(*t*).

3. STOCK FLUCTUATION

Stock fluctuations of sardine, chub mackerel and saury *Cololabis saira* in Pacific Ocean around Japan are shown in Figure 1. Bi-decadal scale fluctuation seems to exist in these stocks at least after 1950s. In the Schaefer model, a stock fluctuation occurs, if either carrying capacity *K* or intrinsic growth rate *r* fluctuates. We examined both cases.

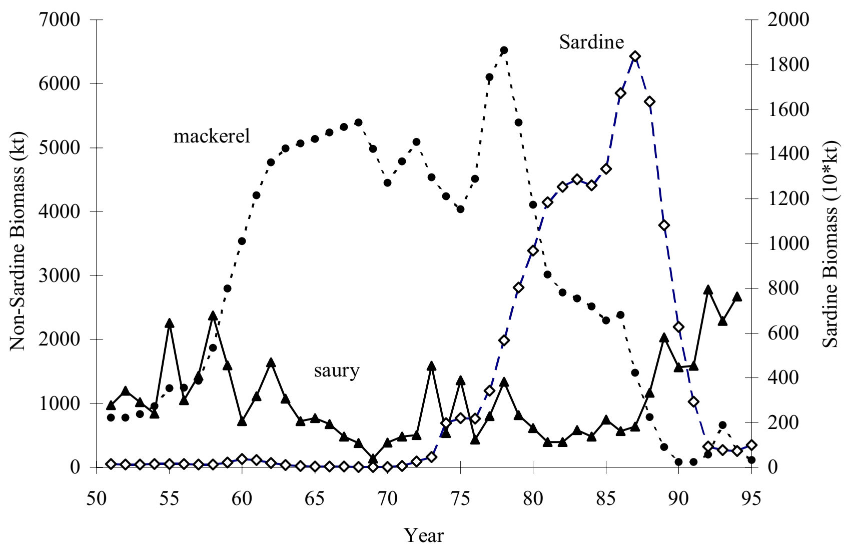

Figure 1. Biomass fluctuation of key pelagic species in Pacific region around Japan
(Source: Hasegawa, 1997; Wada and Jacobson, 1998)

In the case of fluctuating *K*, carrying capacity *K* is assumed to fluctuate according to sine curve with 20 years in one cycle. The maximum and minimum of *K* is set to 25 000 and 5 000, respectively. Intrinsic growth rate *r* is set to constantly 0.8.

In the case of fluctuating r, intrinsic growth rate r is assumed to fluctuate according to sine curve with 20 years in one cycle. The maximum and minimum of r is set to 1.4 and 0.2, respectively. Carrying capacity K is set to constantly 15 000.

The fishing coefficient q was arbitrarily assumed to be 0.0005. Similarly, information was not available from the purse seine fishery to estimate α and β so these were also assumed.

The value β represents the costs per unit of effort. However, as we are attempting to identify the optimal yield in terms of quantity, we express all values in terms of weight rather than money. For example, let the fish price be US$100/tonne, the unit of fishing effort be 1 trip, the cost per trip per vessel be US$200, the fixed costs be US$1 000/year (i.e. a = 5), the upper limit of cruise in a year be 40, the actual number of cruises in a year be 30 and the catch in a year be 150 ton. The revenue of this case expressed by price is as follows:

Y = 150 ton × US$100 =US$15 000
Cost = US$1 000 + 30 trips × US$200 /trips = US$7 000
Prof = US$15 000 - US$7 000 = U$8 000

In this study, however, we express revenue with weight as follows by dividing a and b by p:

$$Prof = \frac{\$15000}{\$100/t} - \frac{\$1000}{100/t} - \frac{\$200/trip}{\$100/t} * 30trips = 80t$$

4. RESULT

4.1 Fluctuations in K

The relationship between N and Y, and F and Y when carrying capacity K is the minimum and maximum of a given range and intrinsic growth rate r is constant are shown in Figure 2. The fluctuation of carrying capacity K, stock size N, and profit *Prof* using the dynamic production model:

$$N_{t+1} = (1 + rF)\, N_t - rN_t^2 / K(t) \tag{8}$$

which takes the change of K with time into consideration are shown in Figure 3. The initial value of stock size was set to 5 000.

F_{MSY} in the Schaefer model is theoretically $r/2$. Therefore, F_{MSY} is constant when r is constant, even if K fluctuates. Estimated F_{MSY} using this model was 0.44 (Figure 4). It is known that the effort level that achieves MEY is less than that of MSY level. In this model, F which maximizes P*rof* was 0.26 when α = 5 and 0.24 when α = 10. In this model, full operation by 22 vessels (880 boat*trip) is equivalent to F = 0.44, since the maximum number of trips was set to 40 per year. Using this fishing capacity of 880 (boat*trip) fully makes an accumulated yield maximum for long-term period under stock fluctuation.

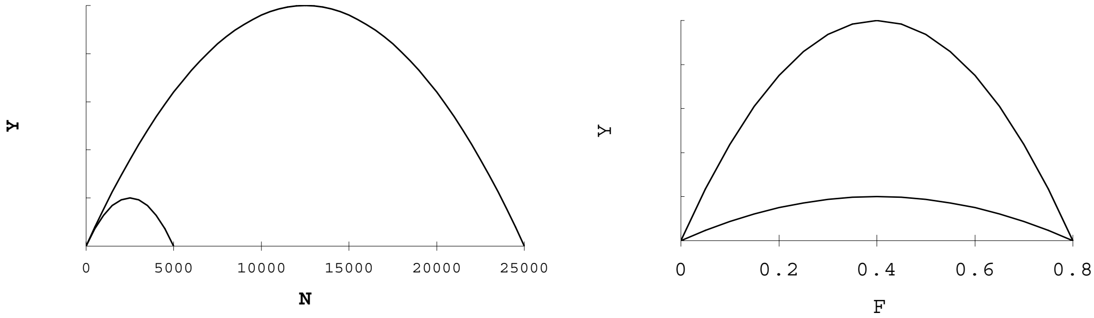

Figure 2. Relationships between *N* and *Y* (left panel) and *F* and *Y* (right panel) when carrying capacity *K* changes 5000 and 25000 in Schaefer model.

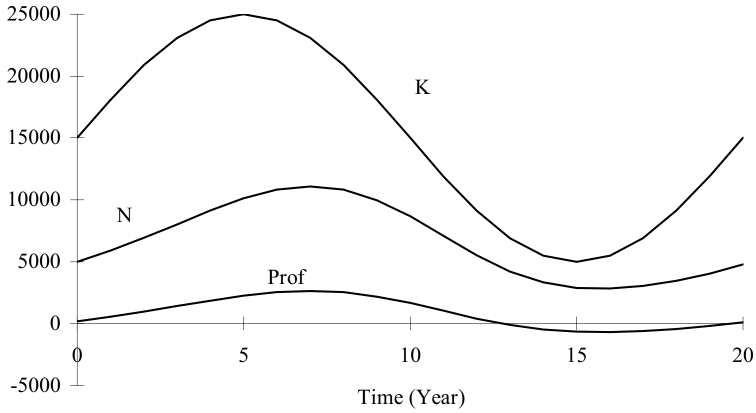

Figure 3. Twenty years simulation of the number in stock *N* and revenue *Rev* when carrying capacity *K* fluctuated. Intrinsic growth rate *r* was constant (0.8) and *a* = 5.

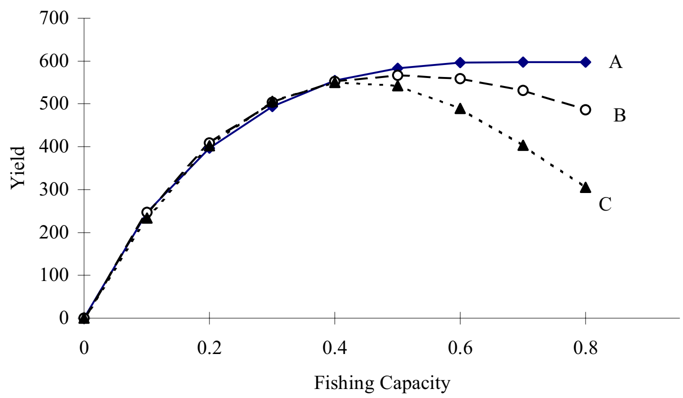

Figure 4. Relationships between fishing capacity and yield at each model. A: *K* was constant (15000), *r* fluctuated from 0.2 through 1.4 and *F* was set to *r*/2. B: *K* was constant, *r* fluctuated and *F* was set to constant (0.4). C: *K* fluctuated and *r* was constant (0.8). Here, fishing capacity is multiplied by *q* and yield is divided by 100.

The bionomic equilibrium point of *F* where *Prof*=0 at low stock level F_{eq}(low) (*K*=5000, *r*=0.8) and high stock level F_{eq}(high) (*K*=25 000, *r*=0.8) in the condition that *a* = 5 were 0.08 and 0.66, respectively (Table 1). These are equivalent to 160 and 1 320 (boat*trips) in fishing capacity, respectively, and equivalent to full (40) trips by four and 33 vessels.

Table 1. Simulated values of fishing mortality F, Fishing Capacity and Yield of each model when a =5.

Model		Fishing Capacity	*F*	Yield	Profit
r = 0.8 (const.)	Feq (low)	160	0.08	7600	0
5000<*K*<25000					
	Max (*profits*)	520	0.26		22 600
	Max (Y*ield*)	880	0.44	55 300	
	Feq (high)	1 320	0.66	63 300	0
K =15000 (const.)	Feq (low)	300	0.15	14 000	0
0.2<*r*<1.4					
1) F =0.4 (const.)	Max (*profits*)	480	0.24		22 800
	Max (*Yield*)	1 040	0.52	56 700	
2) F = r /2	Max (*profits*)	720	0.36		25 500
	Max (*Yield*)	1 400	0.7	59 800	
	Feq (high)	1 980	0.99	92 700	0

4.2 Fluctuations in *r*

Two harvest strategies were examined for the case when carrying capacity, *K*, is constant and intrinsic growth rate, *r*, fluctuates, i.e. let *F* be constant and *F* be *r*/2 to meet fluctuating *r*.

The bionomic equilibrium point of *F* where *Prof*=0 at low stock level F_{eq} (low) (*K*=15 000, *r*=0.2) and high stock level F_{eq} (high) (*K*=15 000, *r*=1.4) in the condition that α = 5 and β = 2 were 0.15 and 0.99, respectively (Table 1). They are equivalent to 300 and 1980 (boat*trips) in fishing capacity, respectively, and equivalent to full (40) trips by 7.5 and 49.5 vessels.

Constant F strategy

The relationship between *N* and *Y*, and *F* and *Y* when *r* is the minimum and maximum of a given range and carrying capacity *K* is constant are shown in Figure 5. The time series of stock size *N*, yield *Y* and revenue *Rev* using non-equilibrium production model are shown in Figure 6. The yield became maximum when *F* = 0.52 which equivalent to full (40) cruise by 26 vessels (Figure 4). The profits became maximum when *F* = 0.24 which equivalent to full (40) cruises by 12 vessels in the condition that *a* = 5 (Table 1 and Fig. 8).

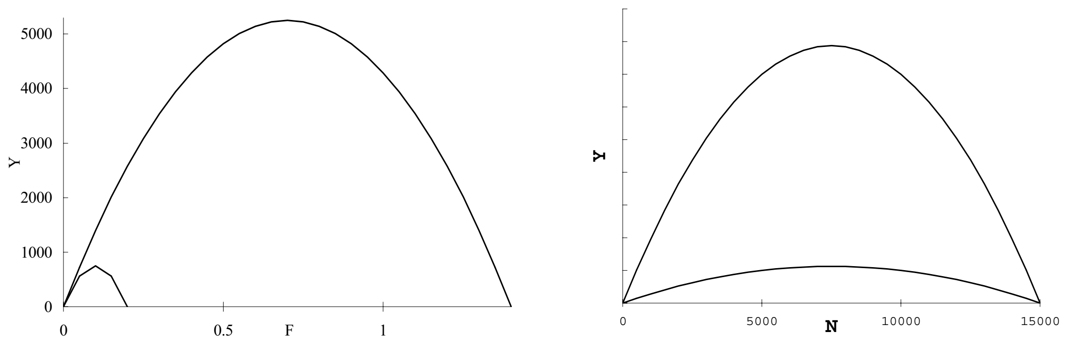

Figure 5. Relationships between *N* and *Y* (left panel) and *F* and *Y* (right panel) when intrinsic growth rate *r* changes 0.2 and 1.4 in Schaefer model.

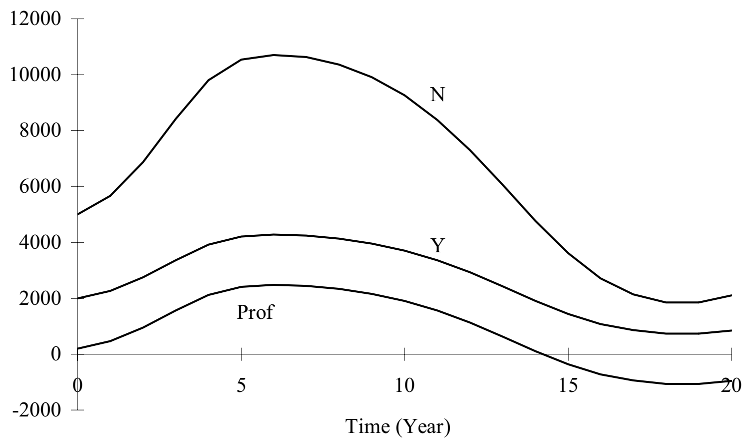

Figure 6. Twenty years simulation of *N*, *Y* and *Rev* when *K* was constant (15000) and α = 5. *r* fluctuated from 0.2 to 1.4 but *F* was set to 0.4.

F = r / 2 strategy

The time series of stock size *N*, yield *Y* and profit P*rof* using the dynamic production model are shown in Figure 7. In this strategy, *F* fluctuates yearly but cannot exceed the upper limit corresponding to the fishing capacity set in advance. This case is the ideal harvest strategy, because *F* responds to the actual property of fish the stock. It is necessary to let excess fishing effort remain by closure of the fishery when *F* should be reduced owing to a low growth conditions.

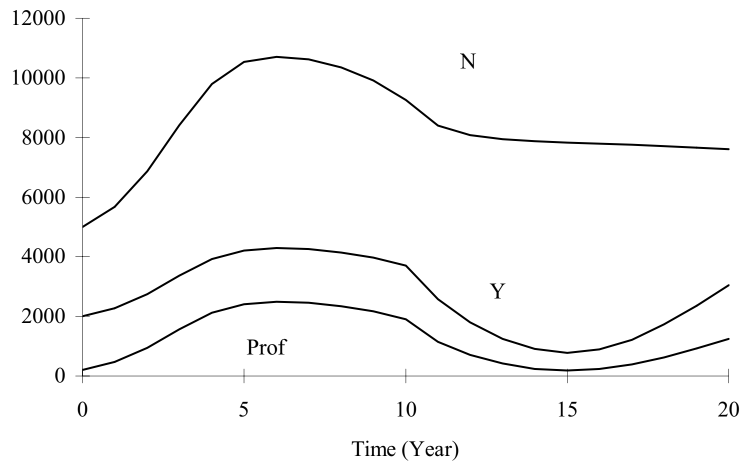

Figure 7. Twenty years simulation of *N*, *Y* and *Rev* when *K* was constant (15 000) and *a* = 5. *r* fluctuated from 0.2 to 1.4 and *F* changed accordingly (*F*=r/2), but fishing capacity was restricted 800 (boat*trips).

In the simulation shown in Figure 7, the stock size gradually converged to *K*/2 (=7 500), the stock size that achieves MSY. The case when fishing capacity exceeds 1 400 (boat*trips) made yield maximum (Figure 4). Fishing mortality of 0.7, is equivalent to the full use of fishing capacity of 1 400 (boat*trips), and is equivalent to F_{MSY}(high), which is also equivalent to a full number of trips by 35 vessels. Fishing mortality *F* that made the profits maximum varied with α. When $\alpha = 5$, $F = 0.36$ (full trips by 18 vessels) made the profits maximum, while $F = 0.30$ (full cruises by 15 vessels) when $a = 10$, and F became smaller as a increased (Figure 8).

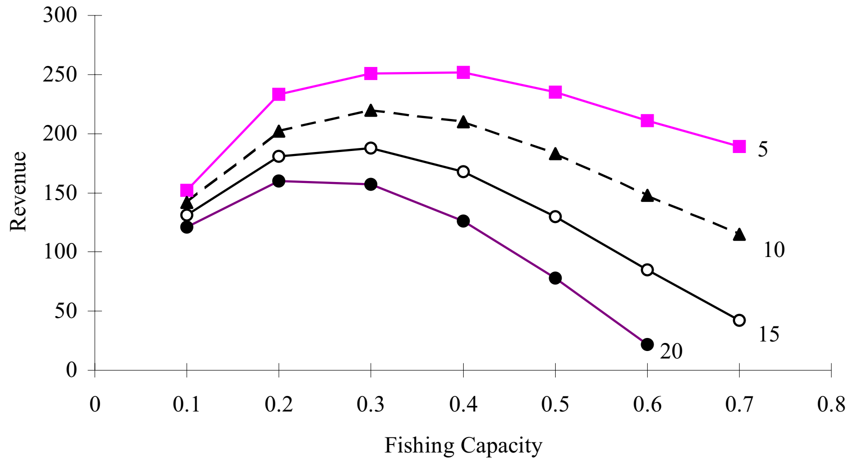

Figure 8. Relationships between fishing capacity and revenue at different α. K was constant (15000), r fluctuated from 0.2 to 1.4, F changed accordingly (=r/2), but fishing capacity was restricted 800 (boat*trips). Here, fishing capacity is multiplied by q and yield is divided by 100.

5. DISCUSSION

The reason why pelagic fishes around Japan fluctuate widely is not clearly understood yet. There may exist cases when carrying capacity changes due to a regime shift in climate and ocean condition, and there also may exist cases due to changes in the intrinsic growth rate by changing natural mortality due to density dependence (Kishida and Matsuda, 1993), predation or competition. Therefore, both cases are discussed here.

In the case when carrying capacity fluctuates and intrinsic growth rate is constant, it is the best decision for both stock sustainability and economy that let F_{MSY} (XMSY) or F_{MEY} (XMEY) which aims to achieve stock size to MSY or MEY level be reference point. The fishing capacity should not exceed the value equivalent to those reference points expressed F or X, because FMSY or FMEY is constant irrespective of stock size in this case. When stock level is the highest, 33 vessels can enter this fishery under open access condition in this model. However, it is necessary to reduce the number of vessel to 22 or 13 to maximize accumulated yield or profits over the long-term. The proper size of fishing capacity does not change irrespective of fixed costs α in seeking MSY. However, it became somewhat smaller as the fixed costs increased for MEY, therefore the actual optimal value of fishing capacity cannot be discussed unless the actual fixed costs are estimated. As shown in Figure 3, it should be noted that even the revenue became plus in average, those in low stock abundance years ran a deficit depends on economic parameters.

The results did not differ in the cases mentioned above, if fishing mortality was set to constant, even in the reverse case, i.e. intrinsic growth rate fluctuated and carrying capacity was constant. Although the bionomic equilibrium point of fishing effort where revenues and costs becomes equal at high stock abundance period indicates that 49.5 vessels can enter at most, it is necessary to reduce the number of vessels to 26 or 12 to maximize accumulated yield or profits over the long-term. It should be noted in this case that although the number of stock increases in the years when intrinsic growth rate are high, stock size decreases remarkably in the years when *r* declines, and the amplitude of stock fluctuation becomes large as a whole as shown in Figure 6. Therefore it may be necessary to manage with this strategy by setting cutoffs for spawning stock biomass or something in low stock level period.

In the case that fishing mortality can be changed annually according to the change of intrinsic growth rate, fishing capacity can be enlarged over 1 400. Fishing capacity of 1 400 which equivalents to full (40) cruises by 35 vessels equivalents to X_{MSY}(high). To make a long-term accumulated yield maximum, it is necessary to reduce the number of cruise in a year when fishing mortality should be reduced due to decline of intrinsic growth rate. Fishing capacity should be reduced 720 (18 vessels) when MEY level is aimed at (when a = 5). As same as the case when *r* is constant, the fishing capacity to aim at MEY level became smaller as the fixed costs increased (Figure 8). Table 1 shows that accumulated yield became the largest in the case when reference point (fishing mortality) could be set annually in detail according to the change of *r*.

As shown above, the optimal fishing capacity for fluctuating stock in this model seems about a half the size of the effort level of bionomic equilibrium point for open access condition in high stock abundance period, if we want to make accumulated yield in long-term maximum. If we want to maximize the accumulated profits over the long-term, further reduction of fishing capacity seems necessary. This size of fishing capacity (Table 1) was about two or three times of X_{MSY}(low) which equalled to 0.1 when *r* fluctuated from 0.2 through 1.4.

In this study, the important parameters *q* and *p* (fish price) are assumed to be constant for simplicity, but if the actual values are taken into consideration, the optimal fishing capacity may change. It is probable that the fishing coefficient *q* becomes smaller as the stock size increases, because the schooling pelagic fish has tendency that the stock size and CPUE shows increasing concave curve (Hilborn and Walters, 1992). Secondly, fish prices generally decrease as catch increase in order to balance demand and supply.

The Japanese statistics shows that the domestic purse seine fishery runs at a deficit in the total. Therefore, we will estimate the actual model of stock dynamics and the values of parameters used in this model and propose the proper fishing capacity for Japanese purse seine fishery.

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