The XIth Annual Conference of the European Association of Fisheries Economists

Dublin 6th – 10th April 1999

Fishing effort:

A review of the basic biological and economic approaches

Jesper Levring Andersen

Danish Institute of Agricultural and Fisheries Economics
(jla@sjfi.dk)

Abstract:

The concept of fishing effort is important when regulating the fishery. This paper contrasts fishing effort as interpreted in biological and economic approaches. To make the approach as usable as possible in empirical analyses the review uses a discrete time set-up. To describe the biological approach to the concept of fishing effort a traditional Schaefer model with some simplifying assumptions is used. In relation to this the traditional biological definitions of fish density, fishing intensity, fishing power, fishing time etc. are reviewed and discussed. For managers that want to regulate the fishery the biological approach to determining fishing effort becomes problematic, primarily because there are no guidelines as to where regulation should be implemented. This is one of the primary reasons why the economic approach to fishing effort is important. It is based on the application of the economic theory of production. Using the production function theory the economic approach is discussed. In light of the two approaches to fishing effort a short literature review of empirical estimations is undertaken. Finally, estimations of fishing effort are calculated based on data of insurance values and the value of assets obtained from the Danish Account Statistics for Fishery.

Keywords:

Fishing effort, production function, insurance values, asset values

1. Introduction

When managers regulate the fishery, they have different instruments at their disposal. These can be grouped into categories of output, input and technical control measures. All three directly or indirectly influence how large the catch is going to be and how much effort is applied when making that catch. Understanding the concept of fishing effort is therefore central, when trying to regulate the fishery. The problem is how to interpret the concept of fishing effort, and how to determine the factors that can affect it.

Because the two academic fields of biology and economics have different objectives when undertaking analyses of the fishery, this gives rise to different ways of approaching the concept of fishing effort. It can become problematic when they co-operate, as is the case in the theory of bioeconomic modelling. It is therefore important to understand different definitions and interpretations of effort used by the biologist and economist in relation to the fishery.

The purpose of this review is to describe the concept of fishing effort using biological and economic approaches. Some of the questions touched upon will be; what is the objective of their analysis? How does it influence the approach to the concept of fishing effort? And which basic factors determine the fishing effort?

In order to understand the link between the biology and economics in relation to the fishery, the review will first describe the biological approach using a common-ly used biological model. At the same time some definitions and terminologies used in biological models will be reviewed. The review then goes on to consider fishing effort interpretations from an economic perspective, and finally some concluding remarks.

To make the review as usable as possible in empirical analyses each section will include a theoretical part and an empirical part. The theoretical part will be based on discrete time, because most empirical analyses are based on data gathered at a point in time or for a period of time. Analyses based on continuous time are very seldom usable in real world analyses. The empirical part gives examples of how the concept of fishing effort has been and can be applied in empirical analysis. In the economic section estimations of fishing effort will be made on the basis of the Danish Account Statistics for Fishery.

2. Fishing effort from a biological perspective

The objective of the biological analyses are primarily concerned with assessing the development of fish stocks and/or fishing mortalities, when fish stocks are exposed to fishing effort, and therefore, catch (Huang et al. (1976), Schnute (1977), Andersen (1979)). Follo-wing this are objectives concerning fish stock conservation and harvest maximisation (Clay et al., 1998).

In biological models five different factors can influence the development of the fish stocks in numbers and/or weight (Beverton et al, 1957). The first is recruitment, which can be defined as the number of individuals alive at a specified time after the egg stage (Hilborn et al. (1992), OECD (1997)). The second is the weight increase that the fish alive have. Natural mortality cau-sed by predators, diseases or environmental elements is the third, and the fourth is migration, which only becomes relevant if the analysis is for a specified area.

The fifth and last is mortality caused by fishing, a major determinant here being the use of fishing effort. This is the only factor that can be influenced by man[1].

In the following a common used biological model based on the work by Schaefer (1954, 1957) will be used to explain how fishing effort is incorporated into biological models. This type of model can be termed as a surplus production model or simply a Schaefer model (FAO, 1992), and surplus production can be defined as

"*The catch plus the net change in biomass over some finite period*" (Hilborn et al., 1992, p. 79).

If a fish stock is in equilibrium, then the surplus production is equal to the catch. Surplus production can therefore also be thought of as the increase in fish stock, if there is no catch.

Because the surplus productions model only incorpora-tes one fish stock and no cohorts[2], it is easy to understand and interpret. At the same time the data demands are moderate, because only knowledge of fishing effort and catch is required to make the analyses. The model describes the fishery in an oversimplified way, but is good enough to meet the purpose of this review. At the same time it can be pointed out that this model lays a part of the foundation for the work done by organisations like ICES and NAFO.

2.1 Catch Per Unit Effort

Ricker (1975) defines catch per unit effort (CPUE) or fishing success as the catch of fish taken by a defined unit of fishing effort. The main assumption in surplus production models is that the CPUE is proportional to the fish stock. Each unit of effort will produce the catch of the same percentage of the stock. The basic equation in the following is that:

$$(1) \quad \frac{C_t}{E_t} = q \cdot N_t$$

C is the catch in period t, while N is the average fish stock measured at time t. The catch and fish stock can be measured in either number or weight of fish. In this review the terms in number will be used.

q is a factor of proportionality also called the catchabi-lity coefficient, which is assumed to be constant. It can be interpreted as a gear efficiency factor or a technical efficiency coefficient. Frost et al. (1995) mention technical development, mesh size and fishing strategy as different factors that can have an influence on this.

---

[1] There are different possibilities to expand recruitment.

[2] A cohort can be defined as a group of fish belonging to the same stock born in a single period or a year class (Rothschild (1986), FAO (1992)). A model that takes different year classes into account is therefore called a cohort model.

E is nominal fishing effort exercised in period t, which will be explained in a moment.

(1) implicitly demand that fish population redistributes after every unit of nominal fishing effort used, and that the average density of the fish D at time t is constant.

The fish density can be defined as the fish population per unit of area A where the population is localised:

$$(2)\quad D_t = \frac{N_t}{A} \Leftrightarrow N_t = D_t \cdot A$$

2.2 Fishing effort

Before explaining the concept of nominal fishing effort, it would be appropriate to explain what is meant by the concept of effective fishing effort, effectiveness of fishing or fishing mortality.

2.2.1 Effective fishing effort/fishing mortality

Effective fishing effort refers to the concept of fishing mortality (Cunningham et al., 1985). A general definition of fishing mortality and therefore effective fishing effort is (OECD, 1997, p. 171):

" *The rate at which fish die due to fishing*"

The rate can either be used in discrete and continuous time. In discrete time the rate of fishing becomes a periodic rate, and can, following Graham (1938, p. 77) cited in Smith (1994, p. 303), be defined as:

" *The catch in a year* [period t] *expressed as a percentage of the average stock in that year*"

In continuous time the rate of fishing becomes an instantaneous rate, and can, following Graham (1938, p. 77) cited in Smith (1994, p. 303), be defined as:

" *The catch in a moment of time expressed as a percentage of the stock at that moment*"

2.2.1.1 Periodic fishing mortality/Fishing intensity

It can be shown under the given assumptions, that the effective fishing effort in discrete time is the same as fishing intensity. Fishing intensity is by Beverton et al. (1957, p. 29) defined as:

" *The fishing effort per unit area per unit time*"

Given that the length of the time period is set to one, where the E units of fishing effort is executed, it follows per definition that the fishing intensity is:

$$(3)\qquad f = \frac{E_t}{A}$$

Inserting (2) into (3) and rearranging gives:

$$(4)\qquad f = \frac{C_t}{A_t \cdot D_t} \Leftrightarrow f = \frac{C_t}{N_t}$$

It is therefore clear that fishing intensity and effective fishing effort is the same in this case of equal fish densities and redistribution after each effort unit applied.

Equation (4) can also be expressed as:

$$(5) \qquad C_t = f \cdot N_t$$

This relationship is known as Baranov's catch equation (NAFO, 1992), and postulates that the catch in number of fish is given as the fishing intensity multiplied be the average number of fish in the fish population. Given data for two of the variables, the third is easy to find.

2.2.1.2 Instantaneous fishing mortality

The instantaneous fishing mortality can be written as (Sanders et al., 1976):

$$(6) \quad F = \frac{1}{N}\frac{dC}{dt}$$

In the case where the time period, where the fishing effort is executed, is going towards 0, the instantaneous fishing mortality and the fishing intensity will coincide under the given assumptions (Sanders et al., 1976).

2.2.2 Nominal fishing effort

By using (1) and (5) the relationship between the fishing intensity (or the effective fishing effort) and the nominal fishing effort can be found as:

$$(7) \quad f = q \cdot E_t$$

The nominal fishing effort may, as stated by Robins et al. (1998), refer to any measure of resources devoted to fishing. Nominal fishing effort is important to know in biological models, because given that this and the catchability coefficient can be measured/estimated in some way, then the fishing intensity can be calculated using (7). Inserting the fishing intensity in Baranov's catch equation (5) will fulfil the biologists' objective of determining the fish population, since catch data is usually known[3].

There is a general agreement that nominal fishing effort is measured as a composite of the fishing power multiplied by the fishing time (Beverton et al. (1957), Sanders et al. (1976), Byrne (1982), Hussen et al. (1986) and Valatin (1992)). For a vessel *i* the nominal fishing effort can therefore be written as:

$$(8) \quad E_t^i = T_t^i \cdot FP_t^i$$

The reason for not just adding up the fishing time, and using this as a measure of nominal fishing effort, is because of different vessel characteristics. Even if two vessels have the same fishing time, they could catch different amounts of fish. The fishing power term takes this into consideration.

---

[3] In Virtual Population Analysis, which includes cohorts, the effective fishing effort can be determined without knowing the nominal effort. This is possible because of some assumptions about the size of oldest fish stock (Hilborn et al., 1992).

2.2.2.1 Fishing time

In the biological terminology the best way to define fishing time g in period t for a vessel or gear would be as the time where the fishing gear is in use (Beverton et al., 1957), and directly give rise to a catch. Measuring fishing time this way can however be complicated and total time at sea is therefore often used instead, because it is easier to measure. Seen from an economic point of view, this is also the best measure to use, as will be explained later.

2.2.2.2 Fishing power

When defining fishing power there can be distincted between the absolute fishing power and the relative fishing power (Kirkley et al., 1998). Because the absolute fishing power (afp) is difficult to measure, the biologists usually use the relative fishing power (frp). The relationship between these two measures is:

$$(9)\quad afp_t = q \cdot rfp_t$$

where q is the mentioned catchability coefficient.

Beverton et al. (1957, pp. 172-173) defines the relative fishing power, also referred to as the fishing power factor, as:

> " *The ratio of the catch per unit fishing time of the ves-sel to that of another vessel taken as a standard and fishing on the same density of fish on the same type of ground*"

For a given vessel *i* compared to the standard vessel denoted by *s*, the relative fishing power at time t is (Sanders et al, 1976)[4]:

$$(10)\ rfp_t^i = \left(\frac{\sum c_t^i}{g_t^i}\right) \Big/ \left(\frac{\sum c_t^i}{g_s^i}\right)$$

where c is the catch made by vessel i during g units of operation in period t.

2.2.2.3 Aggregate nominal fishing effort

The aggregate nominal fishing effort is measured by summarising the fishing time multiplied by the relative average fishing power of all the vessels according to Beverton et al. (1957). It is therefore determined as:

$$(11)\ E_t = \sum_i g_t^i \cdot rfp_t^i = \sum_i g_t^i \cdot \left(\frac{\sum c_t^i}{g_t^i}\right) \Big/ \left(\frac{\sum c_t^i}{g_s^i}\right)$$

The aggregate nominal fishing effort is standardised in this way, and if the fishing time and catch, then the number of "equivalent effort" units can be found (Cunningham et al., 1985).

---

[4] According to Sanders et al. (1976) and Ricker (1975) the assump-tion about the density and ground can be relaxed, so that (11) can be used even when there are different densities and areas as long as each vessel can be calibrated against the standard vessel in the end.

2.3 Empirical biological measurements of fishing effort

There are certain disadvantages in using the approach to measuring fishing effort the way it was explained in section 2.2, which can be called the traditional approach. Problems which the biologists are aware of (FAO, 1992). Firstly the nominal fishing effort, which determines catch, is found using catch data. The proce-dure is therefore circular and the nominal fishing effort /power cannot be regarded as a determining variable (Huang et al., 1976). Secondly the measure cannot be used when managers want to regulate the fishery. There are no guidelines for the regulators as to what to regulate except for fishing time or fishing power.

Instead when biologists measure fishing effort in practice, they:

> “ *have to choose a measure for effort which we* [the biologists] *believe is related to fishing mortality or rather “fishing power”* ” (FAO, 1992, p. 267)

and:

> “ *In certain cases it can be assumed that the fishing power is proportional to some characteristics of the boat or gears which are relatively easy to obtain, such as GRT (tonnage) or HP (horsepower)...*” (FAO, 1992, p. 270)

This is the approach usually used in practice.

In EU’s Multi-Annual Guidance Programmes (MAGPs), which lays the foundation for the restructuring programme of the EU, the fishing effort is measured using two equations. These are based on two measures of fishing power in form of the average horsepower HP and average tonnage TON, and one measure of fishing time in form of number of fishing days at sea g. The nominal fishing effort is not standardised, and is calculated for each single fleet containing N vessels by using the following equations:

$$(12)\ E_i^{\text{Horsepower}} = \sum_{i=1}^{N} g_i \cdot HP_i$$

$$(13)\ E_i^{\text{Tonnage}} = \sum_{i=1}^{N} g_i \cdot TON_i$$

When ICES decided on their management advise for 1998, they measured the nominal fishing effort for the fleets from Scotland, France and Norway in hours of fishing. The effort of the beam trawlers from The Netherlands was measured in million horsepower days. The Danish industrial fleet was measured in days of fishing for the vessels with gross tonnage of 200 tons and the English gill netters and longliners had a nominal fishing effort measured in days at sea. It can already be seen that there are many different ways to measure nominal fishing effort.

Brunenmeister (1984) opts for a standardised nominal fishing effort in the US waters of the Gulf of Mexico shrimp fishery. The first step is to make a standardised measure of the fishing power using a version of (11), where the fishing power is compounded of different vessels characteristics, month, area and depth. These estimates of the relative fishing power is then multiplied by the fishing time measured as number of hours fished. Hence, a standardised measure of the nominal fishing effort is found.

Smit (1996) makes an evaluation of how the nominal fishing effort has developed over the last 25 years for the Dutch Cutter Fleet. Effort is defined as the engine power multiplied by the number of days at sea, and is standardised by using a group of vessels in the fleet for which there has been no development in productivity.

Besides the above-mentioned methods of measuring fishing effort, other possibilities could be the product of fishing days and boat size, fishing days, boat size and engine size, fishing days and crew size, number of hooks, hours soaked and number of lifts or the total number of pot lifts. Several empirical analyses also point at skipper skills as an important determinant for fishing effort and catch. To account for skipper skills, characteristics such as age, education, years of experience, and the flexibility to make changes may be considered. The problem is that these skills are very difficult to observe and to regulate for managers. Segura (1973), Comitini et al. (1967), Hilborn et al. (1985), Huang et al. (1976) estimate empirically the effect of skipper skills in relation to effort and catch.

3. Fishing effort from a economic perspective

The objective of fishery economics is to study:

> " *the optimal allocation of resources to a fishery in such a way that the value of production is maximized*" (Anderson, 1986, p. xviii).

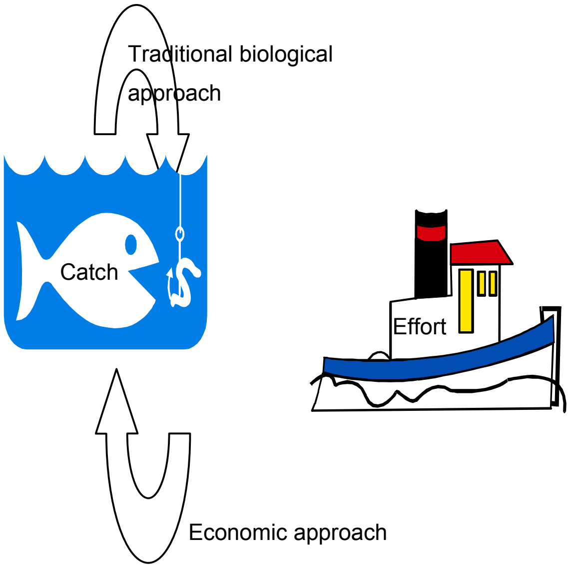
Seen from an economic point of view the biological approach to fishing effort cannot be used to make this kind of analysis, because of certain problems with the biological way of measuring fishing effort. Some of these are 1) the measuring of nominal fishing effort in one single index (Huang et al., 1976), 2) no inclusion of costs and revenues (Hannesson, 1992) and no distinction between fishing capacity and nominal fishing effort (Hannesson, 1992).

Economists prefer the theory of production and production functions to describe a process where some kind of output is produced. The theory is therefore firstly reviewed in relation to the fishery, where the output is the nominal fishing effort. It will then in brief be discussed why cost and revenue cannot be included in the traditional biological approach and why a distinction between fishing capacity and nominal fishing effort is necessary. Finally some empirical estimations are reviewed, and estimations of nominal fishing effort are calculated based on data of insurance values and the value of assets obtained from the Danish Account Statistics for Fishery.

3.1 Production functions

In the traditional biological approach the level of catch determines the level of effort. The causality is reversed in the economic approach, where the level of effort is the determinant of catch, see figure 1. In the economic approach fishing effort is seen as a produced variable (Andersen, 1979). Some would postulate that this is more in agreement with reality, but bear in mind that the objective of biological approach is different from that of the economic approach.

Figure 1.



The traditional and empirical biological approach has measured nominal fishing effort in one single index (Huang et al. (1976), Taylor et al. (1985)), where every production factor used by a vessel is considered homo-genous. This implies that one unit of fishing time increases the nominal fishing effort with the same amount as a one unit increase in fishing power. There seems to be no doubt about the impossibility of assuming homogeneous factors and measuring fishing power in one composite index (see Rothschild (1972), Huang et al. (1976), Taylor et al. (1985)). Using the principles from economic theory of production[5] can help to solve these problems.

The economic theory of production is based on production functions. A firm (vessel) production function is as Quirk (1987, p. 144) puts it[6]:

> ” *a schedule that associates with each combination of inputs the firm employs the maximum output the firm can attain from that combination of inputs*”

As mentioned by Coglan et al. (1998, p. 1) the production function:

> “ *is estimated from observed outputs and input usage and indicates the average level of outputs for a given level of inputs*”

The economic approach to the measurement of nominal fishing effort is still to consider nominal fishing effort as determined by fishing time and fishing power (Segu-ra (1973), Squires (1987a)). Following the traditional

---

[5] Doll (1988) discusses how the assumptions behind production theory can be assumed to hold in the fishery.

[6] Using the word “production function” may as Borglin (1990) mentions be misleading. Principally it describes the production possibility area, where as Quirk’s (1987) definition relates to the maximum output.

neo-classic approach, a production function for the nominal fishing effort produced by vessel *i* in the period t is defined as:

$$(14)\ E_t^i = E(T_t^i, FP_t^i)$$

where T_t^i the time which vessel *i* spend fishing in peri-od t, and FP_t^i is the fishing power of vessel *i* at time t.

3.1.1 Fishing time

Economists will prefer to take all the fishing time into account that have economic implications for the vessel when making a catch. It is not only the time, when the fishing gear is actually deployed, that has economic implications. There may be other time consuming activities as the ones mentioned by Hilborn et al. (1992) and Hannesson (1993), which are travel time, search time and handling time. Because all these activities give rise to costs and revenues and therefore have influence on the profitability of fishing, they should be included in the economic analysis. A measure could be the number of days absent from port or sea days (Carlson, 1973), which is relatively simple to measure.

3.1.2 Fishing power

Instead of estimating the fishing power using the Beverton & Holt approach in section 2.5, Carlson (1973, p. 42) points out that:

> " *one of the important attributes of using a production function is that it allows the simultaneous measurement of as many parameters of fishing power as may be thought to be important in its determination*".

The empirical biological approach has done this by using simple production theory and non-monetary measures. But it has still considered the fishing time and the fishing power to be homogeneous, and the factors that determine fishing power to be the same.

The theory of production makes it possible to estimate the fishing power as determined by a lot of different specific factors and at the same time take into conside-ration that each of the factors may have a different influence (heterogeneous) on the nominal fishing effort. The different specific factors could be either monetary or non-monetary measures. The monetary measures could be in terms of factor prices (Bjørndal, 1987), insurance values (Frost et al. 1995) and/or assets values. The non-monetary factors (physical) could be vessel tonnage, vessel length, vessel width, vessel ton-nage, crew size, crew skills, gear size and/or electronic equipment, see Pascoe et al. (1998) for more examples.

The fishing power of vessel *i* can be written as a func-tion of the average man-made capital K_t^i deployed/ used by vessel *i* at time t and L_t^i the average labour (human) capital deployed/used by vessel *i* at time t[7]:

$$(15)\ FP_t^i = FP(K_t^i, L_t^i)$$

Several different types of man-made and labour capital, which can only be aggregated under very restrictive assumption (see for instance Squires (1987a) or Andersen (1979)), may determine the fishing power

---

[7] Other inputs could be a management variable or one measuring technological change (Segura, 1973).

function. As mentioned earlier the capital could for instance be composed of gear, tonnage and/or engine size, and likewise with the measure of labour capital. Given that these factors are non-homogeneous, K_t^i and L_t^i must be interpreted as vectors:

$$(16)\ K_t^i = (K_t^{1i}, K_t^{2i}, ...)$$

and

$$(17)\ L_t^i = (L_t^{1i}, L_t^{2i}, ...)$$

Substituting (15), (16) and (17) into (14) gives the fishing effort production function of vessel *i* at time t:

$$(18)\ E_t^i = E(T_t^i, K_t^{1i}, K_t^{2i}, ..., L_t^{1i}, L_t^{2i}, ...)$$

When a production function of fishing effort is estimated, it is possible to point at specific measures that managers should regulate to realise a given state. As mentioned earlier economists traditionally prefer the state where the resource rent[8] is maximised.

3.2 The inclusion of costs and benefits

In achieving a state where the resource rent is maxi-mised, and where the scarce resource is used optimally, inclusion of costs and benefits are necessary. This will be almost impossible using the biological approach to nominal fishing effort, because the cost of the single effort index cannot be found (Huang et al., 1976)[9].

Estimating fishing power as a function of different factor inputs could facilitate the inclusion of cost, considering that it is probably easier to find the cost for these different factors than finding the cost of the single effort index. However the inclusion of cost will not be pursued further here.

3.3 Fishing capacity and fishing effort

The fishing capacity measures a vessel's ability to catch fish, while the fishing effort is a measure of the fishing capacity utilised. Some man-made capital and/or labour capital may be unused, and do therefore not have any influence on the fishing effort exercised. Only if the fishing capacity is utilised 100%, will fishing effort and fishing capacity conceive (Lindebo (forthcoming) discusses fishing capacity).

In the biological literature there is no distinction between fishing capacity and fishing effort. This is not a realistic situation because fluctuations in fish stock imply that some fishing capital may lay idle for periods of time. Costs could be a possible measure of the capacity utilised.

---

[8] The resource rent can be defined as the payment to a factor of pro-duction in excess of what is necessary to keep it in its current employment.

[9] Cost can be included in the empirical biological approach to fishing effort, because this uses specific input factors.

3.4 Empirical economic estimations of fishing effort functions

The Danish Institute of Agricultural and Fisheries Eco-nomics (SJFI) produces an Account Statistics for the Danish Fishery on a yearly basis. Reports from appro-ximately 350 fishing firms[10] out of approximately 1600 fishing firms makes the basis for the statistics, which has until now been made for 1995, 1996 and 1997.

In the following data from the account statistics on insurance values and asset values will be used as independent variables to explain fishing effort. First the data sets used are defined and secondly the functional form of the estimated production function is reviewed. Thereafter the correlation coefficients for each data set and the existence of heteroscedasticity will be checked. Finally the production functions will be estimated and tested for separability. The purpose is to see which ba-sic problems are present, and whether a Cobb-Douglas production function can be used as functional form.

It must be pointed out that these results are preliminary, and is part of an on going project. The project seeks to find production functions for the fishing sector, and not for a specific fishery conducted in a specific area. The conclusions made here are therefore not to be taken as the final of the project.

Before these preliminary estimations are reviewed, there will be a short review of the previous studies made and their approach.

3.4.1 Previous studies

When looking at past research on the estimation of production functions in the fishery. It seems to be most common to estimate a catch production function[11]. Very seldom has the effort function been estimated separately. The reason is that data on catch as a dependent variable is easily available, while nominal fishing effort is not. In order to estimate effort functions the nominal fishing effort has to be known in order to include it as an independent variable. Different methods have been applied to calculate this through catch data. These methods will be briefly reviewed.

A commonly cited article in relation to the estimation of production functions in the fishery is Hannesson (1983). Using time series data from the Lofoten winter cod fishery in the years 1971-1978 a Cobb-Douglas catch function is estimated for different fisheries exploiting the same fish stock. As dependent variable, gross value of landings per day at sea was used. Inputs were in form of replacement values of the vessel hull, outfit (except gear) and engine, the number of fisher-men employed and the fish stock biomass calculated from ICES data. He also estimated an effort function with an implied value of nominal effort calculated by dividing the catch with the biomass using the estimated coefficient of the biomass from the catch function.

---

[10] The Danish Account Statistics for Fishery is based on the concept of fishing firms, which might include several vessels. The estimations done in this paper are based on the fishing firms with only one vessel.

[11] In unspecified form the catch function for vessel *i* can with S_i as the fish stock it meets, be written as:

$CV_i = f(T_i, FP_i, S_i)$

Based on cross sectional data on the 1992 UK beam trawl in the English Channel, Pascoe et al. (1998) estimated a vessel catch function with the objective of analysing substitution effects. Physical characteristics in form of tonnage, crew size, gear size, engine size and age for each vessel was used as input in the production function. Because of constant returns to fishing time in form of number of days fished, the dependent variable was catch per fishing day. A trans-log catch function was estimated, which also included monthly and area dummy variables in order to as they say "represent relative stock abundance" (Pascoe et al., p. 24). The estimated coefficients showed a positive relationship between the input variables and the catch per fishing day, while all the significant dummy variables showed a negative relationship. In line with Pascoe et al. (1998) are Campbell (1991), who estimate a Cobb-Douglas effort function the Tasmanian rock lobster fishery using cross sectional data for the season 1983/84. The purpose was to find substitution elastici-ties, and Campbell also used dummy variables to des-cribe intraseasonal variations in the rock lobster stock.

Clay et al. (1998) also had the objective of analysing substitution effects, but for the Scottish Inshore Fishery. They did not directly estimate the trans-log effort function, but used a differentiated part of it. As inputs, however, they included a measure of capital in form of tonnage and horsepower, labour in form of crew days fished, gear type and consumables, which covered inputs that were exhausted during a trip. They estimated some elasticities of substitution, which in relation to management recommendations are impor-tant. The same approach was used by Squires (1987a).

After testing a trans-log catch function Hoyo et al. (1998) estimated the nominal fishing effort function on a trip level using a Cobb-Douglas production function. The data was cross sectional and based on the Spanish trawl fishery operating in the Atlantic Moroccan Waters in 1985, 1986 and 1987. They assumed that the fish stock each vessel exploited was constant over the given year. Fishing time was measured as the number of trips made (the number of sea days per trip was ap-proximately equal to fifteen days no matter vessel size) and tonnage and engine horsepower determined fishing power. Byrne (1982) used the same assumption on the fish stock as Hoyo et al. (1998), but on time series data.

3.4.2 The data sets

The Danish Account Statistics for Fishery deducts between twelve different fleet segments. Estimations will be done for three data sets. The first data set consists of all twelve fleet segments generally (Model I). The second data set consists of vessels that use trawl as their primary gear (Model II), and the final data set of vessels that use nets as their primary gear (Model III)[12]. In each data set vessels with tonnage above 5 GT (GRT), which catch fish for consumption purposes, are included. A production function will be estimated for each data set and year.

The data sets are taken to be cross sectional, and each consists of the following number of observations under the restrictions set above:

---

[12] The other fleet segments do not have enough observations to make reliable estimations.

All fleet segments	**Model I**		
	1995	**1996**	**1997**
Insurance values	159	185	169
Average asset values	189	207	201

Trawler fleet segment	**Model II**		
	1995	**1996**	**1997**
Insurance values	56	77	76
Average asset values	58	80	81

Netter fleet segment	**Model III**		
	1995	**1996**	**1997**
Insurance values	62	71	63
Average asset values	77	80	70

3.4.3 The production function

Using the same approach as Hoyo et al. (1998) and assuming that the fish stock can be considered constant over the year for each vessel, the estimated catch function can also be considered an effort function.

The estimation will be based on a transcendental-logarithmic production function, which is a very flexible function (Lau, 1996). It is a second order approximation to an arbitrary twice-differentiable linear function and makes no a priori assumptions about the input inter-relationships (Clay et al., 1998). This functional form is chosen because it:

> " *impose few, if any, restrictions on the cost* [production] *function, but at the same time, the form must be simple enough that empirical estimation of the model are possible*" (Morey, 1986, p. 37).

The trans-log function is in general given as:

(19) $\ln CV_i = \alpha_0 + \sum_a \alpha_a \ln X_{ai} + ½ \sum_a \sum_b \gamma_{ab} \ln X_{ai} \ln X_{bi}$ where CV_i is the yearly catch for consumption in value[13] of vessel *i*, and can under the given assumption be interpreted as the nominal fishing effort. a and b refers to the different inputs used.

An coefficient symmetry assumption are made:

(20) $\gamma_{ab} = \gamma_{ba}$

The number of sea days that vessel *i* has, will be considered as an independent variable (a=1) in all the estimations, but other independent variables are also included. When using insurance values there will be a deduction between the insurance value for the hull of vessel *i* (a=2), the insurance value for the engine of vessel *i* (a=3) and the insurance value of the electronic equipment that vessel *i* has (a=4).

---

[13] Using the catch in weight as dependent variable seemed to give almost the same results as the catch in value.

Asset values are measured at 1 January and 31 December, and analysis will be made for the average of these. The independent variables will in this case, besides the number of sea days, be the value of the vessel hull etc. (a=2), vessel engines and winches (a=3), vessel electronic equipment (a=4) and vessel fishing gear (a=5)[14].

All in all the three different data sets (Model I, II and III) will be used to estimate the fishing effort produc-tion function with two different measures for capital (insurance values, average asset values) for three years (1995, 1996 and 1997).

Each estimated trans-log production function will be tested, whether it can be assumed in (19) that:

$$(21)\, \gamma_{ab} = 0,\ \forall a,b$$

This hypothesis is a test for separability or weak global separability (Hoyo et al. (1998), Green (1997)). Separability implies that there are no specific interactions between the inputs. This can be important for management purposes, because it becomes possible to isolate the changes in single inputs, without having to take the indirect effects of these changes into consideration. Berndt et al. (1973) and Denny et al. (1977) analyse this kind of test in depth. If the hypothesis of separability is not rejected, the trans-log production function can be reduced to a Cobb-Douglas production function in form of (Green, 1997):

$$(22)\ \ln CV_i = \alpha_0 + \sum_a \alpha_a \ln X_{ai}$$

The Cobb-Douglas function is a commonly used production function in not only fisheries economics. In this function the α_a measures the partial elasticity of the output with respect to the X_{ai} that is analysed, given that the rest of the X_{ai} are considered to be constant.

As opposed to the biological approach all the inputs are considered to be non-homogenous because an increase in for instance the number of sea days with one unit will lead to an increase in fishing effort of α_1 units, given that the other inputs remain constant.

3.4.4 Insurance values

To get an indication, of which factors are relevant in determining the catch, Pearson's correlation coefficients are estimated. Most of the correlation coefficients are statistically significant in relation to the catch in value. There seems to be strong correlation between the insurance value on the hull and engine of the vessel in almost all models and years, which is not surprising.

Heteroscedasticity is a serious problem, because it makes even the F-test values unreliable. A lot of different diagnostics for the detection of heteroscedasticity exist, but there is no sure method of detecting heteroscedasticity (Gujarati, 1992). For each model and year it is tested whether heteroscedasticity could be present using a Park and a Glejser test (see Green, 1997) and the answers are as follows:

---

[14] The Danish Account Statistics for Fishery also collects the values of land based fishery assets. These are however not included in the analysis, because they do not directly influence the level of nominal fishing effort carried out.

	Model I		
	1995	**1996**	**1997**
Park test	No	Yes	Yes
Glejser test	No	Yes	Yes

	Model II		
	1995	**1996**	**1997**
Park test	No	No	No
Glejser test	No	No	No

	Model III		
	1995	**1996**	**1997**
Park test	No	No	No
Glejser test	No	No	No

Note: The dependent variable in the Park test was the ln (residual^2) and in the Glejser tests the absolute residual.

The Park and Glejser test indicates that the estimations in model I in 1996 and 1997 are influenced by heteroscedasticity, while the rest are not. In order to make the F-test values reliable in these cases the trans-log production function are estimated using weighted least squares, otherwise ordinary least squares are used. Considering the residual plots for each of the variables included, the heteroscedasticity seem to originate from either the number of sea days or the insurance value of the hull. No matter which weight is used, the estimated coefficients and test values will not differ that much. The number of sea days is therefore used as weight.

None of the trans-log production function estimates shall be summarised here, but there are strong signs of multicollinearity, because every model has large R^2 value contemporary with many insignificant coeffici-ents. Some of the multicollinearity is a self-inflicted nuisance, because of the product variables that are included. However the F-test values are still reliable, which is sufficient for the purpose that is needed here.

Whether the production function can be reduced to a Cobb-Douglas instead of a trans-log is now tested. The results are as follows:

Insurance values	**Model I**		
	1995	**1996$^{\#}$**	**1997$^{\#}$**
F-statistics	2.1552	2.1434	1.7238
No rejection of (21)	Yes	Yes	Yes

Insurance values	**Model II**		
	1995	**1996**	**1997**
F-statistics	0.3995	0.4348	1.1863
No rejection of (21)	Yes	Yes	Yes

Insurance values	**Model III**

	1995	1996	1997
F-statistics	3.0846	0.9078	0.7622
No rejection of (21)	No	Yes	Yes

Note: Critical values are approximates at a 99% confidence level. # Weighted estimations used.

The Cobb-Douglas production function is suitable as production function for every model type and every year, except for netters in 1995. The probability of observing a test value that supports the hypothesis (21) in the same degree as the observed test value is in most cases high, and there are in most of the estimations a large degree of agreement between the data and the hypothesis (21).

The coefficients estimated in the case of the Cobb-Douglas function are listed below:

Insurance values	**Model I**		
	1995	**1996**	**1997**
Intercept	0.8465	0.0856	0.2483
α_1	0.5063*	0.5557*	0.5715*
α_2	0.4475*	0.2848	0.4076*
α_3	0.2311*	0.3202*	0.2837*
α_4	0.1161*	0.2033*	0.1350*
R^2	0.8736	0.8366	0.8064

Insurance values	**Model II**		
	1995	**1996**	**1997**
Intercept	1.4328	0.8281	1.6949*
α_1	1.0022*	0.5198*	0.5854*
α_2	0.1556	1.0529*	0.3499*
α_3	0.2417	-0.2398	0.1821
α_4	0.1810	-0.0861	0.1902*
R^2	0.8289	0.8003	0.7906

Insurance values	**Model III**		
	1995	**1996**	**1997**
Intercept	N.E.	-0.3127	-0.8317
α_1	N.E.	0.4779*	0.6689*
α_2	N.E.	0.4304	0.4340*
α_3	N.E.	0.3322	0.3260*
α_4	N.E.	0.0910	0.1044
R^2	N.E.	0.8390	0.7634

Note: * statistically significant at a 5% level or greater.

The coefficients, estimated using the data set of model I, are all significant except for the vessel hull (α_2) in 1996. Combined with the high R^2 this gives reason to believe that these estimations give a good description of the data set. However the level of aggregation might be too high, if the estimated coefficients are going to be used in a sector model for the Danish fisheries. There-fore coefficient estimations were also done separately for the trawler and netter data sets. In these estimations only the coefficient for the number of sea days (α_1) are significant in all the estimations. The vessel hull coeffi-cient (α_2) are significant in only three estimations, while the insurance value for the engine and the electronic equipment of vessel are significant in one.

As many other empirical analyses have concluded, the estimations based on insurance values gives rise to conclude, that a Cobb-Douglas production function can in most cases be used as the basic functional form. At the same time the number of sea days and the hull are important variables in explaining the level of nominal fishing effort.

3.4.5 Average asset values

SJFI also gather information on asset values, which are defined as the repurchase value measured as the replacement value of the asset in its present form, corrected for operation depreciation.

It is important to be aware that the asset values are spe-cified for four different variables, which include the value of the vessel, hull etc., engines and winches, electronic equipment and fishing gear. This is one variable more than the insurance values, which do not include the insurance values of fishing gear. This gives an extra management variable when using the asset values, which might be useful. At the same time the insurance values are probably more unreliable than the asset values. Insurance values are usually not yearly updated, can include a certain degree of expectations as mentioned by Frost et al. (1995) and are often higher than the actual insurance value. It might therefore be preferable to use asset values instead of insurance values.

The different data sets for the average asset values will be analysed the same way as the insurance values were.

The Pearson's correlation coefficients show that none of the variables are correlated to a degree that gives rise to concern. All the variables are statistically significant, except for netters where the number of sea days are insignificant in relation to the other input variables, but not with the catch value. The observed correlation between the insurance values of hull and engine does not recur in the average asset values.

The heteroscedasticity test is undertaken in the way as in section 3.4.4, and the test results are:

	Model I		
	1995	**1996**	**1997**
Park test	No	No	Yes
Glejser test	No	Yes	Yes

	Model II		
	1995	**1996**	**1997**
Park test	Yes	No	No
Glejser test	No	No	No

	Model III		
	1995	**1996**	**1997**
Park test	Yes	No	No
Glejser test	Yes	No	No

Note: The dependent variable in the Park test was the ln (residual^2) and in the Glejser tests the absolute residual.

The two tests do not agree on the presence of heteroscedasticity (Model I, 1996 and Model II, 1995). Ordinary and weighted least squares are therefore both used to estimate the coefficients and test values in order to secure that the correct conclusion is made. In the weighted estimations the asset value of fishing gear is used as the weight, based on the residual plots.

Once again all the trans-log estimates shall not be summarised here. As it can be seen from the tables below, it is only in the case of trawlers in 1995 that the trans-log production function can be reduced to a Cobb-Douglas function functional form. There is in general rejection of hypothesis (31).

Average asset value	Model I		
	1995	**1996#**	**1997**
F-statistics	20.9537	35.2697	20.7268
No rejection of (31)	No	No	No

Average asset value	Model II		
	1995#	**1996**	**1997**
F-statistics	2.4054	3.4999	5.0750
No rejection of (31)	Yes	No	No

Average asset value	Model III		
	1995#	**1996**	**1997**
F-statistics	4.6817	3.1168	3.6556
Rejection of (31)	No	No	No

Note: Critical values are approximates at a 99% confidence level.
Weighted estimations used.

Coefficients of the Cobb-Douglas production function estimated for trawlers in 1995 will not be stated here, because it is not possible to make general comments based on this.

Had the hypothesis (31) not been rejected for the given data sets or had the Cobb-Douglas function been postulated initially to be the correct functional form, the conclusions would have been much in line with the ones made for the insurance values. The number of sea days and the asset value of the hull would be significant in all the estimations, and the asset value of engine and winches would be significant in most of them. The asset values of electronic equipment and fishing gear are not significant in a predominant number of estimations.

4. Conclusions

The objective of this paper was to review the basic bio-logical and economic approaches to fishing effort. Fis-hing effort is an important concept when making biolo-gical and economic analysis, but on different grounds.

The objective of the biological approach is primarily to assess the level of fish stocks. This necessitates the measurement of fishing effort, which can be deducted using two approaches. These are the traditional approach, which is based on the work done by Bever-ton and Holt, and the empirical approach, which uses simple production functions and non-monetary/ physical measures.

Because the objective for economists primarily is to maximise production values, there are some problems with the use of the biological approach, because it does not facilitate the inclusion of cost, capacity utilisation and builds on limiting assumptions. Economists can rectify this by using production function theory, when they make their analysis. Still taking fishing time and power as the superior determinants of fishing effort, they specify the determinants of fishing power more specifically. Distinguishing between man-made capital and labour (human) capital these can be measured using either non-monetary or monetary measures.

In order to estimate an effort production function based on catch data, some assumptions about the fish stock have to be made. In former empirical production functions estimations there have, among others, been used four different methods, which are reviewed. For cross sectional data either dummy variables or constant fish stocks have been used enable catch data to describe an effort function.

Under the assumption of constant yearly fish stock some preliminary estimations regarding a fishing effort function for the Danish fishery have been made. Based on data from The Danish Institute of Agricultural and Fisheries Economics different monetary measures have been analysed as determinants for the level of fishing effort. These monetary measures were in form of insu-rance values and asset values for the years 1995, 1996 and 1997. The analyses were made for the entire fleet and two fleet segments in form of trawlers and netters.

A trans-log production function was used as the func-tional form of the effort function, and this function was estimated under the aforementioned crucial assumption about the fish stock. The estimated effort functions were estimated with the number of sea days and either insurance values or average assets values as inputs. These functions were then tested for the presence of heteroscedasticity. In those estimations where it was present, the effort function was reestimated using weighted least squares. The weights used were based on residual plots from the ordinary least square estimation.

Finally the (re-) estimated trans-log function was tested for whether it could be reduced to a Cobb-Douglas production function. This functional form was in general not rejected for the functions estimated using insurance values. However the estimations of the Cobb-Douglas effort functions for the number of sea days and insurance values did not in general agree on which variables to include. Only the coefficient related to the number of sea days were significantly different from zero in all the estimations. The effort functions for the number of sea days and average asset values could not be reduced to a Cobb-Douglas function.

The estimated effort functions all have different problems that will be dealt with in future work. This work will seek to model another assumption about the fish stock in order to model this better. This could be done using one of the other approaches reviewed in section 3.4.1. Using more advanced estimation methods in order to test for specification errors, heteroscedasticity etc. are also part of future work.

5. References

Andersen, P. (1979) “Fiskeriøkonomi”, Sydjysk Universitetsforlag.

Anderson, L. G. (1986) “The Economics of Fisheries Management”, Revised and Enlarged Edition, The John Hopkins University Press, Baltimore and London.

Berndt, E.R. & Christensen, L.R. (1973) “The translog function and the substitution of equipment, structures and labour in U.S. manufacturing 1929-1968”, Journal of Econometrics, 1, 81-114.

Beverton, R.J.H. & Holt, S.J. (1957) “On the Dynamics of Exploited Fish Populations”,2.Ed., Chapman & Hall.

Bjørndal T. (1987) ”Production Economics and Opti-mal Stock Size in a North Atlantic Fishery”, Scandinavian Journal of Economics, 89(2), 145-164.

Borglin, A. (1990) ”Notes on the theory of produc-tion”, Education note 18, Institute of Economics, University of Copenhagen.

Brunenmeister, S.L. (1984) ”Standardization of fishing effort and production models for brown, white and pink shrimp stocks fished in U S waters of the Gulf of Mexi-co”, in ”Penaeid shrimps – their biology and manage-ment”, editor: Gulland, J.A. and Rothschild, B.J., Fishing News Books.

Byrne, J.L. (1982) ”The South Australian Prawn Fishery: A Case Study in Licence Limitation” in ”Policy and Practice in Fisheries Management”, editor: Sturgess N.H. and Meany, T.F.

Carlson, E.W. (1973) “Cross Section Production Func-tions for North Atlantic Groundfish and Tropical Tuna Seine Fisheries”, NOAA Technical Report NMFS CIRC-371, Ocean Fishery Management: Discussions and Research, Editor A.A. Sokoloski, 42-56.

Campbell, H.F. (1991) ”Estimating the Elasticity of Substitution between Restricted and Unrestricted In-puts in a Regulated Fishery: A Probit Approach”, Jour-nal of Environmental Economics and Management, 20, 262-274.

Clay, P.L. & Revell, B.J. (1998) “Input Substitution and Conservation: A Case Study of the Effects of Policy on Fishing Effort in the Scottish Inshore Fishery”, Paper from the seventh conference of the International Institute of Fisheries Economics and Trade (IIFET), Tromso, Norway.

Coglan, L., Pascoe, S & Harris, R. (1998) “Measuring efficiency in demersal trawlers using a frontier production function approach”, Paper presented at the Annual conference of the European Association of Fisheries Economists (EAFE), The Hague, Netherlands.

Comitini, S. and Huang, D.S. (1967) ”A Study of Pro-duction and Factor Shares in the Halibut Fishing Industry”, Journal of Political Economy, 75(4), 366-372.

Cunningham, S. & Whitmarsh, D. (1980) “Fishing effort and fisheries policy”, Marine Policy, 4, 309-316.
Cunningham, S., Dunn, M.R. & Whitmarsh, D. (1985) “Fisheries Economics: an introduction”, Mansell Publishing Limited.

Danish Institute of Agricultural and Fisheries Economics (1995, 1996, 1997) “Account Statistics for Fishery”, serie F.

Denny, M. & Fuss, M. “The Use of Approximation Analysis to Test for Separability and the Existence of Consistent Aggregates”, The American Economic Review, 67(3), 404-415.

Doll, J.P. (1988) “Traditional Economic Models of Fishing Vessels: A review with Discussion”, Marine Resource Economics, 5, 99-123.

European Commission (1998) “Commission Regulati-on (EC) No 2091/98 of 30 September 1998 concerning the Segmentation of the Community Fleet and Fishing Effort in Relation to the Multi-annual Guidance Programmes”, Official Journal L266/36, 1.10.98., p. 0027.

FAO Fisheries Technical Paper (1992) “Introduction to tropical fish stock assessment: Part I - Manual”, 306/1, rev. 1, edited by Sparre, P. and Venema, S.C..

Frost, H., Lanters, R., Smit, J. & Sparre, P. (1995) “An Appraisal of the Effects of the Decommissioning Scheme in the Case of Denmark and the Netherlands”, Danish Institute of Fisheries Economics Research, South Jutland University Centre, working paper 16/95.

Green, W.H. (1997) “Econometric Analysis”, Third Edition, Prentice Hall Inc.

Gujarati, D. (1992) “Essentials of Econometrics”, McGraw-Hill International Editions: Economic Series, McGraw-Hill, Inc.

Hannesson, R. (1983) “Bioeconomic Production Function in Fisheries: Theoretical and Empirical Analysis”, Canadian Journal of Fisheries and Aquatic Science, 40, 968-982.

Hannesson, R. (1992) “Fishing Capacity and Fishing Effort”, Paper from the fourth conference of EAFE, University of Salerno, Italy.

Hannesson, R. (1993) “ Bioeconomic Analysis of Fisheries”, Fishing News Books.

Hilborn R. and Ledbetter, M. (1985) ”Determinants of Catching Power in the British Columbia Salmon Purse Seine Fleet”, Canadian Journal of Fisheries and Aquatic Sciences, 42, 51-56.

Hilborn, R. & Walters, C.J. (1992) “Quantitative Fishe-ries Stock Assessment: Choice, Dynamics & Uncertainty”, Chapman & Hall, International Thomson Publishing.

Hoyo, J.J. G. and Chacón, I.H. (1998) ”The production Function in the Spanish Trawl Fleet in Moroccan Waters”, Paper from the seventh conference of IIFET, Tromso, Norway.

Huang, D.S. & Lee, C.W. (1976) ”Toward a General Model of Fishery Production”, Southern Economic Journal, 43, 846-854.

Hussen, A.M. & Sutinen, J.G. (1986) ”Estimation of Production and Revenue Functions For the Artisanal Fishery of the Gulf of Nicoya (Costa Rica)”, Paper from the third conference of IIFET, Rimouski, Canada.

International Council for the Exploration of the Sea (ICES) (1997) “Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak”, ICES CM 1998, Assess:7, Advisory Committee on Fishery Management, ICES Headquarters 6-15 October 1997.

King, M. (1995) “Fisheries Biology, Assessment and Management”, Fishing News Books.

Kirkley, J. & Squires D. (1998) “Measuring Capacity and Capacity Utilization in Fisheries”.

Lau, L.J. (1986) ”Functional Forms in Econometric Model Building” in ”Handbook of Econometrics”, Volume III, editors Griliches, Z. & Intriligator, M.D., Elsevier Science Publishers BV.

Morey, E. R. “A Generalized Harvest Function for Fis-hing: Allocating Effort among Common Property Cod Stocks (A Generalized Harvest Function)”, Jour. of En-vironmental Economics and Management”, 13, 30-49.

Northwest Atlantic Fisheries Organization (1992) “Introduction to Sequential Population Analysis”, Scientific Council Studies, number 17, editors R.K. Mohn & R. Cook.

OECD (1997) “Towards Sustainable Fisheries: Economic Aspects of the Management of Living Marine Resources”, ISBN 92-64-15448-5.

Pascoe, S. and Robinson, C. (1998) ”Input Controls, Input Substitution and Profit Maximisation in the English Channel Beam Trawl Fishery”, Journal of Agricultural Economics, 49(1), 16-33.

Quirk, J.P. (1987) “Intermediate Microeconomics”, Third Edition, Science Research Associates.

Ricker, W.E. (1975) “Computation and Interpretation of Biological Statistics of Fish Populations”, Bulletin of the Fisheries Research Board of Canada, no. 191.

Robbins, C.M., Wang, Y. G. and Die, D. (1998) ”The Impact of Global Positioning Systems and Plotters on Fishing Power in the Northern Prawn Fishery, Australia”, Canadian Journal of Fisheries and Aquatic Sciences, 55, 1645-1651.

Rothschild, B.J. (1972) “An Exposition on the Definiti-on of Fishing Effort”, Fishery Bulletin, 70(3), 671-679.

Rothschild, B.J. (1977) “Fishing Effort” Chapter 5 in “Fish Population Dynamics” edited by J.A. Gulland, John Wiley & Sons.

Rothschild, B.J. (1986) “Dynamics of Marine Fish Populations”, Harvard University Press.

Schaefer, M.B. (1954) “Some aspects of the dynamics of populations important to the management of the commercial marine fisheries”, Bulletin of the Inter-American Tropical Tuna Commission, 1(2), 26-56.

Schaefer, M.B. (1957) “Some considerations of population dynamics and economics in relation to the management of marine fisheries”, Journal of the Fisheries Research Board of Canada, 14, 669-681.

Schnute, J. (1977) “Improved estimates from the Schaefer production model: Theoretical considerations”, Journal of Fisheries Research Board Canada, 34, 583-603.

Segura, E.L. (1973) “Optimal Fishing Effort in the Pe-ruvian Anchoveta Fishery”, NOAA Technical Report NMFS CIRC-371, Ocean Fishery Management: Dis-cussions and Research, Editor A.A. Sokoloski, 57-64.

Smit, W. (1996) ”An Economic Approach to Mea-suring Fishing Effort: Application to a Dutch Cutter Fleet”, Marine Resource Economics, 11, 305-311.

Smith, T.D. (1994) “Scaling Fisheries: The science of measuring the effects of fishing, 1855-1955”, Cambridge University Press.

Squires, D. (1987a) ”Fishing Effort: Its Testing, Speci-fication, and Internal Structure in Fisheries Economics and Management”, Journal of Environmental Economics and Management, 14, 268-282.

Squires, D. (1987b) ”Public regulation and the structure of production in multiproduct industries: an application to the New England otter trawl industry”, RAND Journal of Economics, 18(2), 232-247.

Taylor, T.G. & Prochaska, F.J. (1985) “Fishing Power Functions in Aggregate Bioeconomic Models”, Marine Resource Economics, 2(1), 87-107.

Valatin, G. (1992) ”The Relationship between Fleet Capacity and Fishing Effort”, Paper from the sixth conference of IIFET, Paris, France.