

*Background document to Workshop on measurement and standardization of fishing effort
Malaga, Spain, 30-31 May 2006.*

Some common definitions of fishing effort and its potential use in assessment and management of GFCM resources in the OU context.

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Terms of reference:

- Preparation of a background paper for the GFCM/SAC transversal workshop on Fishing Effort Parameter identification and Measurement Standardisation to be held in Fuengirola-Malaga (Spain), 30-31 May 2006. The paper should place stress on the following issues:
 - ✓ The definition and measurement of fishing effort and capacity;
 - ✓ Their potential use in the assessment and management of resources in the OU context.
 - ✓ Describe some of the practical constraints that apply such as for multispecies and artisanal fisheries;
 - ✓ Summarise experiences with research programs elsewhere which were dedicated to the collection of fishing effort data and its use in assessing fish stocks, that seem relevant to implementation of the GFCM Operational Unit strategy;

Introduction

This background document provides a brief summary of some basic concepts underlying the collection and use of fishing effort in resource assessment and management, and supplements the review of these issues in GFCM Studies and Reviews No. 70 (Caddy 1998). Rather than repeat the substantial body of information available in FAO reports, photocopied pages will be distributed from various reports at the meeting, which provide easy access to standard forms for the collection of effort and other related data.

The context is of course relative to the concept of Operational Units. Accadia and Franquesa (MS) traced the development of the definition of an Operational Unit to the following final statement:

“For the sake of managing fishing effort within a Management Unit, an Operational Unit is the group of fishing vessels practising the same type of fishing operation, targeting the same species or group of species and having a similar economic structure. The grouping of fishing vessels may be subject to change over time and depends on the management objectives to be reached”.

In general, if an OU is regarded as the only group of vessels fishing a particular resource wherever it is located, the summarised effort data exerted, and the catch realized by this OU, can be used in a standard production modelling approach. However, in the likely case that more than one OU, LOU (Local Operational Unit based in a given port), or Fleet Segment, are fishing the same resource in a Management Unit (Now referred to Geographical Sub-regional Area-GSA), then of course the issue of standardisation and combination of the data generated by each OU must be resolved before an effort-based resource assessment can be attempted. If the intent is to measure the economic performance of a group of vessels fishing resources from different stocks in all areas within access of the port (or on the high seas) the approach will have to be rather different, and perhaps the

definition of targeted resource can be less precise. Nonetheless, Accadia and Franquesa recommend that areas occupied by distinct populations of various species be clearly established before an inventory of OUs is formulated! This seems sound advice, and the present paper (as for all approaches aimed at assessing and managing the specified resource in a sustainable fashion) assumes that this has been done. I address the issue of measuring/standardising the fishing effort exerted by an OU from the perspective of how to manage a group of resources existing within a given GSA, however this is defined. We have to acknowledge that if the unit resource is fished by 2 or more OU's whose economic structures are not similar (e.g., a trawler fleet and a fleet of inshore vessels), then their catch, (and after fishing power intercalibration the fishing effort and intensity they each exert), will have to be combined to arrive at a useful resource assessment.

A brief historical summary relating to the use of fishing effort in stock assessment globally

A geographical differentiation in the development of fisheries assessment techniques is evident globally in the use of fishing effort data. This is seen when comparing the evolution of fisheries assessment and management approaches in the North Atlantic, with fisheries in the NE Pacific as well as tuna fisheries worldwide. The use of fishing effort in production modelling was proposed in Europe by Graham (1935), but has not been much used in the Eastern Atlantic. Schaefer (1954) and later authors developed it, especially for North American fisheries and tuna resources. Notably, in the 1970's-90's, there was a change in production modelling methodology from the equilibrium-based approach promoted by John Gulland, to the non-equilibrium approaches described by Hilborn and Walters (1992) and Punt and Hilborn (1996), and production modelling is still widely used outside of Europe, especially in management of offshore fisheries.

The production modelling approach was not widely used in the NE Atlantic for reasons that relate to the multispecies nature of fisheries, there in which a multi-gear diversity of national regulations by a multi-national fishery made separate calibration of fishing effort by species impractical, especially under quota control. For the same reason, in the Northeast Atlantic, fitting the MSY reference point from time series of catches and fishing effort was abandoned; (a procedure still used in other parts of the world), and was substituted for by the development of RPs based on analytical and SRR models. Most of the assessments in the NE Atlantic so far depend on size and age compositions obtained by comprehensive catch sampling schemes and research vessel surveys. In the tropics, the use of analytical models was also promoted, employing length-based sampling of catches. This has led to a neglect of earlier attempts promoted by John Gulland and others to monitor the growth of fishing pressure directly. These length-based (and now trophic-based) sampling procedures permitted biologists to remain within their area of specialization and were also introduced into the Mediterranean in the 1980s. They had the major disadvantage though, that the main source of mortality on the stocks, i.e., fishing pressure, was not studied in any detail!

More recently (Holden 1994) despite quota control, several demersal stocks in the Northeast Atlantic have declined to historically low levels, while exploitation rates remain high. A re-evaluation of effort assessment and management methods is now underway. Rijnsdorp et al. (2006) saw the lack of synchronous depletion of species quotas as leading to discarding and misreporting of fish species caught incidentally to other species after their quota had been taken. Despite the problems of sharing and comparison of the fishing power of different gears and vessel classes (Martel and Walters 2002), opinion in the ICES area seems to be swinging towards the feasibility of direct control of fishing effort (Ulrich et al. 2002, Shepherd 2003). This last author suggested that under an effort allocation scheme, vessel entitlements be adjusted on the basis of past fishing performance, and enforced by satellite monitoring. His opinion will be discussed in more detail at the end of this report.

Table 1. Advantages and drawbacks of analytical and catch-effort modelling approaches.

	Analytical methods using biological data	Methods using fishing effort data
Some advantages:	<ul style="list-style-type: none"> - Data sets are more closely linked to the biological realities of the species and a monitoring of its potential productivity. - Ecosystem and biodiversity issues are at least potentially, easily linked to assessments. - The net effects of a variety of gears are assumed to be integrated within the size/age composition of catch samples. 	<ul style="list-style-type: none"> - Catch-effort modelling approaches and results are generally understandable to the industry and managers. - Surprisingly, dynamic models using relatively simple ‘black box’ concepts with minor data needs other than catch and effort, give results comparable to much more complex analytical procedures. In fact, the uncertainties in a model are predicted to increase with the number of parameters that need to be fitted. - More recent fisheries models based on catch/effort have been made spatially relevant; representing the real contagious distributions of resources and fishing effort.
Some disadvantages:	<ul style="list-style-type: none"> - A high species diversity and age/size sampling by species imposes impossible requirements for sampling to model analytically the entire suite of commercial species; (some 100’s in the multispecies bottom trawl fishery). - The cost of sampling and size/age analysis would be prohibitive for many small, local fisheries. - Systematic errors can be introduced by exclusive reliance on VPA or its derivatives. - VPA estimates are retrospective, and offer inaccurate information on the size of cohorts currently fished until they have passed through the fishery. - An exclusive focus on biological data for analysis is opposed to the concerns of fisheries management and the fishing industry, which are primarily on catches and the activity of fleets. - Economic models of fisheries performance are largely based on the Gordon-Schaefer production modelling approach. 	<ul style="list-style-type: none"> - Major problems are caused by multinational, multi-gear and multispecies fisheries for both approaches. - The steady growth in fishing power of fleets must take into account new technology introduced. - Issues such as recruitment failure, predation, growth and natural mortality are subsumed within the production model approach and must be sampled or studied by supplementary analytical approaches. Biological sampling will be needed, but not necessarily annually.

The situation portrayed in the above table is not fully realistic, since hybrid methods have been developed that employ aspects of both approaches (e.g. production modelling with mortality rates). Nevertheless, regular annual sampling of commercial catches for biological data remains a problem in many areas, and attention may have to be focussed mainly on sampling survey catches (e.g. MEDITS) for analytical information. For many Mediterranean fisheries the multispecies multi-gear issues remain a major problem. However, studies of local small-scale fisheries carried out by Operational Units within a given Management Unit, usually have the advantage of involving boats fishing locally from only a limited number of fishing ports. The multi-fleet or multi-segment issue may be less important, though it remains a problem to face up to, whichever of the two above approaches is used.

Implementing a fishing effort data collection scheme

Approaches to designing and implementing a frame survey of fishing ports and vessels operating within an OU, and suitable forms to use for this purpose can be modified from those given in Caddy and Bazigos (1985), FAO/DANIDA (1999), and Sparre (2000), and are reproduced in the package of photocopied material distributed at the meeting. Similarly, forms for use by government vessels for Monitoring, Control and Surveillance purposes are also provided there, as well as guidelines for implementing a data collection scheme for fishing effort within the OU. These items may usefully be discussed by the workshop as a possible basis for a standardized data collection system for each OU operating within a Management Unit.

Spatial information.

For fisheries from local ports it is usually assumed that interviews or log book data will easily establish the depth range of the stock, and with rather less reliability, the distribution of the resource being evaluated within range of the port(s). The depth range of species assemblage distribution patterns may also be established by independent surveys such as MEDITS. The spatial data may be stocked into a GIS system that will allow the area of the fishing zone encompassed by the depth range of the resource and the distance fished from port to be estimated automatically, or more laborious work with a squared transparent paper overlay can estimate this area manually. This provides an estimate of \underline{A} to be used to convert the fishing effort measure into a fishing intensity measure.

Units of fishing effort

Several options exist that are given in the following Table. It might seem obvious that the most detailed approach should be the one used, but this is not mandatory, since as emerges from the table, more precise measures may impose difficulties of data collection. In relation to the last two categories for example, the horse powers and tonnages of fishing vessels in a port who are authorized to fish and fish regularly, should be relatively easy to establish. Sampling throughout the year of the number of vessels leaving port during a representative series of days when the observer is present, and the typical number of hours out of port, are obtainable. The Port captain may also keep data on the days fished by each registered boat. Evidently, the unit of measurement that can be put into effect and is statistically reliable for all units, is the one to use. It may also become necessary that reporting of days fished, grounds fished, and weights landed, is obligatory as a condition of licensing.

Table 2: Some possible measures of fishing effort.

Some possible annual measures of fishing effort	Comments*
Σ Days fished/year	Here we need to calibrate between vessel/gear categories (– in theory, also, for ports closer to the grounds more time will be spent fishing in a day trip than for those further away).
Σ Number of tows/year	It will not be possible to add the number of tows for different durations of tow and trawl width.
Σ Time spent actually fishing/year	This may be estimated for a given inshore port knowing the time spent at sea on day trips after subtracting the travelling time.
Σ (Horse power*days fished)	This approach may be appropriate for vessels of different dimensions using the same type of gear.
Σ (Vessel tonnage*days fished)	As above, the assumption is that a larger vessel exerts a higher fishing intensity because of the increased size of net that is supposedly used.

* Some effort definitions define searching time as opposed to actual fishing time (i.e., when the gear is actually deployed) as an important component of fishing time at sea- e.g., purse seiners.

In general, the use of fishing effort in resource assessment can be divided into 4 main modalities:

- Production modelling
- Composite production modelling (see Annex 1)
- Swept area estimates
- Delury estimates.

These will be discussed briefly in the next section.

2) Measurement of fishing effort

Several sources of effort data are identified; collected by:

- a) Port interviews
- b) At-sea observers
- c) Log books or compulsory daily reporting by radio
- d) Patrol vessels
- e) Shore-based radar or satellite monitoring

Further material on this issue is presented in the supplementary material distributed to the meeting and in the annex to Caddy (1998), and will not be discussed further here.

3) The definition and measurement of fishing effort and intensity

Effort units.

In trying to reconcile the effort fished with the fishing mortality exerted, we fit the relationship:

$$F = q.f \dots\dots 1)$$

This is more difficult than it seems at first sight, and the problems of calibration that result are often ignored. Rarely is the catchability coefficient q , a constant, fixed over time, and q may also vary spatially. One distinction to bear in mind, is that regulating fishing pressure by controlling fleet fishing power or days fished is often referred to as an 'Input control', while regulation by quotas is 'Output control', and hence relies the ability to detect changes in fishing pressure from an analysis of outputs (catches, size frequencies etc): inevitably an uncertain process if no effort data are collected.

As Cunningham and Whitmarsh (1980) mentioned, fishing effort is invariably measured nominally at first, but rarely is the effort made to convert it to a direct measure of fishing mortality, which needs it to be converted to fishing intensity. Stock assessments in the NE Atlantic have been focussing almost exclusively on output control; (i.e., stock assessments are based on catch quantity and composition; later analysed by VPA or length-based analyses). However, economic analysis continues to rely on effort and capacity measures (e.g. Greboval 1999), hence an unfortunate divergence between stock assessment and economic analysis has resulted.

Two definitions of fishing effort are in common use:

- (a) 'Nominal fishing effort' is measured in terms of the quantity/volume of resources devoted to fishing, either in monetary or physical units, and:
- (b) 'Effective fishing effort' as a measure of fishing mortality, and is intended to be proportional to the fraction of population biomass extracted by fishing.

This distinction is reflected in the differing uses and formulation of the concept of 'fishing effort' by (a) stock assessment workers, and (b) in economic analysis of fleet capacity; (see section below). To our advantage, a direct regulation of allowable fishing effort (days at sea) may be more practical for OUs consisting of inshore fleets or day-boats, than it is for vessels or OUs that remain at sea for long periods. For these, satellite tracking or observers on board will probably be required to get a good measure of effort expended. The number of boats leaving the harbour daily is more easily monitored, and a control on number and duration of fishing trips by (for example) allowable days of the week when fishing is permitted to occur, is at least feasible. For vessels that carry out longer trips, log-books will be required, but satellite monitoring or shore-based radar and obligatory daily reporting by radio seem the few feasible options for controlling the fishing effort directly, unless observers are used, or a MCS vessel continually patrols the fishing grounds: methods rarely employed on small vessel fleets in the Mediterranean.

The relationship of fishing effort to other variables

A series of definitions of terms related to fishing effort is provided in an annex to Caddy (1998). Cunningham and Whitmarsh (1980) suggested that catch (C) is a function of the mean stock abundance or density ρ , and the effort exerted, f ; i.e., $C = \rho.f$. Substituting $F = q.f$ and rearranging,

they proposed that $\rho \cdot q = C/f$: the mean catch per unit of nominal effort (CPUE). The significance they draw from this relationship is that if either density or fishing power are constant, the other variable can be measured in terms of the CPUE. The idea is that if the fishing power is known and constant, changes in CPUE measure changes in fish abundance, while if stock abundance is constant, CPUE measures changes in fishing power. In actual fact neither assumption can be made safely, hence the requirement for some independent measure of either fishing pressure or stock size to supplement a monitoring of commercial catch rates – hence the priority given nowadays to biological sampling and analysis of research vessel survey data – but not at the expense of fleet/effort monitoring!

Fishing intensity

Fishing intensity = (fishing effort)/(area of fishing grounds), and fishing intensity f' will more closely reflect the fishing mortality exerted in a Management Unit than will a measure of fishing effort (Table 2). Days out of port, days fished, summed HP or tonnage, or even number of hauls may be used. (One particular use of fishing intensity data is described in Annex 1).

The problem in comparing two fisheries in different areas fished by the same OUs, is that a unit of effort expended on a small fishing ground exerts a disproportionately larger fishing mortality than on an extensive ground.

Thus, fishing intensity $f' = f/A$2), where A = stock area fished. Especially if comparisons of performance are to be made between different local grounds, it would seem wise to make comparisons in terms of fishing intensity; especially if the areas fished are of different dimensions. This approach leads logically to the Baranov area-swept approach, which attempts to measure the fishing mortality F resulting from 1 unit of effort exerted, as the ratio of area a swept by 1 unit of effort the gear, to the total stock distribution area or area of fishing grounds A , using a gear of selectivity C as: $F = a \cdot C/A$.

This Baranov (1918) approach is rarely used in assessments since it rests on the assumption of random stock distribution, but can be useful in envisaging the impact of gear on the bottom habitat. Starting with Baranov's equation; $N_1 = N_0 \cdot (1-P)^f$ - where P is the real intensity of fishing, and N_0 and N_1 are the initial number and the survivors after fishing. Caddy (1975) defined $P = c \cdot a \cdot p/A$, where a = area swept per day, A = area occupied by the stock, and c and p are the probabilities of capture and retention by the gear respectively, of organisms in its path. It is unlikely however that values of these parameters will be readily available. Although in theory we could define effort units in terms of the number of gear sets or the number of hours towed, such an approach is impractical unless excellent data are available, and would involve monitoring individual sets of trawls or other gear. Hence, measurement of effort in days fished or days on the grounds is more generally applicable. The Baranov (1918) approach may however be adapted to considering physical impacts of fishing on both the fishing ground and on a sedentary or territorial resource where effort is concentrated onto high density patches.

Whatever the case, GIS methodologies may be usefully employed in analysing and displaying log book data or observer sightings, so as to delineate the fishing grounds being fished. Where the depth distribution and distribution pattern of a species on a narrow shelf is well known from (e.g.) MEDITS survey data, an estimate of A can be bathymetrically defined with relative precision from the species depth range and area of shelf lying within reasonable access from the port. Calculating the 'friction of distance' or the approach used by Caddy and Carocci (1999) to estimate how effort is distributed with distance, together with plotted data from MEDITS, may provide a better idea of the likely commercial effort distribution patterns if log book data are unavailable. The distance of

the ground from the port(s) and the steaming speed and time to and from the grounds, could lead to more precise estimates of fishing time if that is needed.

Fishing vessel/fleet capacity

As defined by IATTC (1999), “A vessel’s carrying capacity is the maximum tonnage (of tuna) it can hold in its freezing wells, and the carrying capacity of the fleet is the sum of carrying capacities of all of the vessels in that fleet”. This definition provides an upper limit to harvesting pressure, given that it will be rare that all vessels return full from all trips. Obviously this measure is more relevant to economic analysis, in that it only converts into a theoretical upper limit to fishing mortality, but not the mortality rate actually exerted. In fact, a fleet returning in two separate years with the same catch may have expended different effort units (and hence exerted a different fishing mortality), if abundance differed in the two years. In this sense, the cost of unused capacity of a fleet is a measure of economic overcapacity, in that a smaller vessel, or one with a smaller hold capacity could take the same harvest, and the measure of overcapacity would be given in terms of the lower cost of harvesting by this second vessel. In contrast, WWF (2000) noted that a ‘physical’ or ‘effective’ overcapacity may also be defined: this presupposes that if the allowable harvest or TAC can be taken with only x% of the fleet hold capacity occupied, then the degree of fleet overcapacity would be (100-x)%.

As must be evident, this second measure can be related to the fishing effort exerted, but in years of high abundance, a given degree of physical overcapacity will be achieved at a lower level of fishing mortality than when the resource is scarce. As such, the actual hold capacity provides a useful secondary indication of the potential for overfishing but does not directly measure the fishing mortality on the stock. Fishing capacity will not be further discussed here, except to note that a system of regulations and a state of stock depletion that results in a very low % of the hold capacity being used, is evidently economically inefficient given the high investment in catching capacity. The proportion of the hold capacity used could then be a useful index of the degree of overcapacity existing in a fleet for a given resource, and should be taken into account in designing vessel replacement criteria. (Recall that vessel age structure shows that many fleets contain boats introduced more or less in the same year under a vessel subsidy or programme – e.g. Caddy 1998 – which is not the optimal strategy for adjusting total effort to available fisheries productivity!!).

The overall conclusion seems to be that a discussion of fleet capacity must be focussed primarily on economic considerations. This will not be discussed further here, except to note that the actual % utilization of hold capacity is inversely related to the overcapacity of the fleet the vessel is a member of, since evidently with a high exploitation rate and individual catches will be reduced, and holds will only be filled after long trips.

Fishing power

The usual assumption will be that individual vessels in an OU have the same fishing power, so that their effort units are additive. This will not be always the case as will be evident from the following, but may be a reasonable approximation in some cases. Even if it is decided to calibrate the fishing power of individual vessels in an OU, the OU presumably still has another function, as a category of vessels that particular management provisions may apply to, within the framework of the fishery regulations that apply.

Hilborn (1985) proposed a vessel’s fishing power as a component of the catch equation as:

Catch (C) = Abundance x Effort x Fishing power = N.f.P ; i.e., $P = C/N.f.$ The question that arises is how to assess the power of fishing boats in a fleet, given that this varies considerably.

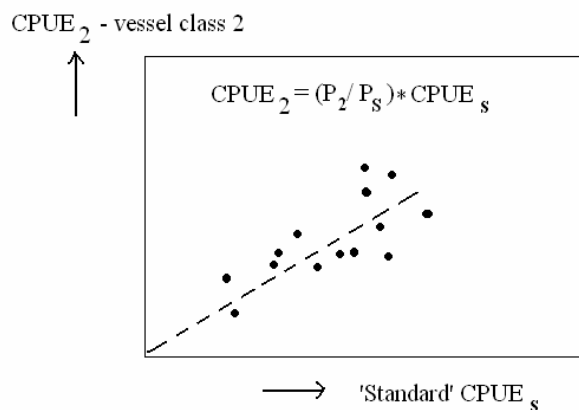


Fig 1. Conventional (Gulland's method) of evaluating fishing power of fleet class 2 in relation to a standard vessel category \underline{s} assumed to be of constant fishing power.

The first conventional method of assessing fishing power was that proposed by Gulland (1956); namely to compare the catch rates under comparable conditions on the same grounds, of each fishing vessel/gear class against a standard vessel/gear type, class or category. The standard vessels were often of an older design, e.g., side trawlers, that had not changed mechanically over a long period: hence its fishing power was expected to be constant (Fig 1): a conclusion that is difficult to justify nowadays, since 2 major components of fishing power are now recognized as fish location and navigational electronics and skipper's skills, and these can fit on all vessel categories! This approach nonetheless, looks for functional relationships between vessel horse power (HP) and tonnage (GT): such a relationship may be derived (e.g. Garcia-Rodriguez et al. 2006) as $HP = a \cdot GT^b$ or between GT and boat length.

Sanders (1983) pointed out that in theory, fleet effort = $\sum P_i \cdot f_i$: with boat effort f_i summed over individual boats i in the fleet, each of a different fishing power P_i . This illustrates the theoretical importance of the fishing power estimation. Although fishing power is usually estimated in relative terms (to other vessels), Sanders suggested that an absolute fishing power P' may be estimated if an estimate of gear efficiency (c/n) and area of influence \underline{a} of the gear, are available, as $P' = a \cdot (c/n)$, where c = catch and n = number of fish. An example is given from Sanders in the box below. This illustrates that this method of calculating fishing power is related to the area swept measure just discussed, and like Baranov's approach, is effectively independent of fish density and hence potentially biased since fish are rarely distributed randomly. This is different from the usual method of estimating 'relative' fishing power, where the fish locating ability and other skills of the skipper play a major role, and hence an 'absolute measure of fishing power' is rarely attempted.

Example of the estimation of absolute fishing power (Sanders 1983).

Data inputs:

Distance between trawl boards: 0.069 km
 Duration of trawl shot: 2.9 hr
 Vessel towing speed: 3.7 km/hr

Assume trawl efficiency = 0.25 (*)
 Area of influence of the gear = $0.069 \times 2.9 \times 3.7 = 0.74 \text{ km}^2$
 Absolute fishing power = $0.74 \cdot 0.25 = 0.185 \text{ km}^2$

(*) Shrimp trawls were quoted by Sanders as having an efficiency of 0.55-0.68 for shrimp and 0.25 for fish.

More often nowadays, a range of variables that may influence fishing power are all collected, and used to fit a Generalized Linear Model (GLM – Nelder and Meade 1975, McCullagh and Nelder 1989; Chambers and Hastie 1992). This procedure can incorporate any of the factors which characterise a vessel, its gear and its captain, which are believed to influence the fishing power, when expressed in terms of the observed catch rate $U = \text{CPUE}$ that results. Thus, Hilborn and Walters (1992) defined the catch rate by time t and vessel class i as:

$$U_{ti} = U_{11} * \alpha_t * \beta_i * \varepsilon_{ti}$$

- where U_{11} is the catch rate by the first vessel class in the first time period, α_t is the stock abundance in year t relative to year 1, β_i the efficiency of vessel class i relative to vessel class 1, and ε_{ti} is a factor accounting for the deviation between observed and expected catch rates; (other factors can be added to this equation if data are available and they are believed to be relevant). The above equation can be converted into a linear statistical model and fitted, by taking logarithms of the individual terms. Hilborn and Walters (1992) found the GLM framework to be particularly powerful for analysing the interaction between a wide range of causal factors, including spatial fishing areas, the presence or absence of equipment such as colour sounders, etc., but they caution that errors can arise if catch rate is not proportional to abundance.

Another example of this approach was provided by Stocker and Fournier (1984), who used it to correct the observed catch per standard unit of effort in a trawl fishery, using data on vessel class, gear type, and percent catch of target species. They found that fishing power and gear type had a minor influence on the catch rate. Vessel tonnage also had a relatively minor effect: the percent catch of the target species was a more influential variable. This type of fine-tuned analysis should be carried out where it is possible to collect fairly complete data on individual fishing units.

These several last-cited authors agree with other studies of this kind, that the fishing skills of the skippers play a major role in determining the overall performance of a vessel; often significantly overriding the effect of other variables such as horse power or tonnage. Comitini and Huang (1967) found for example, that the difference in catch rate between an ‘excellent’ and an ‘average’ skipper in the Pacific halibut fishery was 22%. In general, where skipper skills vary significantly across vessel categories that are not too different in size, this may be the overriding factor. It is possible therefore that correcting effort units for vessel category alone may introduce major changes in the calibration and the overall effort estimation, so that standard tonnage and horsepower corrections may overestimate technological differences and minimize the influence of fish-locating technology and skipper’s skills. Later, a more empirical approach is suggested that is based on overall seasonal performance of vessels sampled for catch/trip and number of days out of port, which does not explicitly consider technological differences, except perhaps for categorising vessels into classes.

A study on the fishing power of shrimp trawlers (Prawitt et al. 1996) suggested one generalization for fisheries where catch handling time on deck, or searching time, are a significant proportion of time on the grounds. While engine horse power is the most important variable for beam trawlers, for shrimping where catch sorting is laborious, a lower towing speed and lighter gear are used compared with targeting finfish, where heavier gear and higher towing speed are needed but less time is spent sorting the catch between hauls. The European Union was reported by these authors to calculate fleet fishing effort as $\sum a_i * J_i$ and $\sum a_i * P_i$, for $i = 1, 2, 3 \dots n$ vessels where a_i is the number days at sea of the i th vessel, J_i is the gross tonnage of the i th vessel and P_i is the engine power (kW) of the i th vessel. Prawitt et al. (1996) found that these effort units, i.e., “summed vessel tonnage x days at sea” and “summed engine power x days at sea” were not reliable measures of the effective fishing effort (*) exerted by a shrimp fishery. They found that none of the examined vessel

characteristics had a significant effect on the fishing power of shrimpers, which is in contrast to some other studies carried out on fishing power: (e.g. Gulland 1956, Guichet 1975, Houghton 1977, Houghton 1977, Large and Bannister 1986, Podesta 1987, Biseau 1991). Again, the substantial differences between performance of vessels (a range of fishing power of 0.76-1.43 was noted), seemed to be mainly due to differences in skipper skills.

Technological creep

One of the more difficult aspects of effort regulation has been the progressive increase in fishing power over time due to technical improvements of fishing gears, vessels and skipper skills, and their increased ability to locate fish and specific fishing grounds more accurately: often to within several metres. Various estimates of this factor have been made. Rijnsdorp et al. (2006) estimated overall increases of 1.6-2.8% annually for the fishing power of beam trawlers on North Sea flatfish; noting that not only fleet replacement, but engine overhaul could lead to increases in fishing power. Europe's fishing fleet has been estimated to have improved in fishing power by 4% / yr over the last few years. In theory, this should have to be matched by a rate of decommissioning of at least this amount for fishing mortality rates to stay the same. Under the new CFP, funds for fleet modernization are reported to have been withdrawn, but until recently, the budget set aside for fleet modernisation was reported as roughly twice as large as that for decommissioning, with a four-fold increase in the modernization budget in the latter half of the 1990s. Hence www.jncc.gov.uk/page-1569 reported that fleet capacity has increased dramatically over the last few decades.

Other types of gear

The foregoing discussion has been largely focussed on towed gears such as trawls, rapido's or dredges, but other types of gear may have specific areas of action and measurement units. Some examples of units used for measuring effort of other gear types is provided in the ancillary material and in Caddy (1977). One author, Treschev (1971), proposed the use of swept volume as a measurement of fishing effort.

However, because of its theoretical nature, Treschev's approach was not accepted by ICES, (but see Van den Broucke et al. 1973). Although this approach does allow a discussion of fishing efficiency of widely different types of gear, swept area estimations are the only related approach to receive fairly wide acceptance.

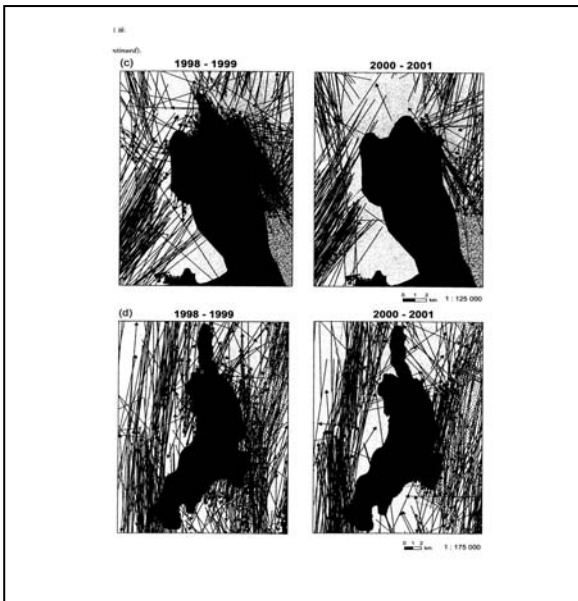
Non-uniform distributions of resources and effort.

Die et al. (1990) considered the frequent situation where the fleet expanded its area of operation over a series of years to cover a progressively larger proportion of the stock area, and noted that fish are not uniformly distributed, and fisheries tend to develop by initially exploiting areas with highest concentrations. Caddy (1975) found that scallop populations are contagiously distributed in relatively dense patches, and similar phenomena have been reported for groundfish from Taylor (1953) onwards. Fleets fishing scallops or aggregated finfish stocks direct their effort at the highest density patches, and are aided in doing this by experience and nowadays by sophisticated sounders. Seijo et al. (1994; 2004) developed a suite of fisheries models to explore the consequences of non-uniform distributions of fish stock and fishing effort, and the existence of non-random or non-uniform distributions has now become well accepted (See Figs 2 & 3).

Fig 2. Showing non-random, clustered fishing effort tracks in each of 4 years on two trawl sites with a rocky patch (black) on the US west coast, before and after introduction of regulations in 2000 to reduce the size of footropes, and hence discourage trawling on rocky areas. The two left-

hand figures show fishing on the black rocky area with 'rock-hopper' type of gear before, and on the right side, after the banning of heavy bottom gears (from Bellman et al. 2005).

Concentration indices



One explicit way of documenting the distribution of fishing effort is through concentration indices (e.g., Rothschild and Robson 1972; Robson 1987). If the stock area can be divided into (say) 10 or so sub-areas, for which effort, catch and catch rates can be determined independently, a concentration index I_r can be defined in terms of the sample estimates of the mean values of catch, CPUE and effort, and the variances $\text{Var}(x)$ of catch rates and effort levels for the subareas, defined as:

$$I_r = \left[\left(\frac{1}{n} \cdot \sum c - \left(\frac{1}{n} \right) \cdot \sum c/f \cdot \left(\frac{1}{n} \right) \cdot \sum f \right) \right] / \text{Sqrt} \left[\text{Var} (c/f) \cdot \text{Var} (f) \right]$$

This index is centred on zero if CPUE is not correlated with fishing effort in the sub-areas, while positive values of I_r (more likely to occur), imply that either there is a concentration of effort on fish aggregations, or for some reason, that fish are concentrated on the areas currently being fished: independent data will be needed to establish which. Interestingly, negative values may occur for this index where species abundance (e.g. from MEDITS data) is, for a number of reasons, positively correlated with increasing effort (Caddy 2006).

In order to obtain estimates of fishing intensity, there is a need to measure the area of fishing grounds, or if this is not possible, the area of trawlable sea floor that is within the depth range of the target species or community. This area, A , may be estimated from GIS data bases/charts, or determined by mapping MEDITS data.

It is to be expected on narrow rocky shelves that shelf areas are not fully trawlable, so that the distribution of effort will be non-random and focussed heavily on areas which are safely trawlable, and where the stock is most abundant. Fig 2 from Bellman et al. (2004) illustrates why some local estimates of trawl intensity may receive 5-10 or more individual trawl sets per year in productive areas. This situation of course depends on migration of fish from surrounding areas onto the trawling ground, but if resources are restricted in distribution, the use of a Leslie–Delury depletion approach may be feasible (see e.g., Braaten 1969).

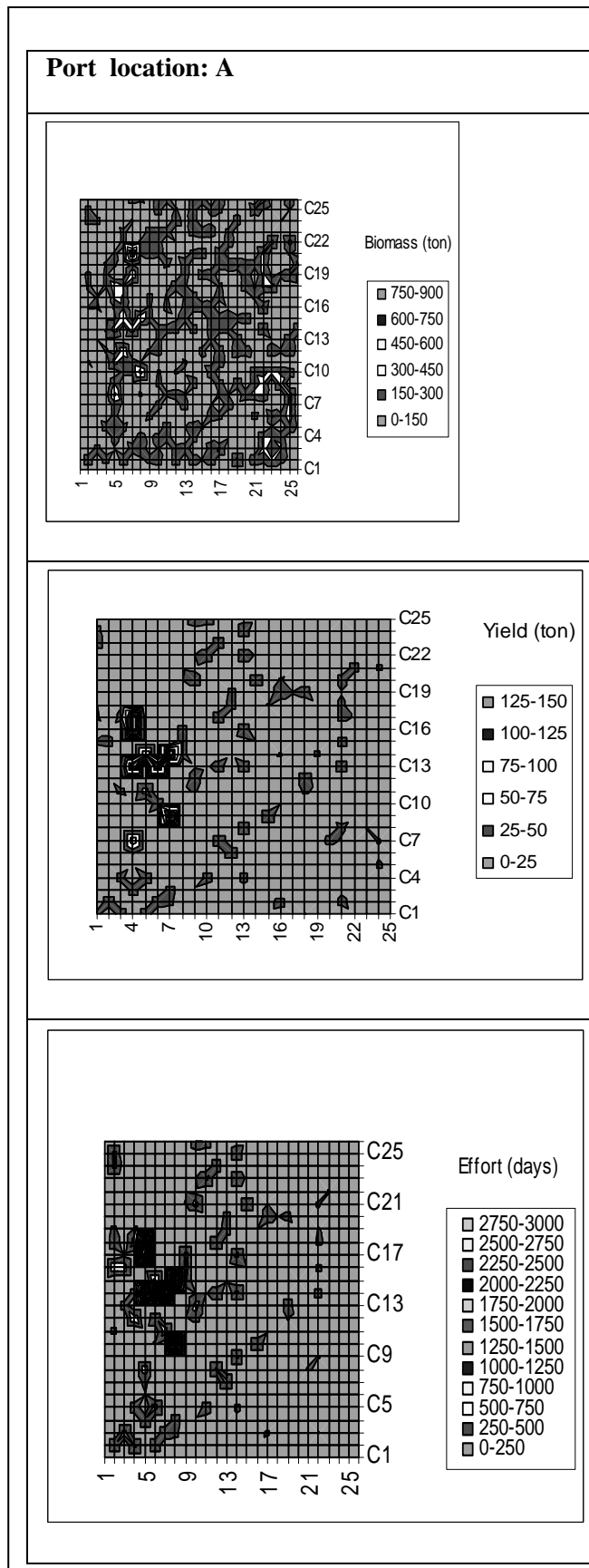


Fig 3. Simulated distributions of biomass, Yield and fishing effort, assuming contagious distribution of resources and effort directed onto the densest patches (from Seijo and Caddy in press).

Availability and catchability

Given the last few comments, the assumption that fishing effort is randomly distributed over the fishing grounds is unlikely to be correct, and it would be useful to clarify this issue. More recent information from telemetry or monitoring the activity of fishing vessels has shown that fishing is often intensely concentrated over limited areas of highly productive or easily fishable bottom (see Fig 1), and that fish may be attracted into this ‘killing ground’ from less easily fished areas around the trawling ground. This situation has been modelled by assuming that resource patches are either distributed as a bivariate normal and that effort is proportional to local density (Caddy 1975), or by assuming the resource is distributed as a negative binomial distribution (Seijo et al. 2004 and Fig 3).

Where fishing grounds are not uniformly fishable, the existence of areas of rough ground which are not easily exploited provides a conservation benefit, which may have to be aided by area closures. This illustrates the idea that there are two aspects to the estimate of catchability, q , namely the fishing power of the (vessel + gear + technology + skipper skills) we have already discussed, and the availability of the stock which may differ throughout its range. Fish on rocky ground may be exploited if they migrate into fishable areas, perhaps attracted by the presence of food displaced by the otter boards and foot rope. An area where availability to fishing is naturally low due to rocky bottom, may form a refugium for the

species concerned. Such areas may be approximately delimited by plotting the distribution of fishing effort, or from experience with MEDITS surveys. This difficulty of trawling on rocky bottom has evidently been overcome by the development of trawl gears that work over rough bottom, and Bellman et al. (2004) point to compulsory gear regulations banning such modifications to preserve these rocky refuges intact. For inshore fleets, availability of fish may also be inversely

proportion to distance from port (Caddy and Carocci 1999), and it could be useful to identify how fishing intensity changes with distance from the main port of the fleets concerned.

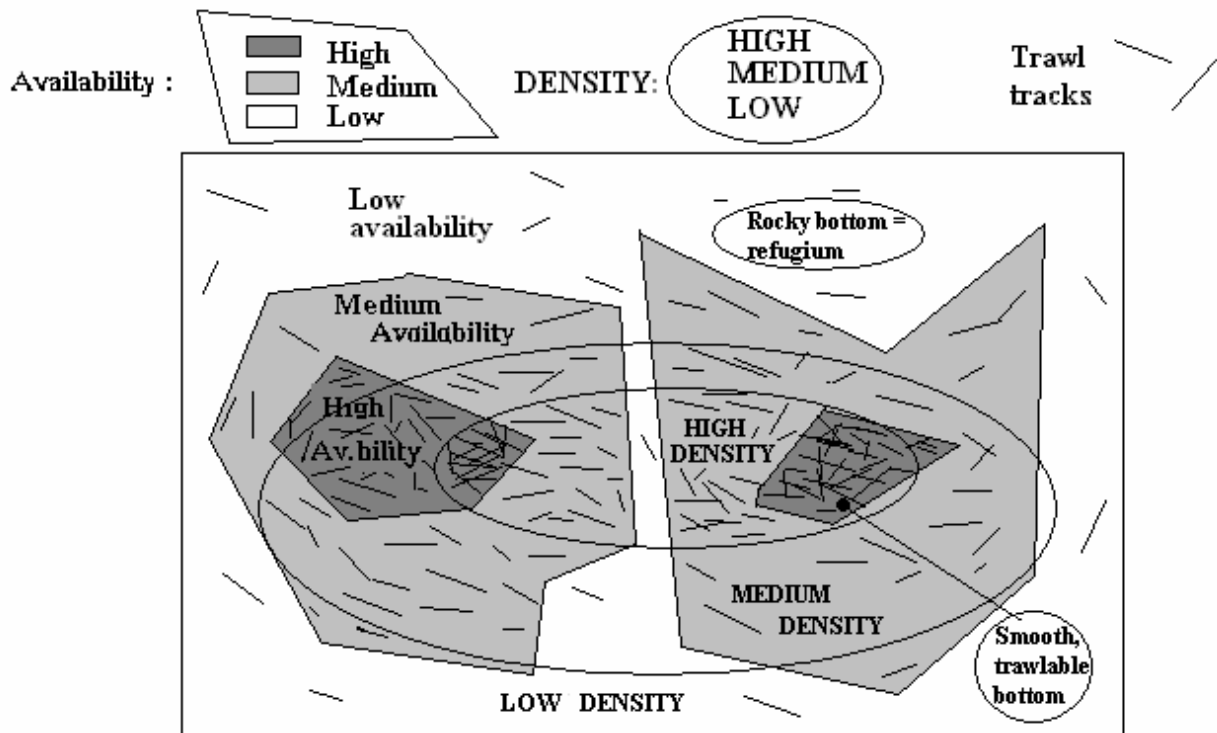


Fig 4. Hypothetical illustration of how stock density gradients (smooth ellipses) may lie across areas of bottom that are either readily fished with bottom gear (dark shading) or relatively unfishable (white areas). These latter areas may be regarded as 'refugia'.

It seems that there will still be the need to calibrate between fishing effort and overall mortality. In this case, the fishing intensity rather than effort per se may be a better measure of fishing mortality (Fig 5).

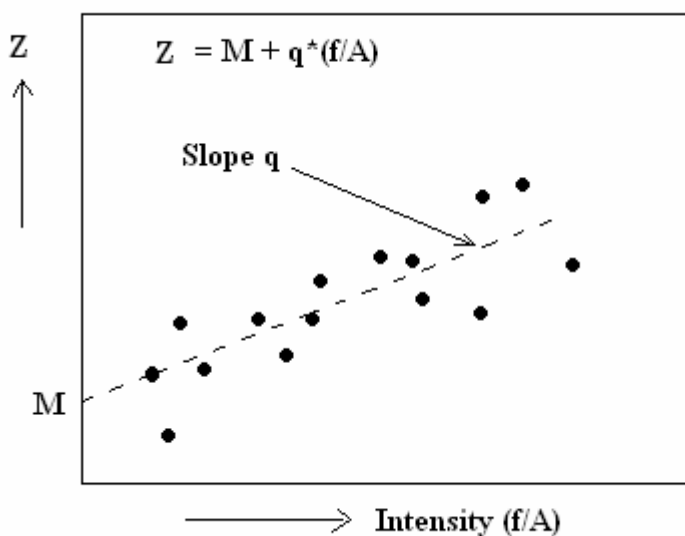


Fig 5. Estimation of overall catchability and natural mortality from a series of annual survey estimates (for Z) and effort measurements (for fishing intensity).

In the (not so!) hypothetical situation illustrated in Fig 4, fishing effort will inevitably be concentrated in the areas where not only are fish abundant, but their availability is high; i.e., the risk of gear damage while towing is low. The presence of high-risk areas is evidently conducive to the creation of refugia, and could be aided by gear regulations that make it difficult to use towed gear on rough bottom areas, or by introducing ‘sleeping policemen: obstacles to prevent trawling.

Effort definition in multi-gear, multispecies fisheries

The problem of implementing resource management by effort control for multispecies fisheries is a methodological one, where there is relatively limited experience to point the way, but where the alternative approach of catch quota control has not proved a success. One conclusion is that short-lived, high fecundity species can usually withstand a higher fishing pressure than slow-growing, low-fecundity species such as most selachians. As a result, as fishing effort increases, the species composition will inevitably change, which suggests to use species composition to measure overall fishing pressure. At the same time, effort control is to be used in the absence of other management methodologies, and the setting aside of closed areas or MPAs, to protect fragile environments and species should coexist with effort control, and can serve the additional purpose of protecting nursery areas and spawning refugia.

Tyler et al. (1982) proposed that the species assemblage in an area may be defined in terms of the resident species present year round, and these could be mapped by cluster analysis to identify depths/bottom types where homogenous species communities exist. Principal component analysis (e.g., Garcia-Rodriguez et al 2006) or cluster analysis (e.g., Garcia–Rodriguez et al. 2006; Jimenze et al. 2004; Caddy 2006) can be used to separate out assemblages. Caddy (2006) selected those species whose time series in the GRUND data base showed a significant negative correlation with the time series of fishing effort for Livorno-Viareggio, and following Tyler’s suggestion, demonstrated that production models could be constructed for the key assemblages after these have been discriminated by cluster analysis.

4) Use of fishing effort to assess fish stocks within a GSA.

The suggested stages in documenting the fishing effort exerted in a GSA are then:

- 1) Collect fleet information for a vessel registry for the Management Unit, including all OUs fishing within it, and use it for fishing power estimation.
- 2) Set up a monitoring procedure involving one of the following: fishermen’s log books, port interviews, at-sea observers, satellite monitoring or shore-based radar.
- 3) Estimate the relative fishing power of vessels, vessel segments and OUs.
- 4) Convert the estimates of fishing effort to fishing intensity; where possible mapping the distribution of fishing intensity in relation to home ports.
- 5) Calibrate measures of fishing intensity against estimates of fishing mortality F or total mortality Z (from e.g., *MEDITS* data).
- 6) Estimate the area of subsections of the fishing ground and estimate the fishing intensity on each.
- 7) Compare the spatial effort distribution with independent (e.g. GIS) estimates of the distribution of fishing grounds and fish stock communities, as revealed by e.g. *MEDITS* surveys.
- 8) Compare the fishing intensity by subsection with the *MEDITS* estimates of survey CPUE for both key demersal/benthic species, and with the overall ‘demersal/benthic species CPUE for the same area.

- 9) Fit composite production models between fishing intensity and CPUE for the categories mentioned in 8).

It is probable that not all of these steps will be possible, depending on data available, but should be attempted. This will allow:

- 10) A joint composite production model for all GSAs sharing similar productivities/ biological communities.

Production modelling.

Conventional dynamic production modelling approaches attempt to fit a statistical model of time series of catch and effort (or catch and overall mortality rate from biological sampling) that can be used for routine management of the stock. Evidently, these data sets will have to be combined if different OUs or fleet segments are fishing the same resource. This may not be possible for many GSAs, at least for a number of years, until and if time series of effort data and catch have accumulated. The alternative mentioned below and in the Appendix may be one of the few practical options available.

Composite production models

Although Garibaldi and Caddy (1998) found the boundaries of faunal provinces to correspond fairly closely to GFCM Divisions, smaller areas within each division may be considered relatively homogenous faunistically speaking, such that the possibility of intra-GSA comparisons remains a possibility. If a series of GSAs host similar faunal communities such that the same species occur in each, the data on fishery production per area can be combined and plotted against standard fishing effort/unit area, as discussed in more detail in Appendix 1. Variants on this approach were proposed recently by Halls et al. (2006) for inland water bodies. The following models assume equilibrium conditions, and are assumed to be fitted separately to different bodies of water for which estimates of CPUTA (Catch Per Unit Area) are available. These were fitted by the authors against fishing intensity measures as Numbers of fishers per km², but obviously some other measure of fishing intensity could be used [e.g., $\sum(\text{boat tonnage})/\text{area}$ or $\sum(\text{vessel HP})/\text{area}$ or $\sum(\text{standard days fished}/\text{area})$]. The assumption is that both the overall yield (all species, or all demersal/benthic species) would be plotted, and also keynote species). The conclusion of Halls et al. (2006) was that of the following models, the second and third models below would be the most appropriate for multispecies fisheries. The logic of the third model is that with higher fishing pressure, multispecies catches may remain relatively high despite the loss of slow-replacing species, hence the overall yield curve may not fall sharply with increasing effort, but will change in species composition (hence, how a ranking of species composition changes over time may also measure indirectly the fishing intensity exerted over a particular area).

1) Yield = $a*f + b*f^2$

2) “ = $f*\exp(a + b*f)$

3) “ = $a*(1-\exp(-b*f))$

- where a and b are the fitted parameters. The best model was judged on the basis of the R² and other statistical criteria: in general, the Fox model (number 2) providing the best fit, giving an estimate of maximal CPUTA and equivalent optimal fishing intensity for African lakes of 98 kg/ha/yr and 2.4 fishers/km².

A simple approach that could be used after fitting an overall multi-species yield curve

Although fitting multi-species yield curves has not been widely used, the logic is that overall multi-species yield varies much less with fishing intensity than for individual species. Once an overall yield curve has been fitted, a sampling approach at each effort level can be used to provide typical proportions of the total catch made up of the key species (Cobb and Caddy 1989, and Fig 6). These proportions can be used to fit approximate yield curves for the key species after calculating the proportion of the predicted yield at each level of fishing intensity made up by the species in question. A simple example where the overall yield model was fitted to combined landings for 2 species of shrimp is shown in Fig 6 from Caddy (1985). Here, overall landings of both species of shrimp were not distinguished in official statistics, but the proportion of the 2 species in the yield was determined by biological sub-sampling of the catch. The individual yield models were reconstructed later from sampling of species compositions over a series of years.

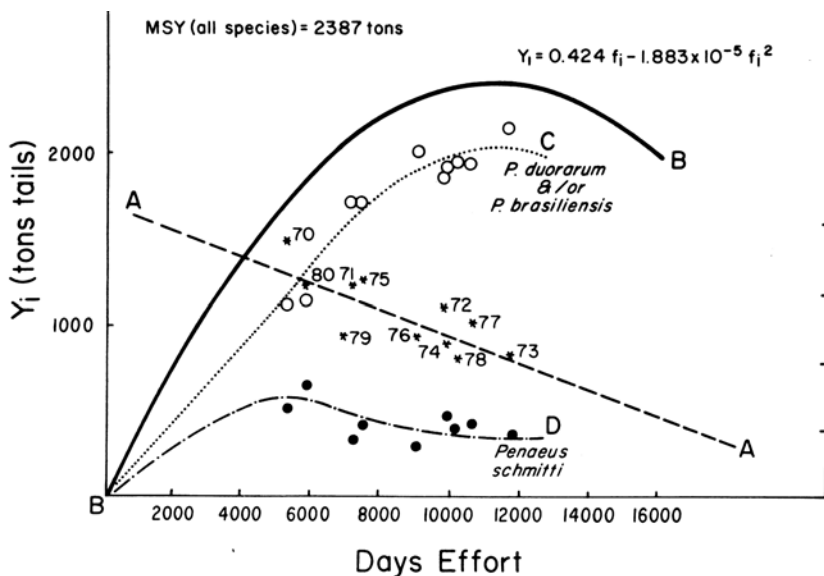


Fig 6. The fishing effort (or better, fishing intensity) versus overall multispecies yield is fitted first by a production model or composite production model for the GSA. At each point on the x-axis where fishing intensity was measured and species composition of the commercial catch is known, the predicted yield given by the fitted line B-B at that level of effort can be plotted for each of the key species from the proportion it made of the total catch of all species. The yield curve for these species can then be fitted separately for species or species components (from Caddy 1985).

Area-swept measures

Here we could include the use of overlays of the fishing intensity distribution with distance from port derived from log books or observers, and plotted in a GIS format. These would resemble the plots in Fig 3, and would allow the distribution of local fishing mortality to be estimated, and local fishing mortality rates calculated following the Baranov (1918) formulation mentioned earlier. (Of course, local Baranov mortality estimates for sub-areas are unlikely to correspond to those for the whole stock).

Returning to the suggestion of Shepherd (2003), it appears worthwhile to collect detailed 'track records' of the CPUE throughout the season for each boat, and use these to estimate the relative fishing power of individual boats directly, as the ratio of catch rates on the same grounds. A variant of this approach may be the only one easily available in measuring effort in multi-gear catches of the same species: select a dominant gear D for the species, and measure vessel and gear

characteristics accurately. It must be recalled however, that such a procedure does not allow 'technological creep' to be measured: i.e., an absolute increase in fishing power that affects all boat classes will not be picked up by this kind of calibration. Comparing actual effort against the overall mortality rate determined by analysis of biological samples may be the only way to estimate this. Nonetheless, the approach here would be to calibrate effort units for other gears E, F, by comparing catches of the same species, and calculating:

Total annual effort of gear E in units of gear D

$$= \text{Annual effort exerted by gear D} * (\text{Annual catch gear E}) / (\text{Annual catch gear D}).$$

A modification of this approach (Rijnsdrop et al. 2006) which measures temporal changes in q , requires that an overall annual estimate of fishing mortality and total catch for key species be available for the area. The relative fishing power of individual boats can be then estimated directly from the proportion of the total catch and the number of days at sea. They noted that the catchability depends on gear efficiency, on the distribution of effort in relation to fish densities, and on the skipper's skills. A new parameter ($F_{pue_{ij}}$) measures the partial F imposed by an individual vessel i per day in week j in which it fished d_{ij} days.

$F_{pue_{ij}} = (c_{ij} * F) / (C * d_{ij})$, where c_{ij} are landing of vessel i in week j out of the total quarterly landings C . Evidently, the value $F_{pue_{ij}}$ for each vessel is related to its fishing power. (Rijnsdrop et al. 2006)

This is similar to the approach adopted by Millischer et al. (1999), who defined the individual fishing mortality rate exerted by an individual vessel as:

$$F_{y,s,n} = F_{y,s} * (W_{y,s,n} / W_{y,s})$$

where $F_{y,s}$ is the overall fishing mortality, and $F_{y,s,n}$ the mortality component exerted on stock s over year y by vessel n to take catch weight $W_{y,s,n}$. While $W_{y,s}$ is the total weight of catch from stock s in year y . Evidently this last equation measures the proportion of the total mortality exerted by an individual boat as a measure of its fishing power.

A simple approach to effort control

Considering the issues just mentioned, and the paper of Shepherd (2003), it is noted that this author expressed concern over the TAC and quota system as applied in the North Atlantic. This 'is no longer adequate' in his opinion, and certainly has not halted declines in key stocks. The difficulties with the catch TAC approach he mentioned are:

- Assessments need to be updated annually
- Assessments must be accurate to better than (+-)10%, if TAC's are to be set correctly
- Under-reporting or misreporting is common, and undermines the whole system
- Discarding a species in a mixed fishery when its quota is filled is common practice.

He advocated some form of effort control, which has the advantages that:

- The level of fishing mortality is restrained directly,
- The level of fishing only needs occasional adjustments as fishing power slowly increases.
- Landings will vary from year to year, but do not need to be predicted, and it is not necessary to know stock size to a high accuracy.
- Occasional assessments require biological sampling of catches and surveys to correct for slow changes in fishing power, but assessments need not be annually.

- The discard problem will largely disappear, and the small fish problem will be addressed by closing nursery areas.
- Equity between fleets/countries will be easier to maintain, involving shares of an overall total of standard fishing effort units, though swaps or loans of effort allocations will be allowed between participants on a short-term basis.
- Days at sea is proposed as the most logical effort measure, but set at the individual vessel level.
- Due to slow increases in efficiency, compensating reductions will need to be applied from time to time, and he envisages these as requiring some state intervention.

He emphasized however that fine-tuning of the fishery by management is impossible under this framework, and anyway, TAC control has not worked as a conservation measure for most species. Management separately by key species will also be difficult to achieve, and as he said, is ‘largely a mirage’ under TAC control; simply increasing the discarding problem. Decommissioning of old vessels and their replacement by smaller ones, will be the best opportunity to correct for fishing power ‘creep’ mentioned earlier.

The key to his proposal is the maintenance of an accurate track record of both catch and effort for individual boats and combining these for fleet segments or OUs; if necessary, after intercalibration. The share of the total recorded catch taken by each boat for a given number of fishing days registered will provide the basis for the fishing effort calculation and eventual effort allocation – thus avoiding the need to do specific fishing power calibrations. The number of standard effort units, fv_i exerted by the i th vessel as a proportion of that for the fleet as a whole, is in roughly the same proportion as its catch is a proportion of the total catch.

It would be advisable however to calibrate the ‘standard catch rate’ from year to year, since this ‘standard effort unit’ will vary from year to year with this procedure, but should at least provide an estimate of the relative number of fishing effort units exerted by different boats (Table 3).

Table 3: Showing a simple method of estimating the number of standard effort units exerted by members of a fleet.

Boat (i)	Days out of port	% nominal effort	Sampling of mean daily catch (kg) through year		Estimated total annual catch (t)	Standard effort No. units exerted		% effort
1	120	14,1	150	Kg	18	93	11,0	
2	230	27,0	256	Kg	59	305	35,9	
3	145	17,0	75	Kg	11	56	6,6	
4	200	23,5	340	Kg	68	352	41,4	
5	156	18,3	54	Kg	8	44	5,1	
851					875 days	164	851	
					Standard CPUE = 0,1929 t/day			

Having done this type of calculation, it would be necessary in order to make further progress, to estimate an overall fishing mortality rate F for the key species components. The recent value for fishing mortality F_{now} can be estimated using analytical methods (catch curve analysis, size frequency analysis, length-based VPA, analysis of survey data etc). If F_{opt} is the target value of F which is believed to optimize returns to the fishery derived from independent yield per recruit or

spawner per recruit analyses, then the proportional reduction in fishing effort needed to arrive at F_{opt} in the above example if all boats took the same cut in standard effort is a total of $(875 * F_{opt} / F_{now})$ days fished.

At this point (Table 3), a decision will have to be made at the political level, whether the effort allocations will be measured in nominal effort units or be divided up between individual boats in terms of the standard effort units. In the above example, this would mean that boat #4 with 23.5% of the total nominal effort, in fact exerted 41.4 % of the total fishing mortality, but the least powerful boat #5 which exerted 18.3% of the number of days fished, in fact only exerted 5.1% of the fishing mortality caused by the fleet. The usual way to adjust these anomalies is to divide the vessels into recognized classes, set different rules for each, and use effort allocation to achieve the political objective for the fishery (i.e. to favour either a semi-industrialized, or an artisanal fleet). Going directly to allocations based on standard effort units, while egalitarian, will penalize the more efficient skippers. At the same time, where several jurisdictions fish a common resource, the national or regional allocations will probably have to be made in terms of standardized effort units. It may be more effective and socially acceptable to make fishing power adjustments slowly by imposing criteria for replacement of old vessels, requiring that they be replaced by those more homogenous with the existing fleet or equity.

DISCUSSION

The GFCM in its 27th Session, required an update, at subregional level and by geographical sub-areas, the inventory of operational units generating catches of shared stocks...” SAC was requested: “to monitor and fine tune, as necessary, the fleet segmentation as adopted in principle....”. The point emerges that the OU concept is subsidiary to the definition of GSAs and relevant geographical subareas, which as noted earlier, have to be defined first.

Management methods to control fishing power and effort

Setting long-term targets enters the political process, and criteria will need to be established involving a mixture of mainly technical measures (gear, access rights, closed seasons or restricted fishing areas), to supplement the effort cap. Shepherd (2003) noted that both fairness, shared equity, and stability of allocations are important principles for public acceptance of new regulations.

Technical measures to be applied in all years, but to manage fishing effort, 2 approaches are possible:

1) Short term management measures:

- Decide on the number of days of the week when fishing vessels can leave port to fish.
- Allocate each vessel a number of fishing days at the start of each season.
- If the spawning stock is depleted, close areas (temporarily?) where adult refugia occur.

Of course in the first option, individual fishers will probably demand the right to specify which of the x days per week they wish to operate – in this case they will be obliged to inform the harbour master when they propose to leave port.

2) Longer-term measures:

- Reduce fleet fishing power at the time of vessel replacement, or require 2-for-1 license swaps, or implement a buy-back scheme.

As suggested by Shepherd (2003), government intervention may be required to bring fleet size, at least initially, into line with productivity.

A first practical issue to consider where a GSA is fished by several fleets, perhaps from different jurisdictions, is to construct a fishing vessel registry including all OUs currently active in the area, and licensing fishing vessels by all parties. The major vessel characteristics and usual port of operation are recorded in the registry. Eventually, it will be desirable for each to use common criteria for license transfer between fishing power category in the case of vessel replacement, but this goes beyond the scope of the present workshop.

Where an absolute estimate of the number of days fished is impossible, a sampling strategy may be feasible where there are several ports and limited personnel for port interviews or sampling. On random days, at a fixed frequency per week, personnel will spend a day in port and register the return to port of fishing vessels; noting the number of boxes/kilograms of fish landed. This may also be checked with the auctioneer or wholesaler operating out of the port. On this basis an estimate of total days fished/year of a boat, and its contributions to the total catch from the GSA can be derived, based on the frequency of port visits.

A control of fleet fishing power is highly desirable, and several options have been proposed in the literature for this purpose:

- a) 1 for 2 swaps or 'build down' procedures
- b) Sleeping policemen
- c) Rotating harvest schemes
- d) Economic or social controls

These issues are suggested for discussion at a later date in a GFCM management forum.

Several options could however be discussed by this meeting:

- a) Direct (control vessel horse power, tonnage, days at sea)
- b) Indirect control (close critical habitats; institute seasonal closures – the Cyprus effect)
- c) Allocate effort units between vessels and fleets.

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Annex 1: A suggested research and assessment protocol for the use of the Composite Production Model (CPM) approach in the Mediterranean, and for production modelling using estimates of total mortality.

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A practical procedure is suggested for applying a Composite Production Modelling (CPM) approach to fish stocks and communities along the narrow Mediterranean littoral, and the advantages and difficulties of this approach are outlined. The use of a common protocol for standard subregional applications of the approach is dictated by the proprietary nature of research data in the Mediterranean, and it is suggested that after applying this approach to local resources, a joint meeting can be held to determine the possibilities for combining sub-regional data, if agreed, in a single assessment.

The CPM approach (Munro 1979; Caddy and Garcia 1983) was designed for use in tropical and sub-tropical shelf resources where small, discrete but similar coastal ecosystems fall under management of local fishing authorities, and are fished by 2 or more adjacent ports. As such, it presents some advantages from the Mediterranean perspective, where (with some exceptions) shelf areas are narrow, and local demersal fishery resources are harvested by local fleets with a high diversity in the catch. It is assumed that the basic productivity of the areas being compared is similar, which may be partially confirmed by species compositions, but is of course difficult to confirm now that fishing intensity is generally high. The return to a specific measurement of fishing intensity requires data on fishing effort and capacity, but also requires that the extent of fishing grounds be delimited in order to estimate the fishing intensity which is a direct measure of fishing mortality rate. Both of these local data sets are available, and can usefully be stocked in a GIS system, such as are in common use in the Mediterranean region. As mentioned later, for precautionary management, we are in a situation where we urgently need to have some idea of where the fishery is currently in relation to MSY conditions. The relatively long period during which effort has been generally high in many areas tends to preclude the use of a conventional production modelling approach which depends on an adequate range of fishing intensity. In the data being fitted, which is rarely the case for mature fisheries such as those of the Mediterranean. Some other advantages of CPM approach will emerge in the following, such as the ability to roughly reconstruct individual production models from a common model fitted to the data sets from individual areas. Such individual areas can be the GSAs or Management Units referred to often by GFCM, or the areas fished by a Local Operational Unit (LOU) around its home port.

The theory of production modelling classically considered the relationship between a variable 'fishing effort' and 'yield', and in its earlier form (e.g. Schaefer 1957, Gulland 1983) and was originally intended to provide what may be called in popular terms, a 'control curve' showing the response of a resource under equilibrium conditions to different levels of fishing effort. Subsequent developments of the theory first considered symmetrical or Schaefer production models (Schaefer 1957), and asymmetrical models such as those proposed by Fox (1975) and Pella and Tomlinson (1969) which became fashionable in the 1970's-80's, but were largely superseded by subsequent developments involving dynamic models since used in many fisheries which use quota control: an issue that is not specifically required for the Mediterranean. Hilborn & Walters (1992) expressed the opinion that production models that assume equilibrium conditions apply are risky and will usually overestimate the surplus production. Methods that aimed to approximate to equilibrium conditions by adjusting the effort data (e.g. Gulland 1983) did not provide reliable results, and it is generally agreed that dynamic approaches should be employed (See Punt and Hilborn 1986). However, the same authors expressed the opinion that "The one type of equilibrium analysis that

appears to be useful on occasion involves spatial contrast in fishing effort”, and this perhaps is relevant to the use of the CPM approach for spatially separate areas over similar but relatively short time periods over which changes in fishing power and strategy are limited. In some cases estimates of fishing effort are not available, and modifications to the equilibrium-based and dynamic approaches to production modelling have been suggested (Caddy and Defeo 1996; Defeo and Caddy 2001). One key advantage compared with most conventional production modelling approaches, is the return to fishing intensity rather than fishing effort as the key variable. Being able to confirm that the fishing intensity is related to fishing rate may be achieved if age composition data allows an estimation of the local rate of total mortality to be used in a parallel production model approach incorporating mortality rates.

At this point it may be noted that production modelling may be employed in two principal ways: most simply, to obtain an estimate of the Maximum Sustainable Yield and the equivalent fishing effort or total mortality rate reference point, or as a predictor of yield in the next or subsequent years under specified levels of fishing. For the purpose of this protocol, we are restricting our objective to the first of these in an attempt to determine where the fishery is currently in relation to the MSY reference point.

Most applications of production modelling have been for large-scale or industrial fisheries, where age or size-structured data are unavailable, and where spatial structure of the population could reasonably be considered homogeneous and which correspond to a unit stock. As illustrated by Die et al. (1990), this may not always be the case, and a fishery may expand progressively from a port as fishing intensity increases after stock components near the port become depleted. The reality that stocks are concentrated in contagious distributions which may follow the negative binomial distribution, (Taylor 1953; Seijo et al. 2004) and fishing effort may be concentrated on either high density patches, or limited areas where trawling is feasible, was the conclusion of Caddy (1975), and resource and effort contagion were built into a package of spatial models developed by Seijo et al. (1994).

That the spatial structure of the stock is important also becomes more evident when modelling approaches are applied to complex local inshore fisheries, such as are typical of Mediterranean demersal shelf resources. Here we may have to relax the requirement that the model is applied to a single stock or genetic sub-unit, since stock boundaries are usually unclear for fisheries on coastal resources. Given that the Mediterranean demersal resources are generally scattered along a relatively narrow coast under the impact of local ports, relaxing the requirement that the models be applied to a single stock may not be a serious impediment, and in fact has to be accepted whatever assessment methodology is used. The assumption is that the local resources and the ports dependent are an integrated production unit which may receive recruits from within or from outside, but where the adult populations tend to be close to territorial in their distribution, even though some species migrate seasonally to deeper water. Where this is evidently not the case, i.e., for resources that migrate along the shelf between adjacent administrative districts for example, combining the data and fitting models for larger units may be advisable.

Fishing effort or fishing intensity?

One comment on many applications of production modelling is that the independent variable, fishing effort, in the production modelling ‘control curve’, is not converted to fishing intensity f^* ; where $f^* = f/A$: where A is the area of the fishing ground, A . This may be because production modelling is usually applied to pelagic resources where A is essentially undefined, and because effort are often applied to schools of fish whose local density perhaps can be considered constant and not a measure of overall local density. Perhaps the lack of calibration of fishing effort to fishing

intensity, together with changes in catchability as the fleet expands from the central areas of the stock to its periphery, is one reason why production modelling using the Pella and Tomlinson (1969) approach shows different degrees of symmetry for different fisheries? To apply the CPM approach to demersal resources, we are comparing abundance changes between two areas supposed comparable in basic productivity; hence the use of fishing intensity as opposed to simple fishing effort is mandatory (the same effort applied to a local trawled resource evidently results in a higher fishing mortality rate than when applied to an extensive one). This adds 2 dimensions to the suggested protocol: those relating first to the definition of the fishing area, and to the definition of the fishing effort units used, as described later.

Differences in catchability q , and changes in q .

In many fisheries there is more than one vessel/gear category, however they are defined: it being assumed that the 2 or more categories of vessels fishing the local resource have different fishing powers, such that $CPUE_1 = a_{1,2} * CPUE_2$ (Fig 1), where $a_{1,2}$ is the relative fishing power of vessel/gear categories 1 and 2. After carrying out such a regression through the origin, the usual practice is to choose one vessel/gear category as the standard, and convert other fishing effort units to that of the standard. Then to add the sum total effort in a year over all vessel categories, and use the sum in the CPM.

One comment can be made on the classical production modelling approaches, notably that $F = q.f$ where q is assumed constant, but there is evidence that systematic changes in catchability occur, not just between vessel categories but also over time. Many studies have shown that fishing power of a vessel is dependent on the skills of the skipper, who progressively learns about the behaviour of a fish stock and introduces new technology, but also depends on improving technology used to locate and harvest a fish. A dramatic change in technology may require a recalibration of the vessel/gear units, although this is not easy to do without specific field experiments, as has been illustrated for example by the effort that must be put into cross-calibration of research vessel performance. Fortunately perhaps, when using the CPM, more than one yearly data point can be used per zone (Caddy and Garcia 1983), although the total duration of the data set is usually short, and hence changes of the order of 5-10% per year in fishing power are unlikely to exceed the error term of the estimate.

Modelling catch-effort data

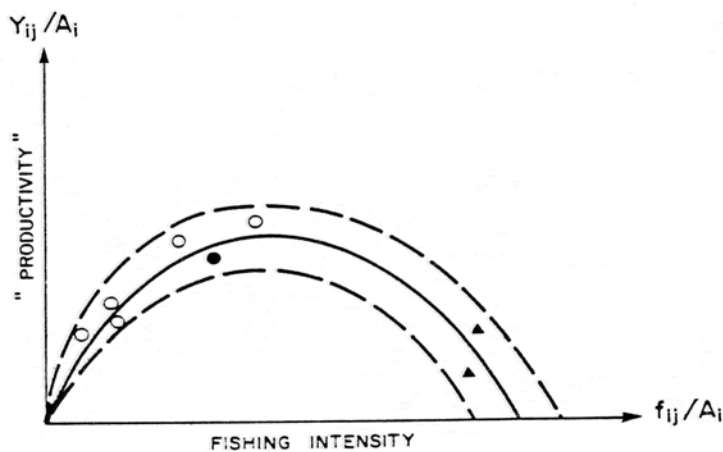
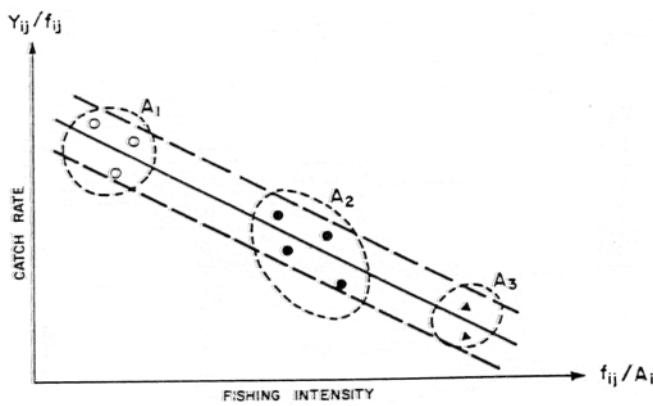
A common limitation of catch-effort modelling in many local situations is that a continuous series of catch effort data is not available over time, or information on catch and the effort exerted is only available for a given location at irregular intervals or comes from catch surveys carried out in the field. If however, these figures are collected separately for sub-areas where the extent of fishing grounds or stock areas are known, and if the basic faunal composition and productivity is similar for the different unit areas sampled, then Munro (1979) suggested that after conversion of effort and catch to area-specific measures for the individual grounds, they could be combined in a single catch-effort plot, and a production curve fitted to the whole data set. Caddy and Garcia (1982) suggested that this method could be extended to situations where a number of years of data exist for each locality.

Noting that effort exerted per unit area (whatever standard unit effort is measured in) – f_{ij} / A_i , is to be compared with the productivity per unit area of the specified grounds, Y_{ij} / f_{ij} : in both cases, for grounds $i = 1, 2, 3 \dots n$, and year $j = 1, 2, 3 \dots m$.

Caddy and Garcia (1982) noted that a regression line: $Y_{ij} / f_{ij} = A - B * (f_{ij} / A_i) \dots (1)$

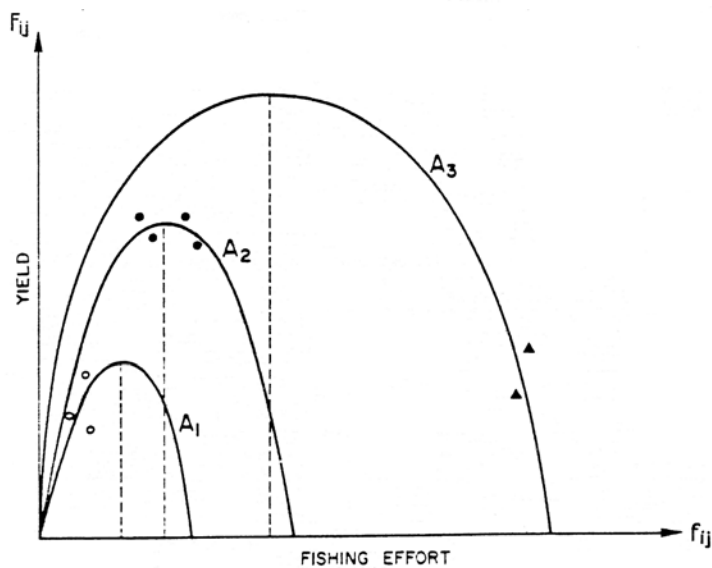
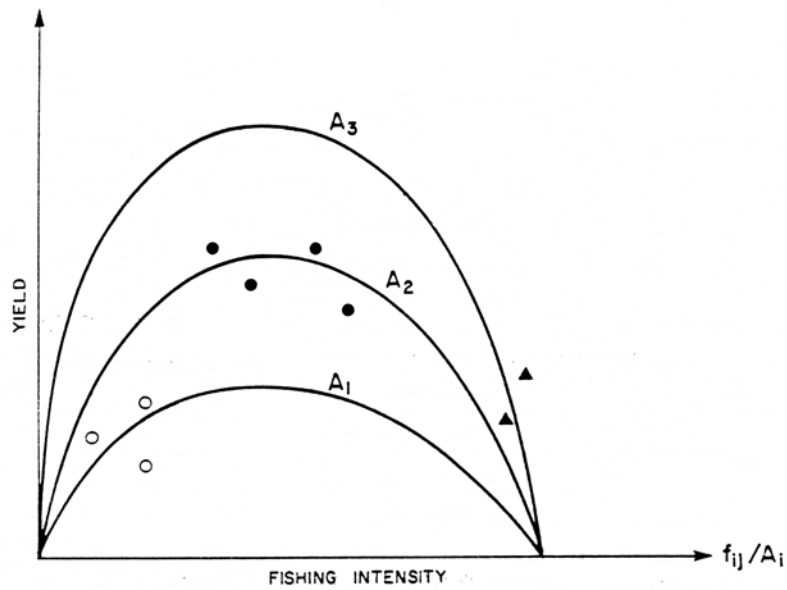
- can be fitted assuming a Schaefer model,
- or by fitting: $\ln(Y_{ij}/f_{ij}) = A - B*(f_{ij}/A_i) \dots \dots (2)$
- if a Fox or logarithmic mode is assumed.

Both approaches can be tested, and the best-fitting function adopted. Mathematical/statistical softwares or routines such as StatistXL can provide confidence intervals to the plots (Appendix Fig 1). In both cases we are assuming that as fishing intensity increases, the catch per unit area will decline. Of course the validity of this 'equilibrium' approach is dependent on basically similar productivities, and an assumption that changes from year to year are not very great. Nonetheless, as noted by Hilborn and Walters (1992), this approach to equilibrium analysis is probably less problematical than when data from a single area is considered over an extensive time series, since environmental conditions are probably similar for the years/areas compared within the regression, and a much more precise index of production is theoretically possible if the areas of operation are well-defined, compared with normal production models where they are not.



Appendix Figure 1 (above): Plot of catch rates against fishing intensity for 3 areas for which data are available for 2, 3 & 4 yr respectively. (Confidence intervals here are hypothetical). From Caddy and Garcia (1982).

Appendix Figure 2 (above): Composite 'fishery productivity' curve (yield per unit area) derived from App. Fig. 1.



Appendix Figure 3 (above): Individual production curves reconstructed from App. Fig. 2.

App. Fig. 4 (above): Production curves reconstructed in terms of fishing effort for the three areas increasing in size from A₁ -> A₃.

There will be a maximum production per area at a specified level of fishing intensity, which will correspond to MSY conditions, and defining the current state of exploitation of the fishery in relation to this is the main objective of the method, and given the problem of obtaining MSY conditions by other methods, we should be prepared to accept approximations for both Y_{ij}/MSY_j and f_{ij} / f_{MSY_i} . For the Schaefer model, the yield curve for all areas $I = 1,2,3,\dots,n$, can be estimated from pairs of independent and dependent variables in equation (1), to give an estimate of the fisheries production per unit area: $Y_{ij}/A_i = (Y_{ij} \times f_{ij}) / (f_{ij} \times A_i)$, and plotting this against fishing

intensity f_{ij}/A_i . The standard production per unit area for all grounds for which the estimates were combined (App. Fig 3), can then be estimated roughly by multiplying the unit production by the area of the individual grounds.

As applied in the OU context, we could, for example, be combining data for similar OUs fishing the same GSA, or if the GSA is large, combining data within it for a series of ports and their local fishing grounds, if this satisfies the constraints mentioned below:

Constraints:

As noted by Caddy and Garcia (1982) the basic assumptions of the method are:

- Similar biological communities and productivities apply to all sub-areas or GSAs combined.
- The first approach may be to combine multispecies data, or demersal/benthic resource data, to get an overall harvest rate, or to fit the same model to the key species in the zone, or to the species which are statistically similar in their reaction to fishing (Caddy 2006). Fitting this type of model to individual species may not be feasible for many of them due to low and variable catches. In this case, the procedure suggested in App. Figs 3-4 may be worth attempting; i.e., to fit the overall yield curve, then 'dissect' using the proportion of the catch at different levels of fishing intensity corresponding to the main species, and draw the yield curves for the key species by hand.
- Looking at the cross-correlation matrix for the multispecies yield, including the effort distribution overtime if this is available, could be a useful supplement to this approach when seeking to combine species belonging to the same faunal assemblage, since as noted by Caddy (2006), not all species are negatively correlated with increasing effort, for a variety of reasons.

Relationship of the method to the MEDITS or other trawl survey

Evidently, the MEDITS survey provides both an estimate of a standard catch rate in a given year and area, and may also be used to estimate the bathymetric range and extent of species or assemblage distributions. Plotting the survey results and estimating the area A_i independently of the estimation of fishing intensities by port and ground allows an independent estimate of productivity:

i.e.: 1) For each unit area, we could in theory, compare the commercial catch rate Y_j/f_j in area j with the effort exerted as estimated by port interview, observer or log book, exerted in the area A_j supporting the assemblage as estimated from the survey, or compare it with the area exerted within area A_j , which is the observed area of grounds actually occupied by the fleet. Probably the second is more appropriate, but the first approach may be more feasible.

What species should the model be applied to?

The model may be considered to be relevant for three types of application:

- 1) For the more abundant species as a single species model
- 2) For assemblages of species occurring together and showing a common response to fishing (As illustrated for example by a high correlation coefficient r in a matrix of r values between cpue trends for different species in a survey data set – see STATISTX software for example).
- 3) For the total catch, all species, from towed demersal fishing gears. This application needs to be tested on specific data sets, with independent monitoring to see if species composition has changed).

- 4) A serious problem may exist for very small management areas and actively migrating as opposed to territorial species.

Using the overall mortality rate as an index of effort

In Csirke and Caddy (1983) and Caddy and Defeo (1996), the use of total mortality as an index of fishing pressure was proposed where effort data are unavailable. This appears to be the case for some areas of the Mediterranean. Evidently, $Z = F + M$ also incorporates natural mortality rate, but if this does not vary significantly between years, but effort does, it may be treated as a constant to a first approximation. What we are dealing with here however, is not yield, but productivity of the population defined as $Z \cdot B_{av}$. We can then write: $Y_{ij}/f_{ij} = A - B \cdot Z_{ij}$: where the last value is the mortality rate in area j in year i . Abella et al.(1999) give an example of this approach.

Measuring overall mortality rate

In theory, one of a number of methods can be used to estimate overall mortality rate Z (See Ricker 1975; Sparre and Venema 1992). These approaches can be divided into two types:

- 1) Comparing the abundance of a year class in two successive years after adjusted for gear selectivity if necessary, in theory will allow the mortality over the last year to be estimated by the equation: $Z_{t, t+1} = \ln CPUE_t - \ln CPUE_{t+1}$. Unfortunately, this approach is very sensitive to changes in gear selectivity between the two years.
- 2) Catch curve analysis or other methods which depend on the rate of decline of numbers over the last n years in the fishery, estimates the ratio of abundance of two successive age groups as above. This ratio tends to be determined prior to, or immediately subsequent to full recruitment to the gear (depending on recruitment success): – i.e., is not a reliable estimate of mortality. However, when the abundances of a series of age groups are combined and compared with the catch rate for the same cohorts a year earlier, this can be an approach to estimating overall Z , referred to as the Jackson or Heincke methods by Ricker (1976). The problem in the Mediterranean with these approaches, is that most of the commercial catch is taken when the cohorts are not fully retained by the gear, so that a correction for selectivity is required, which is not very easily or accurately determined.

In other words, the ratio of the abundance of age 2 to age 3 fish in 2000 summarises mortality events that have occurred since 1998, in a similar way as the ‘equilibrium approximation’ of Gulland, which averages past effort over the last \underline{n} years of the fishery, where \underline{n} is also the average number of years a cohort passes in the fishery prior to full capture. In practice, both methods may provide approximate measures of mortality, if our main objective is to roughly locate the approximate position of the fishery over recent years in relation to MSY.