Measuring capacity in fisheries

FAO FISHERIES TECHNICAL PAPER

445

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PREPARATION OF THIS DOCUMENT

The realization that many world fisheries are either fully exploited or overexploited has resulted in increased attention being paid to the management of fishing capacity. While environmental factors have affected some fish stocks, excessive levels of fishing capacity is the primary cause of these declines.

The management of fishing capacity requires information on both the current level of capacity and some desirable or target level of capacity. However, measures of capacity had largely developed differently in various countries and comparisons between countries or even between different fisheries in some countries was not possible. To address this deficiency, FAO convened a Technical Consultation on the Measurement of Fishing Capacity in Mexico City, Mexico, from 29 November to 3 December 1999. It was attended by delegates from 56 Members of FAO, as well as a number of international observers. The key objective of the Consultation was to determine definitions of capacity that could be commonly accepted, and methods for deriving measures of capacity related to these definitions.

As a prelude to the discussion of the group, a number of papers were presented outlining current approaches used by member states to measure and manage fishing capacity, as well as papers proposing alternative means of measuring fishing capacity. Based on the experiences presented in these papers, the Technical Consultation agreed on a common definition of capacity, and on preferred means to measure fishing capacity. These conclusions are given in FAO Fisheries Report No. 615, published by FAO in 2000.

The papers presented at the Technical Consultation have played a pivotal role in the advancement of the study of fishing capacity. Many of the ‘alternative’ methods presented at the meeting are now becoming standard techniques in the measurement of fishing capacity, and a number of the papers presented at the meeting have been cited in subsequent studies of capacity. The interest in these original papers has increased over the last three years, largely as a result of these subsequent studies. This increased interest has led to the publication of this report, which includes 23 of the papers presented at the meeting. The papers presented in this report cover a range of areas, including theoretical considerations, case studies of current practice, and examples of alternative methods for assessing capacity.

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ABSTRACT

This Fisheries Technical Paper contains some selected papers originally presented at the FAO Technical Consultation on the Measurement of Fishing Capacity held in Mexico City in 1999. The 23 papers have been subsequently edited and are presented in four parts. The first part includes papers addressing theoretical considerations and definitions of capacity. The second part includes case studies outlining the existing practice undertaken in some member countries. These case studies do not necessarily represent best practice, but provide an overview of current practice. The third section includes papers that outline alternative methods for deriving output-based measures of capacity. In particular, the papers describe the data envelopment analysis and peak-to-peak techniques. The methods are applied to a number of fisheries for example purpose. The last section contains papers that outline alternative methods for assessing input-based measures of capacity. These include estimation of fishing power, hold capacity and bioeconomic modelling to determine optimal fleet sizes.

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PART 1: DEFINITIONS AND THEORETICAL CONSIDERATIONS

THE MEASUREMENT AND MONITORING OF FISHING CAPACITY: INTRODUCTION AND MAJOR CONSIDERATIONS

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Abstract: In this paper, major issues to be considered by the FAO Technical Consultation on the Measurement of Fishing Capacity are introduced. Definitions and main approaches to measurement and assessment are reviewed in relation to the requirements of the International Plan of Action for the Management of Fishing Capacity. Conceptual and practical difficulties to be addressed in measuring and assessing capacity, in general as well as in the case of specific fisheries, are also considered.

1. INTRODUCTION

This document was prepared in order to introduce and review major issues to be considered in the context of the FAO Technical Consultation on the Measurement of Fishing Capacity. It introduces basic definitions and major considerations for the measurement and monitoring of fishing capacity. The ultimate objective of capacity measurement is to provide information for the development of a management strategy that will ensure that fleet capacity is moving in the right direction. In this regard, it is important to estimate the magnitude of the difference between current and target capacity in order to determine the existence of overcapacity (or undercapacity), the severity of the problem and the appropriate steps and path that can be taken to bring capacity in line with the long-term target.

In Section 2, the issue of managing fishing capacity is presented briefly in relation to recent international efforts that led to the adoption of the International Plan of Action for the Management of Fishing Capacity. Related measurement and monitoring aspects were discussed by the Technical Working Group on the Management of Fishing Capacity (TWG) which met in February 1998 in La Jolla (FAO, 1998a). Definitions and main approaches and methods to measure and monitor fishing capacity are presented in Section 3. This section reviews and expands on the main conclusions of the TWG pertaining to the measurement and monitoring of fishing capacity. Specific areas for consideration by the Technical Consultation are presented in Section 4.

2. THE INTERNATIONAL PLAN OF ACTION FOR THE MANAGEMENT OF FISHING CAPACITY

The issue of managing fishing capacity has been raised quite recently in reference to growing concern about the spreading phenomenon of excessive fishing inputs and overcapitalization in world fisheries. The issue is essentially one of having too many vessels or excessive harvesting power in a growing number of fisheries. The existence of excessive fishing capacity is largely responsible for the degradation of fishery resources, for the dissipation of food production potential and for significant economic waste. This manifests itself especially in the form of redundant fishing inputs and the overfishing of most valued fish stocks.

Excess fishing capacity affects many domestic fisheries throughout the world and, in an even more pervasive form, many high-seas fisheries. The globalization of the phenomenon

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is illustrated by the relative stagnation of world marine catches of major species since the late 1980s. Evidence provided by FAO indicates that, in reference to all major marine fisheries, 35 percent are subjected to severe overfishing, 25 percent are fully exploited and 40 percent still offer scope for development. Demersal and other most valued stocks are generally the most affected.

At the global level, overcapitalization in world marine fisheries appears to be a relatively new phenomenon, dating from the late 1980s and following a decade of very intense fleet development. FAO data indicate that nominal fleet size seems to have peaked during the mid-1990s. However, actual fishing capacity may still be increasing due to technological development and the refitting of older vessels.

Essentially, the existence of excess fishing capacity is a result of the widespread tendency to over invest and over fish under open-access conditions. Overcapitalization in world fisheries also came about progressively as a result of broader and related factors, such as the:

- resilient profitability of fishing activities whereby technical progress and relative price inelasticity have largely compensated for diminishing yields in overfished fisheries;
- effect of the extension of maritime areas under national jurisdiction on private and public investment strategies and of related ‘nationalization’ policies, generally accompanied by sizable subsidization programmes;
- relative mobility of harvesting capacity, which allowed for a pervasive spill-over of excess capital among fisheries, both within areas under national jurisdiction and on the high seas;
- changing nature of the industry, which is increasingly competitive and capital-intensive, with markets that are now largely based on internationally traded commodities; and above all,
- failure of fisheries management in general, and of commonly used management methods in particular, such as total allowable catch (TAC) and other methods which aim essentially at controlling fishing mortality indirectly through regulating the catch rather than directly by controlling fishing effort or the harvesting capacity itself.

The FAO Code of Conduct for Responsible Fisheries recognized that excessive fishing capacity threatens the world’s fishery resources and their ability to provide sustainable catches and benefits to fishers and consumers. In Article 6.3, it is recommended that “*States should prevent overfishing and excess fishing capacity and should implement management measures to ensure that fishing effort is commensurate with the productive capacity of the fishery resources and their sustainable utilization*”.

In 1997, the FAO Committee on Fisheries (COFI) recommended that a technical consultation be organized by FAO to clarify issues related to excess fishing capacity and to prepare guidelines. Work undertaken by FAO on this basis (FAO, 1998b) led to the preparation of the FAO International Plan of Action for the Management of Fishing Capacity.

The International Plan of Action was adopted by COFI in February 1999, and further discussed by the FAO Ministerial Meeting on Fisheries in March 1999. The Ministers declared to “*attach high priority to the implementation of the International Plan of Action for the Management of Fishing Capacity ... and on putting into place within the framework of* *national plans, measures to achieve a balance between harvesting capacity and available fisheries resources*." [2]

The International Plan of Action (IPA) was elaborated within the framework of the Code of Conduct for Responsible Fisheries, as an element of fisheries conservation and sustainable management. The immediate objective of the IPA is for "*States and regional fishery organizations, in the framework of their respective competencies and consistent with international law, to achieve worldwide preferably by 2003 but no later than 2005, an efficient, equitable and transparent management of fishing capacity"*. The IPA further specifies that, *inter alia,* States and regional fishery organizations, when confronted with an overcapacity problem which undermines the achievement of long-term sustainability outcomes, should endeavour to limit initially at existing level and progressively reduce the fishing capacity applied to affected fisheries. On the other hand, where long-term sustainability outcomes are being achieved, it nevertheless urges States and regional fishery organizations to exercise caution.

The IPA is voluntary, and is based on a number of major principles of the Code of Conduct as well as on complementary principles. These include:

- a three-phase implementation: i) assessment and diagnosis; ii) adoption of preliminary management measures; and iii) a system of periodic reviews and adjustments; with priority being given to managing fishing capacity first where it results in unequivocal overfishing; and
- a holistic approach by which the management of capacity should consider all factors affecting capacity in national and international waters, further recognizing the need to properly account for mobility and evolving technologies.

The IPA specifies a number of actions to be taken urgently. Major actions are prescribed in reference to the main section of the document: assessment and monitoring of fishing capacity, the preparation and implementation of national plans, international consideration and immediate actions for major international fisheries requiring urgent attention.

Regarding the assessment and monitoring of fishing capacity, the IPA recommends*, inter alia*, that States:

- support coordinated effort and research to understand better the fundamental issues related to the measurement and monitoring of fishing capacity;
- proceed within the next two years with preliminary assessment of fishing capacity and with the systematic identification of fisheries requiring urgent attention at national, regional and, in collaboration with FAO, at global level; and
- develop appropriate records of fishing vessels and support the establishment by FAO of an international record of vessels operating on the high seas.

In adopting this International Plan of Action in February 1999, COFI further recommended that FAO organize a technical consultation on the measurement of fishing capacity before the end of 1999. This Technical Consultation is the fulfilment of that recommendation, and will serve as a basis for the preparation of technical guidelines that can

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[2] The Rome Declaration on the Implementation of the Code of Conduct for Responsible Fisheries, adopted by the FAO Ministerial Meeting on Fisheries, Rome, 10-11 March 1999.

be used by countries in their preliminary assessment of fishing capacity and for the systematic identification of fisheries requiring urgent attention.

3. APPROACHES AND METHODS FOR THE MEASUREMENT OF FISHING CAPACITY

The measurement of fishing capacity is in itself quite complex but has been made even more so by the proliferation and confusion of terms used to address this issue. Some of the confusion stems from the fact that fishing capacity can be addressed either by focusing on productive inputs or on production. Difficulties also arise from the ways the various sciences involved are looking at fishing capacity, its measurement and its assessment in relation to the specifics of fish stocks. It is, therefore, important to clarify some basic concepts.

3.1 Definitions

The following general definitions[3] were considered by the TWG: *Fishing capacity is the ability of a vessel or fleet of vessels to catch fish. Fishing capacity* (**capacity output**) *can be expressed more specifically as the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized, given the biomass and age structure of the fish stock and the present state of the technology.*

Capacity utilization can be defined in this context as the ratio of actual output (catch, landings) to some measure of potential output (**capacity output**) for a given fleet and biomass level. It is essentially a short-run concept.

Fishing capacity can be expressed alternatively in reference to fleet characteristics or as the ability of a fleet to generate fishing effort. In this context, economists prefer to use the related concepts of **capital stock** (vessels) or **capital services** (flow of productive services from the capital stock, such as fishing effort) and **capital utilization**.[4] Aggregate proxies are typically used to measure the capital stock which the fleet represents, e.g. gross registered tonnage or horse power. Capital utilization can be defined as the ratio of actual to desired levels.

The TWG noted several advantages to formulating the definition of fishing capacity in terms of catch: a) it is consistent with economic production theory; (b) it facilitates aggregation between fleets and between the harvesting and processing sectors; (c) it makes it easier to deal with complexities due to fisheries interactions, e.g. when the catch of one fishery is a by-catch of another; (d) it is more appropriate to artisanal fisheries as these fisheries can involve rapid changes in inputs, in the form of numbers of participants rather than capital defined *stricto sensu*, and (e) it makes it easier to determine optimal capacity for fluctuating stocks.

The TWG found it more relevant to define "target" capacity rather than "optimal" capacity, in deference to the wide diversity of objectives that might be chosen by policy-makers to ensure sustainability of fisheries and meet other needs. Thus, definitions of 'optimal' would be local and specific. The following definition was agreed upon: *Target fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized while satisfying fishery management objectives*

[3] All definitions discussed in this section may be referred to as "technologically determined", with capacity utilization being necessarily less or equal to 100 percent.
[4] For further details, see Kirkley and Squire (1999).

designed to ensure sustainable fisheries. It follows that excess capacity can be expressed by comparing current and target capacity output.

Overcapacity can thus be defined as a situation where capacity output is greater than target output. **Overcapitalization** will refer on the other hand to a situation where actual capital stock is greater that the optimum capital stock required to produce the target output. The 'optimum' can be defined in a technical manner as the minimum capital stock required, as determined by the production technology, or in an economic manner as the capital stock that will minimize the cost of producing the target output. The two concepts are related and could be equivalent under certain restrictive conditions.

It was suggested by the TWG that target fishing capacity could be better defined in terms of a range rather than a specific quantity or metric. It was suggested that optimal could be specified relative to outer boundaries. According to paragraph 7 of Annex II of the Straddling Stocks Agreement, the minimum standard for a biological reference point should be the fishing mortality rate that generates MSY. The following definition for **limit capacity** was proposed, in conformity with the direction in which international law is developing: *Limit capacity is the maximum amount of fish that can be produced on a sustainable basis by a fully-utilized fleet. Thus, the limit capacity corresponds to MSY.* Thus, the capacity which generates a level of fishing effort which puts stock beyond the F_{MSY} limit[5] is an upper bound on optimal or target capacity. A starting point would be to define the maximum fleet size corresponding to this limit fishing mortality rate. Other considerations may be used to determine the lower bound of a range of target capacity (precautionary approach, economic efficiency, social factors, etc.).

Indicators of capacity output, capacity utilization, capital stock and capital utilisation are many. Some are reviewed below. In some cases, and for relatively simple fisheries, one can readily find correspondence between input-based and output-based indicators. Indicators of overcapacity and overcapitalization are fewer as these require explicit reference to the resource constraint and to economic efficiency, at least in terms of cost minimization. Generally, target output capacity to target capital stock will be determined as a rather separate exercise requiring the consideration of resource status (e.g. an estimation of target biomass and MSY) and the consideration of economic factors (e.g. estimation of target capital stock required to catch target output at minimum cost).

3.2 Indicators of capital stocks and capital services

Various proxy variables have been used to monitor fishing capacity (as capital stock) on the basis of fleet size and major vessel attributes. The major difficulty is to identify the combination of attributes that best reflects the productivity of relatively heterogeneous fishing units. An indicator can be developed by weighting key vessel attributes (e.g. length, breadth and power). Other attributes of importance will be gear type and key characteristics, as well as vessel age and embodied technical change.

Accounting for fishing time allows one to monitor capital services. Fishing time can be accounted for as fishing days or days absent from port. Standardization methods need to be used to account for fleet heterogeneity. If nominal fishing effort is expressed as 'standard fishing days', actual effort can be compared to potential effort to derive an indicator of capital utilization for a given fleet. In the presence of regulations on fishing time, capital utilization

[5] That is, the level of fishing mortality that produces the maximum sustainable yield.

may be significantly lower than one if the fleet has few alternative uses. Even in the absence of such regulation, capital utilization may also be significantly less than one under specific conditions (adverse price, resource or weather conditions).

An alternative is to monitor capital stock directly in financial terms, e.g. by estimating the market value of all fishing units in a fleet. This would generally imply monitoring investments and disinvestments, while accounting for depreciation.

While the monitoring of these indicators is essential, the assessment of overcapacity and overcapitalization requires a definite linkage to the status of exploitation of the resource and the determination of target capacity and target capital stock.

3.3 Indicators of capacity output and overcapacity

The TWG discussed simple indicators of capacity and overcapacity that can be used with limited data in relation to basic fishery production models. The basic elements of such indicators are the number of vessels in each fleet exploiting a stock, the mean catch rates for each fleet, and the amount of time actually spent fishing by each fleet relative to the maximum possible if there were no constraints on fleet operation. These practical measures of capacity can be expressed in terms of a production-based indicator and a vessel-based indicator. These are easily developed for single stock fisheries.

To appropriately set a long-term target capacity, it is necessary to specify a target stock biomass. However, it is recognized that the long-term target may be difficult to estimate at any point in time, partly because future target capacity will generally be defined on the basis of present-day performance. As the fishing fleet moves along the adjustment path towards a preliminary estimate of a target, accumulation of knowledge and a better indication of changes in technology and other factors may result in continual updating of the ultimate target.

One way to approach the problem is to start with a TAC (either current or a long-term projection). The maximum that a given fleet could potentially catch (capacity output) divided by the target TAC is a measure of excess (or under) capacity. Target fishing capacity can be evaluated in reference to both the current and long-term target biomass.

Potential catch by each fleet under current stock conditions can be estimated as the product of number of vessels and mean catch rate, scaled up to a full-time equivalent based on the ratio of maximum time available to the actual time fished. The potential catch in the fishery is the sum of potential catches by all fleets. This can be compared to the TAC to give an indication of overcapacity by the current fleet. The indicator can be calculated under current stock conditions (TAC and CPUE corresponding to current biomass) and for long-term target conditions (TAC and CPUE corresponding to target biomass). A disadvantage is that it does not account for the ‘latency problem’, i.e. vessels not currently present in the fleet, which could enter easily when conditions change.

Another measure is based on calculating, using the same information, the minimum number of vessels needed to take the TAC. This approach may be particularly useful when there are several fleets that cannot meaningfully be aggregated into a single measure. The minimum fleet size required to take the entire TAC is calculated for each fleet. These minima can be compared to the actual size of each fleet to provide perspective on overcapacity. If any of the actual fleet size is close or higher than the minimum required, there will be strong evidence of overcapacity. Otherwise, further assessment would require calculating a composite index of boats needed by using a fishery-wide average catch rate. The method can be applied to current and long-term target conditions.

These measures are extremely simple rules of thumb, but should be capable of indicating the presence of overcapacity in current fisheries. The extension of the techniques to fleets fishing multiple stocks was also reviewed by the TWG. In this context, results may be difficult to interpret when there is evidence of overcapacity for some stocks and undercapacity for others.

3.4 Alternative approaches to estimating capacity output

Hold capacity has been applied widely to measure capacity output. It provides a technological limit to maximum production. Applied as such to a fleet over a year or season, it required data on number of vessels, individual hold capacity and maximum number of fishing trips. Although there are many difficulties attached to this method, it may provide an indication of capacity utilisation (ratio of actual catch to technological maximum).

If fishing time is assessed as a key factor, another approach is to estimate capacity output based on current catch rates, but based on the full use of maximum potential effort. In general, capacity output may also be deduced from cross-fishery comparisons at national or international level, e.g. by comparing the maximum output of similar vessels operating in various shrimp or tuna fisheries.

The TWG suggested two other practical alternatives for measuring capacity: peak-to-peak analysis and Data Envelopment Analysis (DEA), both are briefly described in the following paragraphs. Some of the information documents prepared for the Technical Consultation will provide examples on the application of these methods.

The peak-to-peak method defines capacity by estimating the observed relationship between catch and fleet size over time. The approach is called peak-to-peak because the periods of full utilization, called peaks, are used as the primary reference points for the capacity index. The index is fixed to 100 percent for the years for which full utilization is observed. For other periods, the index is expressed as percentages of full utilization with an adjustment for technologically induced changes in productivity. The approach is based on identifying peaks, or periods of full utilization defined as the maximum value of the ratio of output to capital stock (e.g. catch per vessel). In practice, a peak year is often identified on the basis of having a yield per producing unit that is significantly higher than both the preceding and following years. The peak-to-peak method requires data on landings and vessel numbers and some identification of a technological time trend. This approach does provide for a rapid appraisal of the maximum yield of a fleet given the size of the fleet and the potential utilization of inputs. But this is estimated in the absence of resource constraints. Minimum fleet sizes (number of vessels) that correspond to an otherwise-determined target level of capacity can be calculated on this basis.

DEA is a mathematical programming method to determine optimal solutions given a set of constraining relations. The advantages of this method are that it can estimate capacity under constraints including TACs, by-catch, regional and/or size distributions of vessels, restrictions on fishing time, and socio-economic concerns such as minimum employment levels. DEA can be used to identify operating units (i.e. individual vessels or vessel size classes) which could potentially be decommissioned. By rearranging observations in terms of some criterion, such as capacity by region and vessel size class, the desired number of operating units could be determined by adding the capacities of each operating unit until the total reaches the target. DEA readily accommodates multiple outputs (e.g. species, market categories), and multiple types of inputs such as capital and labour). DEA can also determine the maximum potential level of effort and its utilization rate. The analysis accepts virtually all data possibilities, ranging from the most parsimonious (catch levels, number of trips, and vessel numbers) to the most complete (e.g. a full range of cost data). With cost data, DEA can be used to estimate the least-cost (cost minimizing) number of vessels and fleet configuration. It can also measure capacity relative to any desired biomass or TAC. The method is limited by its deterministic specification, but allows for the consideration of an economic definition of capacity.

3.5 Data and monitoring requirements

A minimal requirement would be to establish a system for the collection and regular analysis of the following basic data: estimates of vessel numbers and the main vessel characteristics determining fishing power (e.g. GRT or GT, engine power, length, hold capacity, gear type and dimensions, with the importance of each of these varying depending on the fishery); basic relevant characteristics of fishing operations (e.g. seasonality, number of fisheries in which vessels operate); landings; and at least a qualitative indication of trends in CPUE or other information that can give at least a rough index of MSY.

An advanced system for the monitoring and assessment of capacity will require the collection and analysis of more specific data and information, such as:

- vessels: hold, engine power, engine efficiency, vessel size, electronics (fish finding equipment);
- gear: type and size;
- biological characteristics of stocks including biomass, fishing mortality, age/size structure, uncertainty in stock assessments;
- participants: numbers of participants, skill levels;
- costs and earnings surveys;
- employment;
- information on subsidies;
- fishing operations relative to fish distribution;
- reaction of fishing industry to management; and
- existence and adequacy of access controls.

3.6 Some unresolved issues on definition and approaches

The TWG identified two major unresolved issues:

- the need to develop an economic definition of capacity; the definitions given above can all be described as technologically determined definitions; and
- if capacity is defined in terms of output, there is a need to make the translation to what managers are really concerned with, which is controlling the capital stock.

This second issue calls to mind the ongoing debate concerning output controls vs. input controls. Although the assessment of overcapacity might be approached from either perspective and independently of the type of control method used, the approach taken is likely to be influenced by the availability of data and thus by the control method used. In countries where TACs are used as control measures, the measurement of overcapacity may be easier to approach on an output basis. On the other hand, many countries (and developing countries in particular), may find it easier to approach measurement in input terms because they rarely use TACs explicitly as output controls, but rely instead on variables that are easier to control (e.g. numbers of vessels, numbers of participants) in relation to indicative long-term TAC figures.

Relating output-based and input-based estimates would generally be difficult except for relatively simple fisheries. Standard fishery production models can be used which relate catch to fishing effort and catchability coefficients (fishing mortality) and biomass. *A priori,* such models could be of use to relate prevailing or target capacity output to prevailing and target capital services if these are expressed, for example, in terms of potential standard fishing days). A major question will be to assess how the catchability coefficient (q) will change as capacity changes from the current (transient) situation to the long-term target, at least indicatively. A related problem stems from the fact that (biological) limit reference points are frequently defined in terms of fish mortality rates (F). It is interesting to note that stock assessment biologists generally assume q to be constant, which is one reason that they often favour constant fishing mortality strategies, which are assumed to be equivalent to constant fishing effort strategies. Thus, as stock size changes (under a constant F strategy), the optimum fleet capacity would not vary from year to year. On the other hand, many economists consider that fishing effort is not measurable and q is made up of some parts that can be measured and some that are unquantifiable. Further work is thus needed to translate measures of capacity into metrics that can be compared to such reference points.

In a technologically determined approach, capacity output is defined as the maximum output that can be produced, given available fixed inputs and the full utilization of variable inputs, but without any reference to economic aspects. Capacity utilization is thus defined as the ratio of output (catch) to capacity or potential output, the latter being determined in an *ad hoc* manner in reference to full use, hold capacity, comparison of annual catches under similar conditions, or international comparisons. The calculation of overcapacity further requires one to independently establish a desired target level of catch (short-term and long-term) and to compare it with capacity output. Economics may be considered at this stage in an *ad hoc* manner by estimating the minimum capital stock required to harvest the target catch (e.g. MSY); by estimating the capital stock required to harvest the target catch at minimum cost or by referring to an independently derived long-term target level of output that accounts for economic efficiency (e.g. by referring to MEY rather than MSY).

A more appropriate economic definition of capacity can however be provided in reference to cost minimization. Capacity output can be defined as the output corresponding to the tangency of short-run and long-run average total cost or alternatively as the output corresponding to the minimum short-run total average cost. Intuitively, this means that capacity output is the level of output for which the vessels in the fleet were designed to operate at lowest average cost. The interest of this definition is that estimates of capacity utilization derived from technological and economic definition can be readily compared. Estimates of overcapacity using the two approaches can also be compared as the ratio of output capacity to short-term and long-term target output.

3.7 Difficulties of application in selected situations

Measurement difficulties are arising from complex situations, such as those created by fluctuation in abundance, both year to year and within a year or season. The latter result in peak load problems, particularly for species that are only available for a short period of the year (or only available in a certain high-priced form such as fish roe for a short period of the year). Proposed definitions may need to be adjusted to deal adequately with such peak load problems. Year to year fluctuations lead to difficulties in the determination of target levels for catch and capital stock. It may be appropriate to consider in this case an acceptable level of potential over or under capacity. Estimates of overcapacity may also be confounded by age-structure effects (e.g. both yield per recruit and price aspects).

Measurement methods should account for the fact that fishing units are multiple-input productive units, generally composed of a vessel, gear, technology and skills. In some cases, the number and type of fishing vessels may be a good indicator of the amount of fishing capacity. In other cases, the capacity of similar fishing units may vary broadly in relation to gear use (e.g. multiple gear), to technology, skills or labour intensity (e.g. artisanal boat used in shifts by different crews). For major and complex fleets, an analysis of the influence of major input characteristics needs to be conducted so as to identify determining factors of production.

Special problems associated with small-scale fisheries also require detailed examination, whether they constitute recreational fisheries or artisanal commercial or subsistence fisheries. There are indeed difficulties associated with the collection of data as well as with input-based or output-based measurements of capacity in such fisheries (e.g. the flexibility with which crafts involved can accommodate additional labour and shift from fishery to fishery). Difficulties also arise with regard to establishing target output and input levels, especially in geographic areas where small-scale fishing constitutes an activity of last resort.

Fleet mobility constitutes one of the main difficulties encountered in measuring capacity and assessing overcapacity. Fleet mobility may relate to geographic mobility and/or the ability of vessels to redirect effort from one target stock to another in the same area. Thus capacity needs to be considered on a fleet basis as well as a species or stock basis, with further consideration being given to the relevant geographic perspective (local, national, regional or global perspective according to fisheries). The key question is where to draw the line and, if starting from a stock perspective, how to define “latent capacity”. This question relates directly to the need to define fisheries as management units that are relevant to the management of fishing capacity.

Fisheries can be defined as interacting stocks and fleets. One can define a fishery with primary reference to stock. For stock-based fisheries, the main difficulty in measuring capacity will be to account for latent fleet or fishing effort. Fisheries can also be defined more broadly with primary reference to fleet characteristics. A fleet-based fishery will generally be specified in reference to gear, vessel size, area and species group, e.g. inshore trawling for demersal fish in specific area. A fleet-based definition allows one to deal more easily with the problem of latent capacity but makes it more difficult to determine target catch levels as fisheries may involve a large number of stocks. The monitoring and measurement of capacity needs to be approached from both perspectives in the context of an appropriate set of related stock-based and fleet-based fisheries (management units). Accounting for mobility would imply a multi-tiered approach by which capacity and overcapacity are measured at various levels in reference to a broader multispecies/ecosystem/industry context. One can start alternatively from the broadest (ecosystem or major fleet) or more restrictive perspective (a stock). In any case allowance will have to be made for major fleet-stock interactions in the disaggregation or aggregation process.

A major problem with the monitoring of fishing capacity is that stocks and fleets are generally monitored quite separately. Typically, one will have numerous data on specific stocks and their exploitation on the one hand, and on vessel characteristics (physical and sometimes economic) on the other hand. The important missing link is information on fleet-stock interactions in time and space. The monitoring and study of fleet deployment in time, space and across stocks is a priority and the only way to properly define relevant fleet-based management units.

Finally, there is a need to establish a link between harvesting and processing capacity. Such a link may be established more easily if fisheries used as management units correspond to a rather specific processed product (e.g. in the case of a major small pelagic fisheries and related fishmeal plants or in the case of species-specific fleet and processing sectors as observed for shrimp, lobsters or crabs in some countries). Otherwise, a relevant link can only be established at a fairly aggregated level.

4. CONCLUDING REMARKS FOR THE CONSIDERATION OF THE TECHNICAL CONSULTATION

The Technical Consultation was invited to examine the matter of measuring fishing capacity, with due consideration being given, *inter alia*, to the following considerations:

- the adoption of a common working definition of capacity which will allow for the estimation of current and long-term overcapacity as well as for international comparison;
- the adoption of a common indicative standard of long-term limit capacity which will allow for international comparison, noting that target capacity can be otherwise determined on the basis of alternative national criteria;
- ways of incorporating complementary economic information in the measurement and evaluation of capacity, noting that this is especially relevant to the issue of avoiding overcapacity as a source of economic waste;
- the need to adopt an aggregation system that accounts for fleet-stock interactions, noting that it may be required to measure capacity at various levels (regional, national and local) and that a common aggregation system will need to be adopted to estimate capacity at regional level and eventually at global level;
- the need to develop indicators that are particularly relevant to the case of well-circumscribed fisheries and to the case of broadly-defined fisheries, further accounting for the applicability of alternative indicators of capacity output and overcapacity under specific conditions related to key characteristics of fleets, stocks or species, such as: fleet mobility and heterogeneity; technological evolution over time; the case of shared stocks and highly-migratory resources; and fisheries showing high fluctuations in stock abundance or availability.

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FISHING CAPACITY AND RESOURCE MANAGEMENT OBJECTIVES

Gordon R. Munro and Colin W. Clark[1]

Abstract: It is recognized, almost universally, that the 'common pool' characteristic of most capture fisheries lies at the heart of the overcapacity problem in fisheries. In regulated open access fisheries, the resource managers are presumed to exercise effective control of the global season-by-season harvest, and thus over the resource. They do not, however, exercise effective control over the fleet size and hence, excess capacity can persist. The consequences of excess capacity are generally agreed upon, namely that excess capacity results in pure economic waste and serves to threaten the ability of the resource managers to control the global harvest. In this paper, we will not focus on the refining of definitions, but rather shall devote ourselves to addressing head on what these authors see as a major debate on the significance of excess capacity, under conditions of pure open access. Furthermore, we shall point out that, where excess fleet capacity does not exist in any meaningful sense, resource overexploitation can, and does, readily occur. We shall also argue, however, that excess capacity adds, at a minimum, two, if not three, significant dimensions to the resource overexploitation problem, which are wholly ignored in most, if not all, of the standard economic models of the fishery.

1. INTRODUCTION

This paper will take, as its starting point, the discussion paper prepared by one of the two authors and Dominique Gréboval for the FAO Technical Working Group (TWG) Meeting on the Management of Fishing Capacity, April 1998 (Gréboval and Munro, 1999). That paper, although designed to deal with the issue of the control of capacity, did, as well, address in some detail the question of the underlying economics of fishing capacity and resource management. We contended in that paper that, without a clear understanding of the underlying economics, it was difficult to deal effectively with either the question of the control of capacity, or the question of the measurement of capacity.

The Gréboval and Munro (1999) paper was limited in its rigor, because of the strict time constraint to which the authors were subject. In this paper, we shall attempt to provide a somewhat greater degree of rigor to several of the issues raised by Gréboval and Munro, and to some new issues, by drawing on a paper currently under preparation by Clark and Munro (1999). The reader will, however, be spared the highly technical aspects of the Clark and Munro paper.

In the discussion that follows, all references to capacity will be confined to fleet capacity. Everything that we have to say, however, could be applied, with appropriate modification, to capacity in the processing sector and to human 'capacity', in the form of human capital.

It is recognized, almost universally, that the 'common pool' characteristic of most capture fisheries lies at the heart of the overcapacity problem in fisheries. In their discussion of the underlying economics of the overcapacity problem, Gréboval and Munro (1999) made use of the distinction between 'regulated open access' fisheries and 'pure open access' fisheries. In regulated open access fisheries, the resource managers are presumed to exercise effective control of the global season-by-season harvest, and thus over the resource. They do not, however, exercise effective control over the fleet size. In pure open access fisheries, by way of contrast, there is no effective control over harvesting, with the consequence that the exploitation of the resource is unrestrained.

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We shall, in this paper, proceed by adopting the Gréboval and Munro (1999) distinction. The regulated open access case is relatively straightforward, and the measurement of excess capacity is comparatively easy. The consequences of excess capacity are generally agreed upon, namely that excess capacity results in pure economic waste and serves to threaten the ability of the resource managers to control the global harvest.

In our discussion, we shall point out that the economic waste, once incurred, is not readily reversible, particularly through 'buy-back' schemes. Furthermore, although this meeting is concerned with the measurement of capacity, rather than its control, we shall use the opportunity to make the point that, under not unreasonable circumstances; 'buy-back' schemes can easily exacerbate, rather than mitigate, the excess capacity problem.

Finally, under the heading "regulated open access", we discuss a recently adopted technique in a major British Columbia fishery designed to deal with excess capacity and its effect on the resource managers' ability to control the harvest. The technique has some of the flavour of ITQs, but is much less elaborate and easier to apply. It does, moreover, provide a 'rough and ready', but nonetheless effective, measure of excess capacity.

The question of overcapacity in the context of pure open access fisheries was found, in the Gréboval and Munro (1999) paper, to be much more difficult to address, because, in the first instance, the definition of excess capacity is much less clear. We shall in this paper not focus on the refining of definitions, but rather shall devote ourselves to addressing head on what these authors see as a major debate on the significance of excess capacity, under conditions of pure open access[2].

One school of thought appears to argue that excess capacity is the root cause of resource overexploitation under conditions of pure open access. The second school of thought maintains that the first school of thought is confusing symptoms with causes of the disease. Overexploitation of the resource arises from perverse incentives created by the aforementioned 'common pool' characteristics of the fisheries. Perceived overcapacity is simply a by-product, or symptom, of resource overexploitation.

If the second school of thought is correct, then attempting to define and measure excess capacity under conditions of pure open access is largely a waste of time. Moreover, the focus on capacity could be a harmful distraction, by diverting attention away from the real problem, i.e. the true causes of resource overexploitation.

In this paper, we shall support the second school to the extent that we shall argue that the incentives resulting in perceived overcapacity are indeed identical to those resulting in resource overexploitation. Furthermore, we shall point out that, where excess fleet capacity does not exist in any meaningful sense, resource overexploitation can, and does, readily occur. We shall also argue, however, that excess capacity adds, at a minimum, two, if not three, significant dimensions to the resource overexploitation problem, which are wholly ignored in most, if not all, of the standard economic models of the fishery (e.g. Clark and Munro 1982). The fears and concerns of the first school of thought, we shall conclude, are by no means devoid of merit.

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[2] The authors' perceptions of the debate are based much less upon documentary evidence, than upon discussions which one of the authors, Munro, had and has had, with participants in the TWG Meeting of April 1998, prior to, during, and after the meeting.

Gréboval and Munro (1999) argued that, for excess capacity to be meaningful, the relevant capital had to exhibit some degree of non-malleability. Perfectly malleable capital is capital that can be easily and quickly removed from a fishery, or fisheries, without risk of capital loss.

Since we shall be using the concept of non-malleable (fleet) capital throughout the paper, let us try to provide a reasonably rigorous definition. To do so, we turn to the article of Clark, Clarke and Munro (1979). This was the first article to deal explicitly with the issue of non-malleable fleet capital in capture fisheries.

In following Clark, Clarke and Munro (CCM hereafter), let us denote fishing effort by *E(t)* and the stock of fleet capital by *K(t),* where *K(t)* can be thought of in terms of the number of "standardized" fishing vessels. We then have (CCM, *ibid.*)*:*

$$0 \le E(t) \le E_{\max} = K(t) \quad (1)$$

which asserts that maximum fishing effort capacity is determined by the existing number of vessels, and that the actual effort cannot exceed $E_{\max}$.[3] Effort capacity may, or may not, be fully utilized.

Given an initial stock of fleet capital $K(0) = K^0$, adjustments in the stock of capital are given by:

$$\frac{dK}{dt} = I(t) - \gamma K \quad (2)$$

where *I(t)* is the gross rate of investment (in physical terms) and γ (a constant) is the rate of depreciation.

Now let c_1, a constant, denote the unit purchase price of fleet capital, and let c_s, a constant, denote the unit "scrap value" (resale value) of capital. We deem the fleet capital to be perfectly malleable if:

$$c_s = c_1 \quad (3)$$

which implies that freedom from risk of capital loss is assured. Conversely, we deem the capital to be *perfectly* non-malleable if:

$$c_s = \gamma = 0 \quad (4)$$

The capital has no re-sale value, and never depreciates.

The intermediate cases of quasi-malleable capital are given by the following:

$$c_s = 0; \ \gamma > 0 \quad (5)$$

and

[3] This concept of fleet capacity expressed in terms of the fleet's ability to generate fishing effort per unit of time is, we would argue, entirely consistent with the definitions of capacity used by Gréboval and Munro (1999), and with the 1998 Technical Working Group meeting (FAO 1998).

$$0 < c_s < c_1;\ \gamma \geq 0 \tag{6}$$

In the case indicated by equation (5), capital can be divested over time through depreciation. In that indicated by equation (6), capital can be disposed of through depreciation or by selling the capital at a positive price, but a price below the purchase price.

With these preliminary matters now in hand, we turn first to the case of excess capacity in the context of regulated open access fisheries. We do so because the regulated open access case is by far the easier of the two.

2. REGULATED OPEN ACCESS FISHERIES: AN ELEMENTARY MODEL

In discussing regulated open access fisheries, we shall deliberately introduce some rather extreme assumptions in order to simplify the exposition. We shall argue, however, that the principles to be developed would remain valid, with only minor modification, if less extreme assumptions were introduced.

We commence by assuming an absence of 'crowding' externalities, that all harvested fish is sold into the fresh market that the fisheries collectively face a perfectly elastic demand for harvested fish, that vessels and crews are identical in nature and ability, and that technology is frozen. Next we assume, initially at least, that the resource managers are capable of exercising *iron* control over total harvests. Thus, there are no resource management consequences of excess capacity, and all economic consequences are confined to the harvesting sector.[4]

Finally, we make the highly simplifying assumption that the rate of depreciation of vessel capital is equal to zero. We then contrast the extreme cases of perfectly malleable capital, with that of perfectly non-malleable capital.

Let us assume that the resource managers specify an annual Total Allowable Catch (TAC), or the equivalent thereof, which remains fixed for all future time. Let Q denote this fixed annual TAC in tonnes. Entry into the fishery is initially unrestricted; the variable K denotes actual entry of vessels into the fishery. The catch rate of fishing is q tonnes/day/vessel. Thus, if K vessels fish for D days during the year, the fleet's total annual catch, or harvest, is equal to qKD tonnes.

Let $D_{\max}$ denote the maximum possible length of the annual fishing season. If the fleet size is such that $qKD_{\max} \leq Q$, then the fishing season will be at its maximum length. If $qKD_{\max} > Q$, then the season must be reduced below its maximum length in order to ensure that the TAC is not exceeded. Thus:

$$\text{Total Annual Catch} = \begin{cases} qKD_{\max}, & \text{if } K \leq Q/qD_{\max} \\ Q, & \text{otherwise} \end{cases} \tag{7}$$

Now, let the price of harvested fish be denoted as p, a constant. Let the daily operating costs for a given vessel be denoted as c. The fleet's annual operating profits are thus given by

[4] This is one assumption that we shall definitely relax at a later point in the discussion.

$$\text{Fleet Annual Operating Profits } = \begin{cases} (pq-c)KD_{\max}, & \text{if } K \leq Q/qD_{\max} \\ (p-c/q)Q, & \text{otherwise} \end{cases} \qquad (8)$$

Next, recall that the unit, or purchase price of vessel capital is denoted by c_1, and let the annual rate of interest be denoted by r. If vessel capital is perfectly malleable, then, as it will be further recalled, the unit resale value of a vessel, at any time, is also equal to c_1. The relevant capital cost, for a vessel owner is a 'rental' cost. Given our assumption that the rate of depreciation of vessel capital is zero, the annual capital 'rental' cost for a fleet of size K would simply be Kc_1r.[5]

Now let K_0 denote the number of vessels that would be required to take Q, if $D = D_{\max}$. Thus, $K_0 = Q/qD_{\max}$. Fleet annual operating profits would then equal: $(pq-c)K_0D_{\max}$ and fleet annual, 'rental' capital costs would equal K_0c_1r. We shall assume that $(pq-c)K_0D_{\max} > K_0c_1r$, otherwise the fishery is not viable. Given this assumption, fleet annual operating profits and fleet annual 'rental' costs can be depicted as functions of K (Figure1).

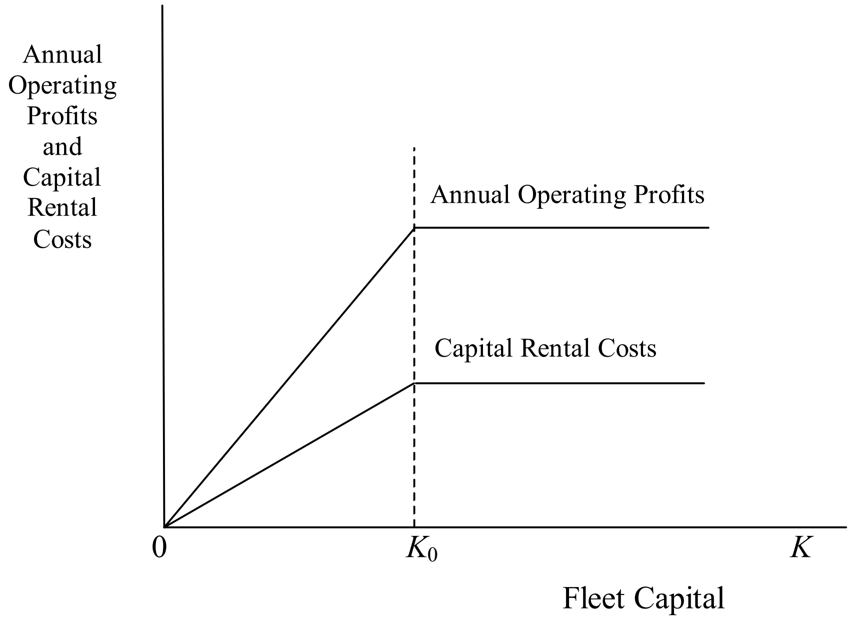

Figure 1. Annual operating profits and capital costs

Total fleet annual net profits obviously achieve a maximum at $K = K_0$. Suppose that actual $K > K_0$. Fleet annual operating profits and 'rental' costs, and thus net profits, would be identical to what they would have been, had actual $K = K_0$. The basic reason is that, in this situation, the 'rental' cost of capital is really another form of operating cost. Hence suppose for the moment that $K_0 = 200$ and $D_{\max} = 360$ days. Then suppose that K was doubled to 400 and as a consequence D was reduced to 180 days. The total annual fleet costs, total revenue, and thus annual net profits would remain unchanged.[6]

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[5] We shall in the discussion to follow assume (implicitly) that interest is compounded annually. Given that assumption, the annual "rental" cost of capital is, strictly speaking, equal to: $Kc_1rD_{max}/365$. To minimize unnecessary complications, the reader may safely assume, at this stage, that $D_{\max} = 365$.

[6] This is, in fact, a well known result. See for example, Munro and Scott (1985).

Thus, *given that the resource managers are able to exercise iron control over the total harvest,* there is, under regulated open access, with perfectly malleable fleet capital, no unique optimal fleet size, and hence no such thing as 'excess capacity'. Attempts to measure excess capacity are pointless.

We turn now to the other polar extreme of perfect non-malleability of vessel capital. A vessel, once purchased, lasts forever and has no resale value. Consequently, the rational would-be investor must compare the cost of the vessel with the share of the present value of fleet operating profits the acquisition of the vessel promises him/her. Since the vessels (and crews) are assumed to be identical, an owner of a single vessel can be assumed to enjoy an average share of the aforementioned present value, i.e. total present value of operating profits divided by the number of vessels, *K*.

If the total annual harvest *Q* is taken, then the present value of fleet operating profits will be equal to: $[(p-c/q)Q]\cdot(1+r)/r$. Thus, investment in additional vessel capital will unquestionably be profitable, if it is true that:

$$c_1 < [(p-c/q)\cdot Q]\frac{1+r}{r}\cdot\frac{1}{K} \tag{9}$$

Given conditions of regulated open access, we would predict that investment in fleet capacity would continue up to the point that:

$$c_1 K_{\mathrm{OA}} = (p-c/q)Q\cdot\frac{1+r}{r} \tag{10}$$

where K_{OA} denotes the regulated open access equilibrium level of fleet capital. Observe that equation (10) implies that:

$$c_1 = \left[(p-c/q)Q\cdot\frac{1+r}{r}\cdot\frac{1}{K_{\mathrm{OA}}}\right]. \tag{11}$$

Now consider Figure 2, which shows the present value of fleet operating profits and the total capital cost of fleet acquisition, c_1K. The present value of resource rent is, not surprisingly, maximized at $K=K_0$, where it will be recalled that K_0 is given by:[7]

$$K_0 = Q/qD_{\max} \tag{12}$$

Thus, when fleet capital is non-malleable the concepts of optimal fleet size and 'excess' capacity do unquestionably become meaningful. In terms of our model, 'excess' capacity, in physical terms, arising under conditions of regulated open access is simply: $(K_{\mathrm{OA}} - K_0)$. We can re-express this excess capacity in economic terms as:

$$c_1(K_{\mathrm{OA}} - K_0) = \left[(p-c/q)Q \cdot \frac{1+r}{r} - c_1K_0\right] \tag{13}$$

[7] Return, for the moment, to the case of perfectly malleable fleet capital. So long as the entire TAC = Q is taken, year in and year out, the annual rental cost will always be equal to K_0c_1r, regardless of the fleet size. The capitalized value of K_0c_1r through time is, of course, simply equal to: c_1K_0 .

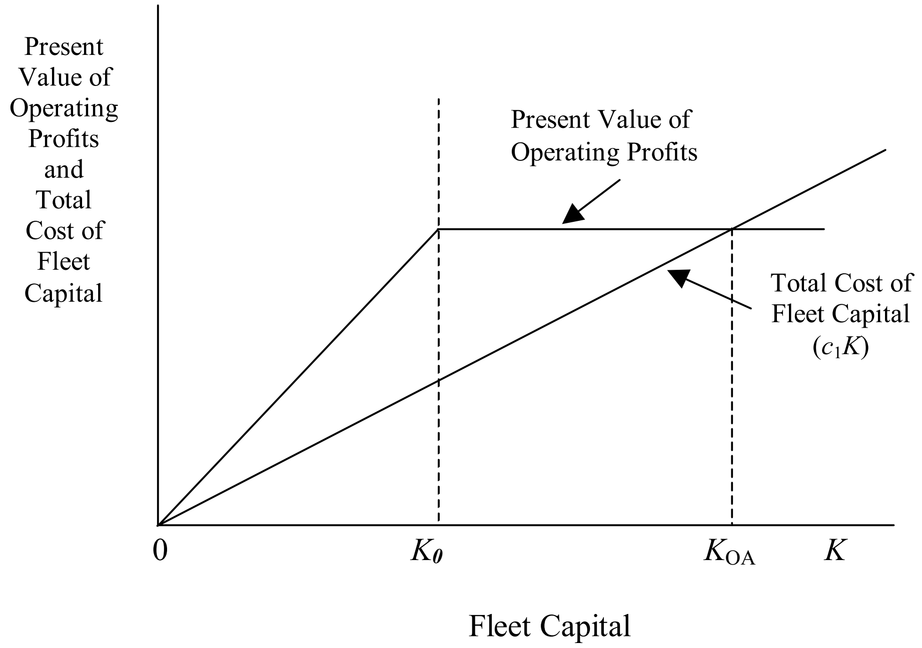

Figure 2. Present value of fleet operating profits and capital costs

Thus the economic measure of excess capacity under regulated open access is equal to the present value of dissipated resource rent. Let us refer to the L.H.S. of equation (13) as the regulated open access Redundancy Deadweight Loss. Given K_0, and given that c_1 and r both exceed zero, the Redundancy Deadweight Loss, under regulated open access will be greater the smaller is r, for obvious reasons.

Let it be noted that the Redundancy Deadweight Loss is incurred the *instant* that 'excess', or redundant, vessel capital is acquired. Moreover, the economic damage, once done, cannot be undone.

If we were to relax our extreme assumption about the rate of depreciation and allow for a positive rate of depreciation, the 'excess' capacity would be removed over time. Attention could then be directed towards preventing the 'excess' capacity's re-emergence, and thus preventing another round of economic waste.

2.1 Buy-back programmes and perfectly non-malleable capital

An obvious, and widely used, technique for addressing 'excess' fleet capacity in hitherto regulated open access fisheries is to combine a licence limitation, or limited entry, programme with a buy-back programme. We have already implied that, in economic terms, the buy-back scheme may be very much a case of locking the barn door after the horse has well and truly bolted.

Jorgensen and Jensen (1999), in discussing buy-back, or decommissioning, programmes, in the context of the European Union, argue that experience shows that fishers, and their bankers, are not all myopic with respect to investment in fleet capital. Decommissioning schemes, if repeated, will come to be anticipated and will influence investment decision making. The authors then argue, on the basis of a simulation model, that decommissioning schemes are likely to destabilize, rather than stabilize the fishery.

We would agree and would argue that one can, in the context of our model, show very simply that the impact of a buy-back (decommissioning) scheme will depend critically upon whether the scheme is, or is not, anticipated by the vessel owners. If this assertion appears to academic economists to carry with it some of the flavour of the rational expectations school of macro-economic theory (e.g. Sargent, 1986), it does so for good reason.

Let us illustrate with the aid of a simple numerical example. Let it be supposed that D_{max} = 200 days. We assume, in addition that:

Q = 10 000 tonnes
q = 1 tonne per vessel per day
p = US$1 000 per tonne
c = US$500 per vessel per day
c_1 =US$500 000 per vessel
r = 0.10 – i.e. 10 percent per annum.

Total annual fleet net operating profits will therefore be:

$$TP_{oper} = (p - c/q) \cdot Q = \$5\,000\,000 \text{ per year}$$

$$K_{opt} = \frac{Q}{qD_{max}} = \frac{10{,}000}{200} = 50 \text{vessels.}$$

Let it be supposed that the fishery commences at time period t = 0. It is not unknown for resource managers to react to an ‘excess’ capacity problem, only after the problem has emerged. Therefore, let it be supposed that, if ‘excess’ capacity does emerge, the resource managers will react by, say, time period t = 10, by introducing a buy-back/licence limitation scheme with the objective of reducing K to 50 and of maintaining that fleet level thereafter.

Let us commence by also assuming that, at t = 0, the resource managers’ future responses are wholly unanticipated by vessel owners. They assume, incorrectly, that regulated open access will continue forever. We can thus anticipate that at t = 0, investment in capital capacity will be given by:

$$K_{OA} = (p - c/q)\frac{Q(1+r)}{c_1 r} = (\$1{,}000 - \$500) \cdot \frac{10{,}000(1.10)}{0.10(\$500{,}000)} = 110 \text{ vessels}$$

Thus there is excess capacity of 60 vessels, representing a Redundancy Deadweight Loss of US$30 million.

At t = 10, the resource managers do introduce a ‘sudden death’ buy-back programme, to the surprise of the vessel owners. The vessel owners are, however, convinced that the authorities will do whatever is necessary to reduce the fleet to 50 vessels and are further convinced that the accompanying limited entry programme will be effective forever.

The present value of the operating profits of the remaining 50 vessels, discounted back to t = 10 will be US$1 100 000. Thus, we can be assured that the resource managers cannot offer less than US$1 100 000 per vessel. We shall assume, somewhat unrealistically, that the authorities are able to achieve their goal by offering a purchase price of US$1 100 000 and the accompanying limited entry programme is indeed fully effective. The fleet remains at $K = K_0$ from henceforth.

Let us suppose that the buy-back scheme is financed by the government drawing upon its general revenues. If one can assume that resultant increase in taxes and/or increased government borrowing and/or reduced government expenditures on other activities causes no perceptible loss to the economy, we can say that each vessel owner will enjoy a windfall gain of US$600 000 (evaluated at t = 10)[8] and that the Redundancy Deadweight Loss (incurred at t = 0) remains at US$30 million. The initial loss to the economy cannot be undone by the buy-back programme, but at least no further damage is done.

Now let us change the example by supposing that, at t = 0, the vessel owners have perfect foresight. They anticipate, correctly, that, at the inception of the fishery, the resource managers will do nothing about the possible emergence of "excess" capacity. They anticipate further that, by t =10, the resource managers will react to the appearance of excess capacity by introducing a "sudden-death" buy-back programme and the resource managers will, moreover, offer a price of US$1 100 000 per vessel. The vessel owners also know that the fleet will be stabilized at 50 vessels, and that the accompanying limited entry programme will be entirely successful.

We can now calculate the level of investment in vessels at t = 0, which we shall denote by K'_{OA}. Equilibrium will be achieved when:

$$c_1 K'_{\mathrm{OA}} = \sum_{i=0}^{10} (\mathrm{p} - \mathrm{c/q}) \frac{\mathrm{Q}}{(1+\mathrm{r})^{\mathrm{i}}} + \frac{c_3}{(1+r)^{10}} \cdot K'_{\mathrm{OA}} \tag{14}$$

where c_3 denotes the resource managers' offer price at t = 10. Observe that it is a matter of indifference whether an individual vessel owner sells his/her vessel at t =10, or whether his/her vessel continues on as one of the remaining 50. Also observe that equation (14) can be re-written as:

$$K'_{\mathrm{OA}} = \left[\sum_{i=0}^{10} (p - c/q) \frac{Q}{(1+r)^i} \right] \cdot \frac{1}{c_1 - c_3/(1+r)^{10}} \tag{15}$$

In any event, in our example, we have:

$$K'_{\mathrm{OA}} = \$35{,}722{,}836 \cdot \frac{1}{\$75{,}093} \cong 476$$

The implication is that the eminently 'successful' buy-back programme would lead to a Redundancy Deadweight Loss of: US$500 000 (476–50) = US$213 million. Recall that, if the authorities had done nothing, i.e. had foregone a buy-back programme, the Redundancy Deadweight Loss to the economy would have been US$30 million, less than 15 percent of the loss brought on by the buy-back programme.

Note as well that, what we might term the 'do nothing' policy, results in the net economic returns from the fishery being reduced to zero – the usual result from the standard fisheries economics model. The present value (at t = 0) of net operating profits from the fishery is US$55 million; while total expenditure on vessel capital would be US$55 million. In our example of the anticipated buy back programme, the net economic benefits from the fishery to the economy at large (discounted back to t = 0) will be equal to minus US$158 million.

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[8] If there had been no buy-back programme, then, at t = 10 , the present value of operating profits accruing to each vessel, evaluated at t = 10 , would have been $500 000, and thus each vessel would, at t = 10 , have been worth $500 000 – hence the $600 000 windfall gain.

The reason that the anticipated buy-back programme induces a large investment in fleet capacity is made transparent by the R.H.S. of equation (15). The effective purchase price of vessel capital, for would be vessel owners, at $t = 0$ is: $c_1 - [c_3/(1+r)^{10}]$, which carries with it the implication that the vessel owners would be receiving a subsidy. Indeed, as the reader can verify in our example, exactly the same outcome could have been produced under a 'do nothing' policy (i.e. $K_{OA} = 476$) by having the government offer the vessel owners, at $t = 0$, a subsidy per vessel equal to 77 percent of the purchase price c_1.

Of course we do not live in a world of perfect certainty. Nonetheless, the point remains. As Jorgensen and Jensen (1999) in their study of European fisheries were at pains to stress, it is foolish to suppose that vessel owners will simply ignore the knowledge they have acquired about the behaviour of resource managers and that they will neglect to incorporate that knowledge in their investment decisions.

2.2 Regulated open access and the monitoring of TACs

To this point, we have assumed that the resource managers are able to exercise iron control over the TACs. Often this is not the case. Indeed, a major cost of 'excess' capacity is often seen to be the fact that it can readily lead to the undermining of the resource managers' control of the TAC. The 'swarm' of vessels with which the resource managers must deal can present an impossible policing problem.[9]

The policing problem provides us with an opportunity to bring to light an apparently effective scheme for dealing with that problem, which does not require the use of buy-backs. It does, moreover, provide an effective first approximation of a measure of actual excess capacity in a regulated fishery.

The scheme has been put into effect in the British Columbia roe herring fishery. In response to claims that there is no assurance that the scheme is applicable to other fisheries, we would counter by saying that there is even less reason to assume that the scheme is unique to the aforementioned fishery.

The British Columbia roe herring fishery is a short, intense fishery. There is a licence limitation scheme for the two gear classes – seiners and gillnets. Nonetheless, there had, historically, been a chronic policing problem. In the decade 1987–1997, for example, the actual annual harvests exceeded the coast-wide TAC by an average of 20 percent (G. Thomas, Department of Fisheries and Oceans (Canada), personal communication).

Commencing in 1998, the Canadian Department of Fisheries and Oceans (DFO) introduced a pooling system, first for seiners, and subsequently for gillnets (DFO, 1999). There are five designated openings for roe herring. Licence holders must beforehand declare the opening in which they plan to participate. It is well nigh physically impossible to participate in more than one opening. With respect to a given opening, the licence holders are, beforehand, required to form themselves into pools. Each seiner pool must have a minimum of eight participants; each gillnet pool a minimum of four. There is no upper limit to the number of participants in an individual pool.

[9] What we might term the "swarm" effect does perhaps provide us with an exception to the rule that "excess" capacity is meaningful, only if the fleet capital is non-malleable. Even if the fleet capital is perfectly malleable, the policing problem, can obviously arise.

At a given opening all participants of the pools appear, with their vessels. Each pool is given a quota based upon the TAC and the number of licences per pool. Furthermore, each pool is required to appoint a pool captain who works with the resource manager to determine which vessels from the pool shall actually engage in fishing. The net profits of the pool are, however, divided among the pool members.

Thus, for example, one could have a pool containing 20 independent vessels, but in which only two vessels actually engage in harvesting. All 20 vessel owners will, nonetheless, share in the profits.

The race for the fish, within pools, is eliminated. From the resource managers' perspective, monitoring a few pools rather than many vessels is far easier. It should also be added, that, if a pool exceeds its quota, the overage is distributed elsewhere at the discretion of the resource managers (DFO, 1999).

The scheme does, of course, have a certain ITQ flavour to it. It is, however not a fully-fledged ITQ scheme, and is much simpler to organize.

To date, the scheme has apparently been very successful (G. Thomas, personal communication). Unquestionably, it will evolve through time. One can conjecture that, if at a given opening, industry profits should prove to be higher, the smaller the number of pools, the industry would not be slow to realize this fact. We could then look forward to a pooling of the pools – to the benefit of the resource managers.

With regards to measures of excess capacity, if, at a particular opening, there is one seine pool of fifty vessels, while the actual harvesting is done by, say, four vessels, then we would have a rough measure of excess capacity. This, in turn, raises a question about further evolution of the scheme.

At the present, licences, plus vessels, provide fishers (companies) with the ‘tickets to the dance’. One can foresee the scheme evolving in a manner in which participants receive shares of the profits, but without vessel redundancy being perpetuated. The driving force would enhance industry profits.

3. PURE OPEN ACCESS FISHERIES

We now examine the case in which we commence with a pure open access fishery in that there is, initially at least, a complete absence of intervention by resource managers. The standard economic models of the fishery, going back to that of Gordon (1954), predict that, in these circumstances, the resource will be ‘overexploited’ from the point of view of society. The question that we shall raise is whether fleet capacity, as we have defined it, has a distinct role to play in the over-exploitation process, or whether apparent ‘excess capacity’ is no more than a symptom of the overexploitation disease. To repeat our earlier point, if apparent ‘excess capacity’ is no more than a symptom, the attempt to measure the ‘excess capacity’ may be a pointless exercise.

Our discussion will have as its foundation two articles. These are the aforementioned article by Clark, Clarke and Munro (1979) (CCM), and a companion article by McKelvey (1986).

In contrast to the discrete time model used in Section 2, we find it more convenient in the discussion to follow to use a continuous time model. We shall also find it convenient, and appropriate, to relax the restrictive assumption, adopted in Section 2, that fleet capital is perfectly non-malleable. We shall rather assume that the fleet capital is quasi-malleable (see Section 1), and assume, specifically, that, while the re-sale value of capital, c_s, is equal to zero, the rate of depreciation of vessel capital is positive. Finally, we shall assume, for ease of exposition that we commence with a virgin fishery. It could be that, heretofore, the fishery was not commercially viable, but that, with a once and for all change in market conditions (e.g. increase in demand for the harvested fish); the fishery does suddenly become commercially viable.

In keeping with the CCM and McKelvey articles, we initially model the fishery resource stock with the standard Schaefer model (see: Clark, 1990, Ch. 1)

$$\frac{dx}{dt} = F(x) - h(t) \tag{16}$$

where $x = x(t)$ denotes the fish stock, or biomass, and where $F(x)$ denotes the natural rate of biomass growth, when the resource is unexploited. It is assumed, in the Schaefer model, that the natural growth function is a pure compensatory one (Clark, 1990). The harvest rate, or harvest production function, is assumed, as before, to be given by:

$$h(t) = qE(t)x(t) \tag{17}$$

where E and q are the rate of fishing effort and catchability coefficient respectively.

The adjustment in the stock of fleet capital is given by:

$$dK / dt = I(t) - \gamma K \tag{18}$$

where $I(t)$ and dK/dt are to be seen as the rates of gross and net investment in K respectively. Given our assumptions we have $I(t) \geq 0; \quad dK/dt \geq -\gamma K$. We now express the flow of net *operating* profits, at each point in time, as:

$$\pi(t) = (pqx(t) - c)E(t) \tag{19}$$

where, as before, c, a constant, denotes unit operating costs, and p, a constant, the price of harvested fish. Alternatively, we can express equation (19) as:

$$\pi(t) = (p - c_{\text{var}}(x))qx(t)E \tag{20}$$

where $c_{\text{var}}(x)$ denotes unit variable cost of harvesting, given by $c_{\text{var}}(x) = c / qx$.

If $\pi(t) > 0$, we can assume that the existing fleet will be used to capacity, i.e. $E(t) = K(t)$. There will, however, be a biomass level at which $\pi(t) = 0$, that we shall denote as $x(t) = x_a^0$. The biomass x_a^0 is given by

$$p - c_{\text{var}}(x_a^0) = 0 \tag{21}$$

We can be certain that the resource would not fall below that level, since at biomass levels below x_a^0, fleet operating profits would be negative. Hence we have:

$$E(t) = \begin{cases} K(t), \text{if } x(t) > x_a^0 \\ 0, \text{if } x(t) < x_a^0 \end{cases} \tag{22}$$

There exists another biomass level, which we shall denote as x_b^0. This is the biomass level that would be the pure open access equilibrium level, if vessel capital was perfectly malleable. It is given by:

$$p - c_{\text{total}}(x_b^0) = 0 \tag{23}$$

where $c_{\text{total}}(x)$ is the unit total cost of harvesting, given by $c_{\text{total}} = \left[c + (\delta + r)c_1\right]/qx$ and where $(\delta + \gamma)c_1$ is the unit 'rental' cost of vessel capital (recall the discussion in Part II) where δ denotes the rate of interest (in continuous time).[10] Obviously, $x_b^0 > x_a^0$. The biomass level x_b^0 corresponds directly to the Bioeconomic Equilibrium level, as originally defined by Gordon (1954); see also CCM (1979). It can be shown (and should come as no surprise), that vessel owners will have *no* incentive to invest (positively) in vessel capital at biomass levels below x_b^0 (McKelvey, 1986).

With all of this in mind, we can state the following. Assume that $x(0) > x_b^0$. Then at $t = 0$, i.e. at the time of the once and for all change in market conditions, investment in vessel capital by vessel owners will occur, and will occur (by assumption) instantaneously. How the level of investment is determined is a matter to be discussed momentarily. Exploitation of the fishery resource commences, and the resource (x) declines.

Given our assumption that $c_s = 0$, the only costs relevant to the vessels, once they have been acquired, are operating costs. Hence the biomass may (but not necessarily will) be reduced to the level $x(t) = x_a^0$. Thus, the biomass level x_a^0 is an equilibrium level, but only over the short-run. The fleet continues to depreciate, and since it will not pay vessel owners to invest in additional capital at biomass levels below x_b^0, the time will come when the fleet is too small to harvest at $x(t) = x_a^0$ on a sustainable basis.

When this time arrives, the biomass will experience positive growth and will continue to grow until $x(t) = x_b^0$. At this point, it will pay vessel owners (collectively) to invest in fleet capital up to, but not beyond, the point that will enable the fleet to harvest sustainably at $x(t) = x_b^0$. In other words, once x_b^0 is achieved, the rate of *net* investment in fleet capital (dK/dt) will be equal to zero. It is for this reason that we refer to the biomass level x_b^0 as the long-run equilibrium level. Finally, it can be shown, of course, that should the biomass rise above x_b^0, it would pay vessel owners to invest in sufficient new capacity to an extent that they would renew the process of resource depletion (i.e. we would find that $dK/dt > 0$).

Now let us consider the determination of the initial fleet size at $t = 0$, which we shall denote as K^0. Recall that, by assumption, the investment is done instantaneously. Denote the

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[10] It is being assumed (implicitly) that each fishing 'firm' is subject to constant returns to scale.

initial biomass level at $t = 0$ as x^0. If K^0 vessels are introduced into the fishery at $t = 0$, then we have: $K(0) = K^0$.

Once the vessels K^0 have been purchased, the operating profits from the vessels alone become relevant. The present value of these operating profits is given by:

$$PV_{op}(x^0, K^0) = \int_0^\infty e^{-\delta t}\{pqx(t) - c\}E(t)dt \tag{24}$$

where $x(t)$ and $E(t)$ are as specified above, for all $t > 0$.

We continue to assume that vessels and crews are identical. Employing the same form of argument used in Section 2, we can argue that, at $t = 0$, investment in capacity will proceed up to the point that:

$$\begin{aligned} c_1 K^0 &= PV_{\text{op}}(x^0, K^0) \\ c_1 &= PV_{\text{op}}(x^0, K^0)/K^0 \end{aligned} \tag{25}$$

Consider now Figure 3 and focus on the 45° line, the curve σ_{OA} and the fleet-size, biomass trajectory W. The figure can be viewed as a type of 'feedback' prediction of both the level of investment in vessel capital and the amount of fishing effort that will be used.

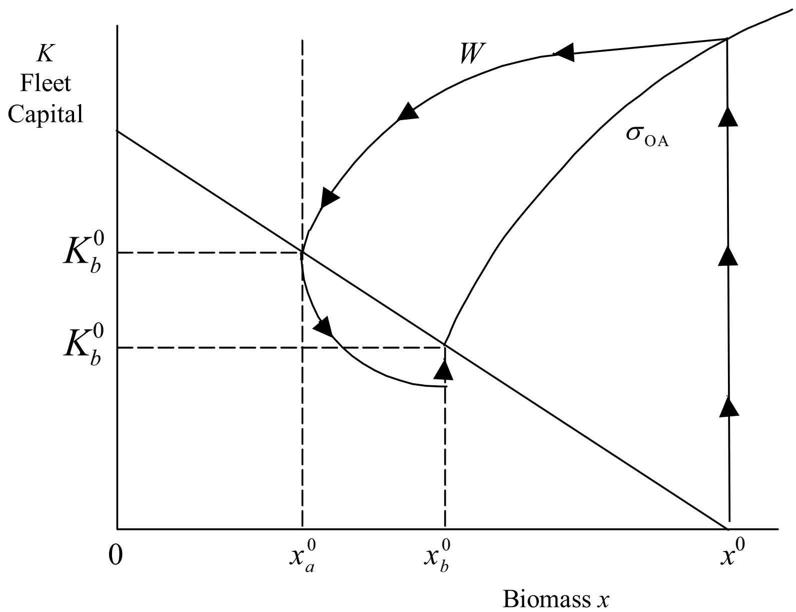

Figure 3. Investment/biomass feedback trajectory

In the example given in Figure 3, the trajectory indicates that the biomass is, in fact, driven down to level x_a^0. While we cannot, in fact, be certain that the biomass will be driven down to x_a^0, we can be certain that the resource will be driven down below x_b^0 (McKelvey, 1986).

We could accompany Figure 3 with a similar figure showing what the optimal resource exploitation and fleet investment path would have been had the resource been under the complete control of a resource manager from the instant that the fishery became commercially viable. The underlying analysis is indeed mathematically demanding, so that we shall only report the results here (for a complete discussion see Clark and Munro, 1999). If we assume that the resource manager and vessel owners use the same discount rate, then it can be shown, and will come as no surprise, that, at each stage, the level of investment in fleet capital deemed optimal by the resource manager would be less than that which would occur under conditions of pure open access.[11]

The underlying reason is straightforward enough. The resource manager in controlling, or monitoring, a fleet investment programme must always be aware of the impact of the programme, and the subsequent use of the capital, upon the 'natural' capital in the form of the resource. The impact upon the resource can be seen as one of the 'costs' of investment in vessels. Vessel owners operating under conditions of open access will effectively set the "cost" associated with the resource at zero.

This, however, is the sort of argument that is normally used to explain overexploitation of the resource in pure open access fisheries. Hence, it would indeed appear that resource over-exploitation and 'overcapitalization' (as perceived by the resource manager) are but two sides of the same coin.

Furthermore, consider the following. Suppose that the fleet capital was perfectly malleable, i.e. $c_1 = c_s$. In this case, x_a^0 and x_b^0 would be identical. All costs would be variable, all costs would be relevant, and equation (24) would be replaced by:

$$PV(x^0, K^0) = \int_0^\infty e^{-\delta t}\{pqx(t) - c_{\text{total}}\}E(t)dt \qquad (26)$$

where $c_{\text{total}} = c + (\delta + \gamma)c_1$. It can easily be shown that, commencing with a virgin fishery resource, exploitation of the resource, under pure open access, would lead to the depletion of the resource to the level $x(t) = x_b^0$, i.e. Bionomic Equilibrium. This, of course, is the prediction of the standard economic model of the fishery (see as well: CCM, 1979). Thus, while 'excess' capacity does not exist in any meaningful sense, overexploitation of the resource would most certainly occur.

Thus, the argument would seem to go in favour of the second school of thought to which we referred in Section 1. Fleet capacity, per se, under conditions of pure open access does not really matter, and indeed may be a distraction.

Yet, before accepting this conclusion, let us return to Figure 3 and our analysis of the pure open access fishery with non-malleable fleet capital. Note that, with the existence of such capital, our model predicts a heavier degree of resource exploitation, under conditions of pure open access, than does the standard economic model of the fishery. The resource will be driven down below the long-run Bioeconomic Equilibrium level, x_b^0. Once the vessels are acquired, the capital costs of the vessels (c_1K_0 in our example) cease to be relevant. The vessels, once acquired, can be viewed as generators of "cheap" fishing effort. If, however, the Schaefer model is the appropriate biological model for the resource, then we can rest assured

[11] Needless to say, the extent of resource exploitation deemed optimal would also be less than that which would occur under pure open access.

that Bionomic Equilibrium (x_b^0) will eventually be achieved. Thus it would appear that the aforementioned 'heavy' exploitation is strictly temporary and is of only passing interest.

The Schaefer model assures us that the resource will not face the risk of extinction through over-harvesting. In a world that has produced resource management disasters, such as Northern Cod, one cannot rest content with the assurances of the Schaefer model. Suppose in fact that the Schaefer model does not strictly apply. Suppose rather, in following an example developed by McKelvey (1986), that, while the harvest production function remains as specified in Equation (17), the natural growth function, rather than being a purely compensatory one, is characterized by critical depensation (Clark, 1990). Suppose further that, as a consequence, there exists a minimum viable population, $\bar{x}$, greater than zero.[12] The biomass levels x_a^0 and x_b^0 are determined as before. There is, however, no guarantee that: $x_a^0 > \bar{x}$ (McKelvey, 1986).[13]

Now consider the following example. Let it be supposed that $x_b^0 = 500$ while $\bar{x} = 200$. Thus the Bionomic Equilibrium biomass level lies comfortably above $\bar{x}$. Consequently, if fleet capital was perfectly malleable, we could rest assured, other things being equal, that the resource would be safe from extinction.

If, however, the fleet capital is not perfectly malleable (let us return to our assumption that: $c_s = 0$; $\gamma > 0$), and if $x_a^0 < \bar{x}$, then the resource could be driven to extinction. Furthermore, the degree of risk will, we would argue, be dependent critically upon the nature of the fleet capacity.

The measure of capacity which we have employed, which we express as the power to generate fishing effort, per period of time,[14] is, of course, really a mix of inputs – capital, labour, etc. We can think of various forms of 'capacity', as varying in terms of 'capital intensity'. For want of a better measure, let us use, in our example, as a measure of 'capital intensity' that fraction of $c_{\text{total}}(x)$, at any given level of x, accounted for by capital 'rental' costs. It can be shown that for *any* level of $x > 0$, the fraction can be expressed as follows:[15]

$$\psi = \frac{(\delta + \gamma)c_1}{c + (\delta + \gamma)c_1} \tag{27}$$

where $0 \leq \psi \leq 1$. Let us refer to ψ as the 'capital intensity coefficient'.

If vessel capital is non-malleable, the lower bound to resource exploitation, x_a^0, will be determined by the 'capital intensity' of the mix of inputs constituting 'capacity'. Given the harvest production function as set out in Equation (17), and given the degree of non-malleability of vessel capital which we have assumed,[16] it can be shown that:

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12 McKelvey made the point in his article that his minimum viable population case was only but one of *many* cases in which the assurances offered by the Schaefer model could prove to be illusory (McKelvey, 1986).

13 For that matter, there is no guarantee that $x_b^0 > \bar{x}$. We shall, however, assume that x_b^0 is in fact greater than $\bar{x}$.

14 See footnote 8.

15 See footnote 15.

16 i.e., $c_s = 0$; $\gamma > 0$.

$$x_a^0 = (1-\psi)x_b^0 \tag{28}$$

To illustrate, suppose that a fishery resource could be exploited through the use of two alternative forms of fishing 'capacity': K_{I} and K_{II} . A unit of K_{I} has equal fishing effort generating capacity to a unit of K_{II}. The relevant harvest production function is that given by Equation (17). The relevant catchability coefficients are identical. Furthermore, let it be supposed that:

$$[c^{\text{I}} + (\delta+\gamma)c_1^{\text{I}}] = [c^{\text{II}} + (\delta+\gamma)c_1^{\text{II}}]$$

Hence, it follows that $[x_b^0]^{\text{I}} = [x_b^0]^{\text{II}}$. Let it be supposed, in keeping with our previous example, that:

$$[x_b^0]^{\text{I}} = [x_b^0]^{\text{II}} = x_b^0 = 500$$

Let it also be supposed, also in keeping with our previous example, that there exists a minimum viable population, $\bar{x}$, $\bar{x} = 200$.

Let it further be supposed that:

$$\psi_{\text{I}} = 0.10$$
$$\psi_{\text{II}} = 0.90$$

which implies that:

$$[x_a^0]^{\text{I}} = 450$$
$$[x_a^0]^{\text{II}} = 50$$

If the resource was exploited under conditions of pure open access with Class I fishing capacity (alone), we could be confident, other things being equal, that the resource would be safe from extinction $([x_a^0]^{\text{I}} >> \bar{x})$. If, on the other hand, the resource was exploited with the much more capital intensive Class II capacity, we would have to conclude, that with $[x_a^0]^{\text{II}}$ equal to but 25 percent of *c*, the resource would indeed be at risk of being driven to extinction.

Thus we must conclude that, if fleet capital is other than perfectly malleable, fleet capacity can indeed add a further, and very significant, dimension to the resource exploitation problem under conditions of pure open access. We must also conclude that the *form* that the capacity takes is of significance. The greater is the degree of 'capital intensity' of the capacity, other things being equal, the greater will be the magnitude of the aforementioned dimension.

The existence of fleet capacity, as we have defined it, adds a second dimension to what we might call the general resource management problem that we shall describe only briefly. Suppose that a fishery commences as a pure open access one, but that, after a period of heavy resource exploitation, the resource managers intervene to control the fishery and to rebuild the resource. Previous investment by the industry in non-malleable fleet capital will have an impact upon the resource managers' optimal harvest programme. The existence of previously acquired fleet capital/capacity will call for a slow, rather than a rapid, restoration of the resource stock over time (CCM, 1979). In practical terms, a policy of rapid resource restoration carries with it the cost of possible severe disruption to the industry and communities dependent on the industry.

In any event, 'optimal' fleet capacity over the resource restoration (or adjustment) phase is not a constant, but becomes a function of time. This issue has been discussed in some depth in Gréboval and Munro (1999). On the assumption that the Gréboval and Munro paper is readily available to the reader, and with the aim of keeping this paper to a reasonable length, we will not explore the issue further here.

4. SPILLOVER EFFECTS

The term 'spillover effect' refers to the situation in which fleet capacity is removed from one fishery, but rather than disappearing, makes its way into another fishery. Once again this is a reflection of the fact that fleet capital may be non-malleable – particularly from the perspective of world fisheries, combined with the fact that the capital is mobile.

The 'spillover effect' provides yet another dimension to the resource exploitation problem created by fleet capacity. The implication of the 'spillover effect' is that it is no longer adequate to examine the problem of resource overexploitation in terms of isolated fisheries. The 'spillover effect' carries with it the possibility of linkages between and among fisheries suffering from overexploitation.

The question now to be considered is whether these linkages are real or ephemeral. We respond first by conceding that not all 'spillovers' are harmful. If the recipient fishery is well managed, for example, the recipient fishery can be expected to benefit from any 'spillover', taking the form of an offer of 'cheap' capital. The resource managers of the recipient fishery could look forward to profiting from the resource mismanagement of others.

We shall rather argue that there are no safe grounds for assuming that 'spillovers' will *always* be harmless. To make our point, we need construct but one example of where a 'spillover' can lead to disaster.

Let us take as our example two independent fisheries α and β, exploiting the same species, using identical fishing vessels and facing identical costs, including the purchase price of vessels, c_1. Assume that the vessels have no value (including for true scrap) outside of the two fisheries, but that they are subject to a common depreciation rate γ. It is also reasonable to assume that, in the evolution of the two fisheries, movements of vessels between the two fisheries would eliminate any profit differential.

Assume in addition that the resource in each fishery has a minimum viable population, which we shall designate as $\bar{x}_\alpha$ and $\bar{x}_\beta$ respectively. Both fisheries are pure open access fisheries. Let is also be supposed that:

$$(x_a^0)_\alpha < \bar{x}_\alpha$$
$$(x_b^0)_\alpha > \bar{x}_\alpha$$
$$(x_a^0)_\beta < \bar{x}_\beta$$
$$(x_b^0)_\beta > \bar{x}_\beta$$

Let it be further supposed that the solutions to the equivalent of Equation (25) result in a fleet size in each fishery that is insufficient to reduce the resources to $\bar{x}_\alpha$; $\bar{x}_\beta$. Note from Equation (25) that the fleet size will, *inter alia* (and to the surprise of no one), depend upon c_1. In any event, both fisheries stabilize at Bionomic Equilibrium, $(x_1^0)_\alpha$; $(x_1^0)_\beta$.

Now let it be supposed that, while Fishery β remains a pure open access fishery, Fishery α becomes subject to rigorous and thorough management, with the resource managers being able to exercise iron control over both the resource and the fleet size. It is true that the past investment in fleet capacity will influence the resource management programme in Fishery α, and that the resource managers are unlikely to engage in a wholesale disposal of vessels (Gréboval and Munro, 1999; CCM, 1979). It is also true, however, that if the resource managers were faced with a positive re-sale price for the vessels, they would sell off some of the vessels.[17]

Recalling our assumption that the vessels have no value outside of Fisheries α and β, the question becomes whether the Fishery α managers could find buyers for their vessels in Fishery β. We know that, at the purchase price of vessels, c_1, investment in fleet capacity in Fishery β would be such as to maintain the rate of net investment in fleet capacity equal to zero. In other words, investment in capacity would be for replacement purposes only.

Suppose, however, that fishers in Fishery β were offered vessels by the Fishery α resource managers at a fixed posted price of $c_1' < c_1$. Fishers in Fishery β would recognize this as a once only offer. The number of 'cheap' vessels purchased by the Fishery β fishers would be determined by a variant of Equation (25). Fishers would be prepared to purchase vessels up to the point that their expected per vessel share of the present value of the additional fleet operating profits was equal to c_1'. We shall not attempt to determine the equilibrium level of c_1'.

We need only note the following: If c_1' was low enough and if the supply of 'cheap' vessels at that price available to fishers in Fishery β was great enough (suppose, for example, that Fishery β was much smaller than Fishery α), the β fishery resource could readily be driven below $\bar{x}_\beta$.[18] We do not have to demonstrate that disaster must occur, only that it could occur.

The reason that Fishery β was safe before, but might now be faced with disaster, is straightforward. Other things being equal, the level of c_1 was sufficiently high to ensure that the β fleet would not be great enough to drive the resource to $\bar{x}_\beta$. With vessels from Fishery α being sold at 'fire sale' prices to Fishery β , that assurance is lost.

Let us also note the importance of 'capital intensity'. The more capital intense the fishing operations, the more vulnerable will the resource be to destruction. If, for example, our measure of capital intensity, ψ, was low with the consequence that $(x_a^0)_\beta >> \bar{x}_\beta$, a

[17] This point is analyzed in detail in CCM (1979).

[18] If c_1' was equal to zero and the supply of "cheap" vessels to Fishery β fishers was unlimited, then obviously the resource would be promptly driven down to $(x_a^0)_\alpha$. Of course, c_1' will be positive and the supply of "cheap" vessels will not be unlimited. Nonetheless, the point remains.

'spillover' from α to β would cause some temporary additional exploitation of the β resource, but would cause no lasting harm.

Finally, we conclude with a conjecture. The straddling fish stock/highly migratory fish stock problem, which emerged with such ferocity in the 1980s and early 1990s, could be seen as a 'spillover' phenomenon. The eviction of distant water fishing (DWFN) fleets from newly formed EEZs could be viewed, in turn, as producing a 'spillover' into hitherto commercially uninteresting high seas open access fisheries. Furthermore, one could, even without precise measures, argue that the DWFN fishing operations were nothing, if not 'capital intensive'. Thus, one could argue further that, as 'capital intensive' DWFN fleets 'spilled over' into high seas areas, such as the Donut Hole and Peanut Hole of the North Pacific, one should not be surprised that these once productive areas were transformed into marine deserts.

5. CONCLUSIONS

We have attempted to examine the issue of fishing fleet capacity in the context of both 'regulated open access' and 'pure open access' fisheries. In so doing, we have followed the lead of Gréboval and Munro (1999).

In both cases, we stressed the significance of the 'non-malleability' of fleet capital. We questioned whether 'excess' capacity had any substantive meaning in cases in which such capital can be viewed as being perfectly malleable.

With regards to regulated open access fisheries, we argued that the measurement of excess capacity should be straightforward. Then, although this TWG meeting is not directly concerned with measures of control, we did raise some questions about buy-back, or decommissioning, schemes to mitigate the economic waste associated with 'excess' capacity. We first pointed out that much, if not most, of the economic damage is done once the excess capacity is acquired, and cannot be easily undone. We then emphasized that concerns about anticipated buy-back schemes making a bad situation worse are very well founded.

One aspect of excess capacity, under conditions of regulated open access, is that the excess capacity weakens the control of resource managers over harvesting. We used this issue as an opportunity to discuss a recent management technique employed in a major British Columbia fishery, which appears to address effectively the harvest control problem and does, in addition, provide a good first measure of excess capacity.

The question of excess capacity under conditions of pure open access is, as Gréboval and Munro emphasized, a much more difficult one. We addressed the perceived debate over whether capacity plays a direct role in the resource overexploitation associated with pure open access, or whether it is no more than a symptom, or by-product, of the overexploitation. If perceived excess capacity is no more than a symptom, then attempts to measure excess capacity may be of little value, and may in fact be a distraction.

That the incentives leading to investment in 'excess' capacity are identical to those resulting in resource overexploitation is not in doubt. Moreover, there is also no question that, if fleet capital was perfectly malleable, overexploitation would occur. Nonetheless, we argued that when fleet capital is less than perfectly malleable, fleet capacity does add several dimensions to the resource exploitation problem and to resource management in general, not captured in the standard economic models of the fishery.

First, in the context of a single isolated fishery, the existence of non-malleable fleet capital will, under conditions of pure open access, lead to a greater degree of resource exploitation than that predicted by the aforementioned standard economic models. As Robert McKelvey first pointed out over a decade ago, under the 'right' set of circumstances this added dimension can have very serious consequences indeed.

Furthermore, the nature, or form, of the fleet capacity will influence the magnitude of this dimension. The more 'capital intensive' is the fishing operation, other things being equal, the greater will be the magnitude of this dimension; the greater will be the threat to the resource.

Next, investment in non-malleable fleet capital under conditions of pure open access will have an impact upon optimal resource management strategies, should the fishery become subject to effective management at a later stage. Attempts to determine 'optimal' fleet capacity, and thus measure 'excess' capacity, will be seriously flawed if these facts are ignored.

The final dimension that we considered takes the form of the 'spillover' effect, which arises from the existence of 'non-malleable' fleet capital, combined with the mobility of such capital. The implication of the 'spillover' effect is that it can no longer be deemed adequate to examine the management of individual fisheries in strict isolation. Apparently highly commendable attempts to address problems of resource exploitation and excess fleet capacity in one fishery can, through the 'spillover' effect, result in disaster in other fisheries.

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CAPACITY AND CAPACITY UTILIZATION IN FISHING INDUSTRIES

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Abstract: The definition and measurement of capacity in fishing and other natural resource industries possess unique problems because of the stock-flow production technology, in which inputs are applied to the natural resource stock to produce a flow of output. In addition, there are often multiple resource stocks, corresponding to different species, with a mobile stock of capital that can exploit one or more of these stocks. In turn, this leads to three unique issues: (1) multiple stocks of capital and the resource; (2) that of aggregation or how to define the industry and resource stocks to consider; and (3), that of latent capacity or how to include stocks of capital that are currently inactive or exploit the resource stock only at low levels of variable input utilization. This paper presents appropriate definitions of capacity and methods for measuring capacity in fishing industries taking into consideration these issues.

1. INTRODUCTION

Excess capacity of fishing fleets is one of the most pressing problems facing the world's fisheries and the sustainable harvesting of resource stocks. Since 1989, both world marine fish catches and the world-wide number of vessels have levelled off, with many species fully or over-exploited and with a general excess number of vessels (FAO, 1998a). In addition, the widespread adoption of the Precautionary Principle (FAO, 1995a), calling for resources stocks higher than those of maximum sustainable yield and sustainable catch levels correspondingly lower, exacerbates the existing problem of excess capacity.

International organizations and national governments show increasing concern over overfishing and excess capacity. In 1995, Articles 6 and 7 of the FAO Code of Conduct for Responsible Fisheries directly addressed the issue of excess capacity, calling on nations to take measures to prevent or eliminate excess fishing capacity and to reduce capacity to levels commensurate with the sustainable use of fishery resources (FAO, 1997).[3] To this end, the Committee on Fisheries of the FAO (FAO/COFI) agreed in March 1997 to launch an initiative on managing fishing capacity, which led to the Technical Working Group (TWG) on the Management of Fishing Capacity, La Jolla, United States, 15-18 April 1998. The results

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[3] The Kyoto Declaration's Plan of Action from the 1995 International Conference on the Sustainable Contribution of Fisheries to Food Security called for action to reduce excess capacity as soon as possible (FAO, 1997). Cooperative actions at the international level include implementation of the 1995 UN Fish Stocks Agreement and the 1993 FAO Compliance Agreement and implementation of the FAO Code of Conduct for Responsible Fisheries.

from the TWG form the basis for the current FAO/COFI-led global plan of action to manage world fishing capacity. In May 1998, FAO called for a drastic reduction of at least 30 percent of world fishing capacity on the main high-valued species (FAO, 1998a). In the United States the Sustainable Fishing Act (1997) requires that resources be rebuilt to at least maximum sustainable yield (MSY) levels within a ten year period. Under the present United States regulatory regime, the only permissible option for rebuilding fish stocks is a drastic reduction in fishing activity.

Excess capacity creates a number of problems. It generates intense pressure to continue harvesting past the point of sustainability in order to keep as much of the fleet working as possible. With revenues spread among many vessels operating under little or no profits, reductions in fleet size become politically and socially more difficult.[4] Vessels are more vulnerable to changes in the resource base and regulations when they are only marginally viable because of excess capacity. Excess capacity encourages inefficient allocation and constitutes a major waste of economic resources. Over investment occurs and an excessive amount of variable inputs are used. Excess capacity also complicates the fishery management process, particularly in regulated open access, frequently leading to microregulation. Excess capacity substantially reinforces the increasing tendency for management decisions to become primarily allocation decisions, i.e. decisions about the gainers and losers of wealth and profits (or losses) from alternative management choices over an overfished or even declining resource stock.

Fishing industries are particularly vulnerable to excess capacity and overcapitalization because of the open-access property right found in most fisheries. Generous subsidies found in many fisheries exacerbate the tendencies for capacity to expand with few checks (Milazzo, 1998).

Surprisingly, given the widespread and deep concern over excess capacity in many of the world's most important fisheries, enormous confusion persists over the definition and measurement of capacity and capacity utilization in fishing industries (Kirkley and Squires, 1999). Yet, a precise definition and widely applicable method of measurement is required for monitoring and measuring excess capacity, especially at the international level, where clearly agreed upon definitions and measures are required to develop international consensus and cooperation for global and regional plans of action to monitor and reduce excess capacity.

Individual transferable quotas obviate a need to formally manage fishing capacity, by letting decentralized market forces match capacity to Total Allowable Catches (TACs), but the management of fishing capacity among the developed countries is still largely accomplished through moratoria on new entrants, limited access systems, and vessel buyout programmes. Capacity management in less developed countries, especially those in the tropics with the wide species diversity, is also likely to rely primarily upon limited access rather than individual transferable quotas given the infrastructure otherwise required to operate such a system and the species diversity.

This paper addresses this issue of defining and measuring capacity in fishing industries. The paper draws upon the corresponding background paper (Kirkley and Squires, 1999) and discussions from the Breakout Group on defining and measuring fishing capacity in the FAO Technical Working Group on the Management of Fishing Capacity, La Jolla,

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[4] Moreover, owners and crew of some vessel size classes or gear types, and in some regions or species-specific fisheries, struggle to even make a living. In turn, families and fishing communities come under stress or even their very existence and way of life is threatened.

United States, 15-18 April 1998 (FAO, 1998b), the United States NMFS National Capacity Management Team meeting, La Jolla, 25-26 January 1999, and various meetings of the United States Congressional Task Force on Investment.

Capacity can be defined and measured following either a technological-engineering approach or explicitly predicated on economic optimization from microeconomic theory (Morrison, 1985a, 1985b and 1993). These papers, Kirkley and Squires (1999), and the different working groups primarily focus on the former because the general paucity of cost data in most fisheries world-wide militates against estimation of cost or profit functions to derive economic measures of capacity and capacity utilization. Similarly, the technological-engineering approach is the one used by the United States Federal Reserve Board (Corrado and Mattey, 1998) and in most other countries to monitor capacity utilization throughout the economy.

The definition and measurement of capacity in fishing and other natural resource industries possess unique problems because of the stock-flow production technology, in which inputs are applied to the natural resource stock to produce a flow of output. In addition, there are often multiple resource stocks, corresponding to different species, with a mobile stock of capital that can exploit one or more of these stocks (Gréboval and Munro, 1999; Kirkley and Squires, 1999; FAO, 1998b). In turn, this leads to three unique issues: (1) multiple stocks of capital and the resource; (2) that of aggregation or how to define the industry and resource stocks to consider; and (3), that of latent capacity or how to include stocks of capital that are currently inactive or exploit the resource stock only at low levels of variable input utilization. In fishing industries, the current stock and flow of catch frequently differs from a sustainable target or reference stock and flow level (such as a Total Allowable Catch or TAC), so that different measures of capacity and excess capacity correspond to current and target resource conditions and intermediate states. Because most fisheries are multiproduct due to multiple species or product forms and may employ multiple stocks of capital, measures of capacity must contend with the corresponding special issues. Finally, in many fisheries, such as artisanal or in isolated regions, labour may be immobile and overemployed. The stock of labour may then form a fixed factor and the definition and measurement of capacity is extended to include this additional fixed factor (Gréboval and Munro, 1999).

The widespread use of industry output quotas corresponding to target resource flows, such as TACs, leads to a distinction between input- and output-oriented measures (Kirkley and Squires, 1999). When there is a TAC, an input-oriented measure considers how inputs may be reduced relative to a desired output level. An output-oriented measure indicates how output could be expanded to reach the maximum possible output level, given the capital stock and full variable input utilization. Both the corresponding input- and output-oriented measures of excess capacity can help design vessel decommissioning schemes such as a vessel buyback programme.

The balance of the paper is organized as follows. Section 2 reviews the literature on fishing capacity and provides a definition consistent with economic theory. Section 3 discusses measurement of capacity in fishing industries. Section 4 provides concluding remarks.

2. FISHING CAPACITY

2.1 Fisheries literature review

The concept of fishing capacity has been used in a number of ways in the scholarly fisheries and governmental grey literatures and in fisheries management, but in its most widespread usage is equated with the capital stock (Kirkley and Squires, 1999). Specifically, fishing capacity is conceived as the maximum available capital stock in a fishery that is fully utilized at the maximum technical efficiency in a given time period given resource and market conditions. Capacity reduction then becomes reduction of the capital stock in a fishery or fleet. In short, the discussion of capacity and capacity utilization in the literature is often actually of capital and capital utilization, so that the primary focus of concern is the optimum utilization of capital.[5] Some of the names given to this concept include available fishing effort, effort capacity, harvest capacity, maximum effort utilization, maximum potential effort, and potential fishing capacity.

This approach equates fishing capacity with fishing power, but not the concept of fishing power developed by Garstang in the latter part of the 19th century (Garstang, 1900; Smith, 1994) and refined by Gulland (1956), Beverton and Holt (1957), and others.[6] That is, fishing power is not conceived in terms of relative catch rates per unit of time. Instead, fishing power is considered to measure the potential ability of a vessel to catch fish, where this potential is measured in terms of average vessel characteristics (see Taylor and Prochaska, 1985; Hilborn and Waters, 1992; Valatin, 1992). Hence, fishing capacity is equated with the heterogeneous capital stock available to the fishery. Fishing effort then denotes the product of the fishing power (capital stock) and the amount of time spent fishing, giving a flow of capital services.[7] Capacity utilization is related to one of the variants of the neoclassical economics concept of capital utilization, discussed by Hulten (1990), as the ratio of capital services to the stock of capital. The second, and less widely adopted, specification of fishing capacity as capital stock directly accounts for fishing time, and capacity becomes a flow measure.

Equating the capital stock and capital utilization to capacity and capacity utilization implicitly assumes a linear relationship between the capital stock and capacity and the two corresponding utilization rates.[8] These measures coincide only if there is but one fixed input

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[5] Capital utilization captures how much of the existing capital stock is being used and capacity utilization provides information about short-run versus long-run equilibrium and economic incentives for investment and disinvestment. Capital utilization has been defined as the ratio of the desired capital stock (given output quantity and input prices) to the actual capital stock (Berndt, 1990; Färe *et. al.,* 1994). An alternative definition of capital utilization is the ratio of capital services to the stock of capital (Schworm, 1977; Hulten, 1990). The idea of capacity is sometimes developed in the context of capital utilization rather than capacity utilization, directly implying that capital is the only important fixed input (Morrison, 1993). However, since capacity utilization reflects overall firm behavior, it depends on all fixed factors facing firms rather only a given amount of capital. Moreover, the capital stock may itself be heterogeneous rather than homogeneous.

[6] Garstang (1900) developed the notion of fishing power to measure relative efficiency between gear and vessel types and over time, based on total annual catch (Smith, 1994). Garstand tried to account for the greater relative efficiency of one type of fishing gear compared to another. In the process, Garstand developed the procedure of standardization. Gulland (1956) and Beverton and Holt (1957) and others subsequently further developed the notion.

[7] The heterogeneous capital stock is frequently aggregated into a single composite measure or measured by a single proxy variable, such as vessel size or numbers.

[8] As was noted in the TWG, this corresponds to a constant q (catchability coefficient) in the population biology model. Moreover, the vast bulk of the bioeconomics literature is actually concerned with capital utilization and optimal capital stock even though the term capacity is frequently employed; this literature also implicitly equates capital with capacity.

(a single stock of capital), all variable inputs are in fixed proportions to the fixed input, and if production is characterized by constant returns to scale (Berndt, 1990; Berndt and Fuss, 1989). Thus, given a constant optimal capital-output ratio $g = K_t/Y_t^*$, capacity output Y_t^* can be expected to vary directly with the observed capital stock K_t (Berndt, 1990).

Fishing capacity has been conceived in other ways besides the capital stock, most notably maximum potential catch (Kirkley and Squires, 1999). There are several approaches discussed in the fisheries literature to measure maximum potential catch: (1) fleet hold capacity; (2) the peak-to-peak method; (3) maximum sustainable yield; and (4) fishing mortality. In some instances, the impact of various regulations or fishery management measures are considered, and in other instances they are not.

Economic measures of capacity have received substantially less attention than engineering-technological measures (Kirkley and Squires, 1999). Economic notions of capacity define output as the economic optimum when outputs are freely varied or correspond to a target level (such as total allowable catches, or TACs) or are exogenously determined in some other manner given one or more quasi-fixed or fixed inputs.[9] In the fisheries literature, gross proceeds, measuring total output, have been suggested. When TACs are taken as given, the focus has shifted to examining the optimal fleet size rather than the maximum potential catch level, often using linear programming. Break-even analysis has also been used, where excess capacity can be defined as the reduction in fleet size required to provide a break-even catch level to the remaining vessels. Duality-based econometric estimates of economic capacity and capacity utilization, as developed by Berndt and Morrison (1981), Morrison (1985a, 1985b and 1986), and Nelson (1989), have been used on a limited basis.[10]

2.2 Capacity and capacity utilization

Capacity is a short-run concept, where firms and industry face short-run constraints, such as the stock of capital or other fixed inputs, existing regulations, the state of technology, and other technological constraints.[11] Johansen (1968: p. 52) defined capacity for the technological-engineering approach as, "*...the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted.*" Capacity output thus represents the maximum level of production the fixed inputs are capable of supporting. This concept of capacity generally conforms to that of a full-input point on a production function, with the qualification that capacity represents a realistically sustainable maximum level of output rather than some higher unsustainable short-term maximum (Klein and Long, 1973). This approach gives an endogenous output and incorporates the firm's *ex ante* short-run optimization behaviour for the production technology (given full utilization of the variable inputs). This approach does

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[9] Quasi-fixed inputs are factors of production that can be adjusted in a time period, the short-run, but will not be adjusted all the way to the equilibrium level because of constraints such as adjustment costs.

[10] These studies include Squires (1987), Dupont (1990), Segerson and Squires (1990, 1992), Squires and Kirkley (1996), and Weninger and Just (1997).

[11] Capacity output and capacity utilization are inherently short-run concepts since the capital stock is fixed in the short-run, so that optimal short-run output might differ from that in a steady-state, long-run equilibrium (Morrison, 1985a, 1985b). However, the optimal capital stock or capacity decision is a long-run concept, and as the firm adjusts its capital stock to the long-run, steady-state optimum, capacity output adjusts to the new short-run optimal level (Nelson, 1989). If all inputs are completely variable, the problem of capacity, as such, does not exist; available inputs will be utilized in terms of their most effective long-run equilibrium mixes and a given capacity is not defined, and full utilization – in an economic sense – of available inputs will be the norm (Morrison, 1993).

not directly capture the influences of changes in economic variables and is not based on economic optimization.

In fisheries, we actually consider the maximum potential nominal catch or maximal level of landings. Rarely is it possible to know what is actually caught and discarded at sea. The maximum potential catch in fisheries is the maximal or expected harvest that fishing effort is capable of producing given the observed capital stock, other vessel characteristics, the state of technology, and the resource stock (Kirkley and Squires, 1999). The definition adopted by the TWG Break-Out Group is (FAO, 1998b). Fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully-utilized, given the biomass and age structure of the fish stock and the present state of the technology. Fishing capacity is the ability of a vessel or fleet of vessels to catch fish. This definition was adopted by the United States National Marine Fisheries Service and a very closely related one was adopted by the United States Congressional Task Force.

A second basic approach to capacity explicitly builds upon an economic foundation (Morrison, 1985a). Capacity can be defined as that output pertaining to one of two economic optimums: (1) the tangency of the short- and long-run average cost curves (Chenery, 1952; Klein, 1960; Friedman, 1963), so that the firm is in long-run equilibrium with respect to its use of capital, or (2), the tangency of the long-run average cost curve with minimum short-run average total cost curve (Cassel, 1937; Hickman, 1964); these measures coincide for a linear homogeneous technology. These capacity output levels are in steady state in that the firm does not have an incentive to change output levels provided that input prices, stocks of fixed inputs, and state of technology remain constant (Morrison, 1985a). Berndt and Morrison (1981), Berndt and Fuss (1986), Hulten (1986), Morrison (1985a, 1985b, and 1986) and Nelson (1989) developed the dual approach with exogenous output, which measures the cost gap when actual output differs from capacity output.[12] This cost-minimizing economic approach, in which outputs are exogenous, neatly fits the widespread application of TACs in fisheries, where the output level is exogenously defined by population biologists.[13] The use of exogenous output contrasts with the endogenous output of the output-oriented technological-engineering approach. The economic approach requires cost data, which hinders its applicability on a widespread and consistent basis in fisheries.

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[12] It may be deemed dual because it does not directly compare physical output levels. Instead, it captures the cost gap when the actual output differs from capacity. This cost gap of disequilibrium is measured not by the differences in actual and capacity output levels, but by the difference between the firm's implicit marginal valuation (shadow price) of its capital stock and the rental or services price of that capital stock. The dual CU measure contains information on the difference between the current short-run (temporary) equilibrium and the long-run equilibrium in terms of the implicit costs of divergence from long-run equilibrium. The firm's optimal capital stock can be derived given the firms observed output or capacity output can be derived given the existing capital stock. The primal economic capacity utilization measures capture the output gap that exists when actual output differs from capacity output but is calculated from a cost function (Morrison, 1985a, 1985b). In addition, Segerson and Squires (1992), Squires (1994), Squires and Kirkley (1996), and Weninger and Just (1997) consider CU under quotas and rations, where Weninger and Just (1997) should be referred to as the last word.

[13] The economic approach to capacity and capacity utilization was extended to endogenous outputs and profit maximization by Squires (1987), Segerson and Squires (1990, 1992), and Kim (1999) and to revenue maximization by Segerson and Squires (1992, 1995). The use of endogenous output gives a profit- or revenue-maximizing optimal output and incorporates the firm's *ex ante* optimization behavior, including demand information through product prices. Capacity output is then defined as the output for which the current capital stock is optimal, i.e. the output level corresponding to the tangency of the short and long-run average cost curves. The optimal and capacity output levels can differ, since optimal output corresponds to the equality of short-run marginal cost and marginal revenue. Capacity utilization corresponds to the ratio of observed output to capacity output, and measures the effects of current operations on capacity. Optimal capacity utilization corresponds to the ratio of optimal output to capacity output (Kim, 1999).

Capacity utilization (CU) represents the proportion of available capacity that is utilized, and is usually defined as the ratio of actual output to some measure of capacity output (Morrison, 1985a, 1985b; Nelson, 1989). In the technological-engineering approach that was adopted by FAO, NMFS (1998), and the United States Congressional Task Force, full CU represents full capacity and the value of CU cannot exceed one (1). A CU value less than one indicates that firms have the potential for greater production without having to incur major expenditures for new capital or equipment (Klein and Summers, 1960).

CU can be measured in two different ways with the technological-engineering approach. CU can be measured as the ratio of observed output to capacity output, which is the standard approach. When TACs are used, observed output and the industry level is the TAC. CU can also be measured as the ratio of technically efficient output to capacity (Färe *et al.,* 1994). The latter definition corrects for any bias that could otherwise arise from technical inefficiency. That is, the technological-engineering measure of capacity is made with full technical efficiency, so that the ratio of technically efficient output to capacity is consistent in that both numerator and denominator are technically efficient output levels. In contrast, the ratio of observed output to capacity contains a numerator that may be technically inefficient and a denominator that is technically efficient. In turn, this may provide a capacity utilization measure that combines both deviations from full technical efficiency and full capacity.

2.3 Two stocks: capital and resource

In the short-run of stock-flow production processes in natural resource industries, two types of stocks are paramount, the stock of capital and the natural resource stock (and in some instances, the stock of labour). The resource stock is often specified as another type of capital stock (in which case, capacity and capacity utilization can be indeterminate, a topic we turn to in greater detail below). When resource stocks are specified as another type of capital stock, they can be treated as either discretionary or nondiscretionary inputs.[14] The resource stocks may best be treated as nondiscretionary. Resource stock levels lie beyond the control of the vessel captain. Nonetheless, the vessel captain has the option of selecting when and where to fish, which provides some control of the resource level available for harvesting. Calculation of capacity and technical efficiency with discretionary or nondiscretionary inputs is straightforward (Charnes *et al.,* 1994).

The resource stock can also be specified as a technological constraint rather than as a fixed factor (in which case the above indeterminancy problem does not arise). Different levels of the resource stock shift the production frontier or cost curve up or down, and can even twist their shapes depending on whether or not there are Hicks-neutral or biased relationships between the resource stock and production technology.

Capacity with either specification of the natural resource stock must contend with both of these stocks changing over time, not simply the capital stock. Five basic combinations of these stocks are possible, the existing capital and natural resource stock levels, one at the long-run equilibrium level and the other not, both at the long-run equilibrium levels, or one or both at future levels that differ from the current and long-run steady-state equilibriums; this allows for the transition path between the current stock levels and the long-run optimum. Moreover, in almost all fishing industries, some target level of output maintains the resource

[14] A nondiscretionary output is an output whose production is not under the control of management (Charnes *et al.,* 1994). A nondiscretionary input is an input whose level or utilization is not under the control of management. It corresponds to a quasi-fixed or fixed factor of production. It may also be viewed as a minimum required level of an essential variable input.

stock at the desired level, which might be a TAC. Capacity can be defined and evaluated with the resource stock at existing or long-run equilibrium levels.

2.4 Excess capacity

In fisheries and other renewable resource industries, excess capacity[15] should ideally be defined relative to some biological or bio-socio-economic reference point that accounts for sustainable resource use. To appropriately set the target capacity, it is necessary to specify a target resource stock size. The TWG recommended that the target level of output be evaluated at both the current and target stock sizes (FAO, 1998b).

In practice, the long-range target, such as the long-run steady-state optimum, may be difficult to estimate, so that the most important objective is to develop a capacity management strategy that moves in the right direction.[16] It is important to determine the magnitude of the difference between current and target capacity to determine severity of problem, and the appropriate step size in the future. As the fleet moves along the adjustment path towards a preliminary target estimate, accumulation of knowledge and a better indication of changes in technology and other factors may result in continual updating of the ultimate target.[17]

Excess capacity, in an output-oriented approach, can be defined as the difference between capacity output and desired or target level of capacity output, such as the TAC (OECD, 1997, Kirkley and Squires, 1999, FAO, 1998b).[18] The target level of output was defined by the TWG as (FAO, 1998b), "*... [t]arget fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized while satisfying fishery management objectives designed to ensure sustainable fisheries...*".[19] The TWG observed that current and target capacity need to be evaluated and compared relative to the same stock size (FAO, 1998b).

Excess capacity, in an input-oriented approach, starts with a TAC (either current or long-term projection) and determines how many of each vessel type would catch this TAC, then compares to current fleet size, given full utilization of the variable inputs and the

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[15] Excess capacity differs from overcapitalization. Excess capacity refers to the excess use of inputs, including labour and capital, to produce a potential output, whereas overcapitalization refers to the excessive use of only capital. Overcapacity and overcapitalization are usually equated because of the standard use of a single composite input, fishing effort, which in turn is equated to the capital stock and capital utilization.

[16] The optimal capital stock, capacity, and resource stock decisions are ultimately long-run in nature, with optimal levels in some very long-run, steady-state equilibrium, and new short-run optimal positions corresponding to intermediate stages along some approach path to this optimum.

[17] See Stone (1997: p. 513). However, there is little consensus on what would constitute the "right" capacity, or the "right" level of inputs, against which excess capacity should be measured. For instance, the safe catch level for any stock is always controversial and fluctuates from year to year. In light of the uncertainties, it is not clear what level of fishing activity will net the "right" catch. The fact that fishing capacity is an artifact of regulation complicates the definition of "excess". It is unclear how much of the "overcapacity" is an economically rational response to (suboptimal) regulation. Wilen (1979) made the same points. A related issue is the peak load problem. A fluctuating and stochastic resource generates periods when sufficient investment is desired to harvest this fluctuating capacity but in other periods ostensibly appears as excess. See Hannesson (1993) for a fisheries discussion.

[18] The OECD Fisheries Committee (1997) defined excess fishing capacity as in excess of the minimum amount required to harvest the desired quantity of fish at the least cost.

[19] This definition directly corresponds to the engineering-technological definition of capacity and excess capacity. Nonetheless, it can be readily extended to allow for an economic or socio-economic optimum and the corresponding definitions of capacity and CU.

resource stock. The maximum that a given fleet could potentially catch divided by the target TAC is a measure of excess capacity.[20]

Optimal capacity, if defined, can be better defined as a range rather than a specific quantity or metric (FAO, 1998b). Optimal can be specified relative to outer boundaries. According to paragraph 7 of Annex II of the Straddling Stocks Agreement, the minimum standard for a biological reference point should be the fishing mortality rate that generates maximum sustainable yield. The capacity corresponding to a resource stock beyond this mortality rate limit is an upper bound on optimal or target capacity. The following definition for "limit" capacity conforms to the direction in which international law is developing: Limit capacity is the maximum amount of fish that can be produced on a sustainable basis by a fully-utilized fleet. Thus, the limit capacity corresponds to MSY (FAO, 1998b: para 68).

2.5 The measurement of capacity and the natural resource stock

In fisheries and other renewable resource industries with stock-flow production processes, capacity can be *measured* conditional upon the size and composition (e.g. age structure, species, and density) of the resource stock or without the resource stock. When capacity is measured conditional upon the size and composition of the resource stock, it is a measure of the maximum potential output that could be produced at given resource stock levels, where the resource stock abundance also sets an upper limit on output in the stock-flow production technology. When capacity is defined without the resource stock, it provides a measure of the potential output that could be produced in the absence of resource constraints, such as after a resource stock as begun rebuilding beyond the current depleted level.

Whether or not to include resource abundance in a measurement of capacity depends upon the information desired by resource managers. In turn, this often depends on the time frame of concern. Inclusion of the resource stock gives greater fixity to capacity output and provides information pointed towards policy questions dealing with current resource stock levels, i.e. with short-run conditions. When capacity is calculated conditional on available resource abundance, the capacity measure is not truly indicative of the total potential catch a fishing operation or vessel could harvest when constrained by current resource conditions (which could be very low and restrictive). In contrast, exclusion of the resource stock in capacity measures pertains to a longer-term period when current resource conditions – say of a depleted stock – do not limit capacity. When resource managers seek information about capacity for the purpose of reducing overall harvesting capacity and achieving medium or long-term harvest goals, capacity should be assessed without the inclusion of resource levels, or as discussed in the previous section, at a target resource stock size.

Including the resource in the assessment of capacity makes it possible to determine whether or not certain levels of resource abundance rather than the fixed inputs limit the harvest. In this latter case, capacity is calculated with and without the resource abundance. If the capacity output with abundance included equals capacity output with abundance excluded from the analysis, the fixed factors and not resource abundance are constraining production.

[20] The TAC does not necessarily (and almost always does not) correspond to an economic or socio-economic optimum. However, in practice fisheries use TACs that correspond to solely biological objectives and limited ones at that, since they do not generally incorporate multispecies and ecosystems concerns.

2.6 Full utilization of variable inputs

Capacity output (in the technological-engineering approach) is the level of output attainable by fully employing or full utilization of the variable factors of production, given the current technology and keeping fixed factors at their current levels. This raises the question of defining the full-employment or full utilization level of variable inputs (Corrado and Mattey, 1998; Morrison, 1993). For example, is the capacity of a plant (e.g. fishing vessels) and equipment (e.g. nets, winches, engines) determined by the production of this plant and equipment operating throughout the day or season or year, and should downtime for repair and maintenance, offloading, institutional constraints such as holidays, and the like be considered?

The answer varies by the type of technology and institutional factors that constitute issues such as normal downtime (Corrado and Mattey, 1998).[21] Short-run output varies with technology type in different ways according to duration and intensity or speed of operations.

Fishing vessels operate a stock-flow production technology with relatively continuous production punctuated by transit times to and from port to offload the catch, for repair and maintenance, and time with families. Catch from this stock-flow production process is also subject to resource availability and weather conditions, which vary by season and even over longer annual and decadal cycles. Maximum catch – given the fishing grounds and resource stock (abundance, age distribution, density, species mix), weather, other technological constraints, fishing skill, and the plant and equipment – varies with the length of time the gear is in the water, i.e. duration. Over a year, the length of time the net is in the water depends on institutionally derived downtime and markets. Moreover, as resource availability, species abundance, and weather temporally varies, maximum catch and its product mix from this stock-flow production process varies, given any full utilization of variable inputs and plant and equipment. The intensity or speed of operation in fisheries is of lesser or no importance, since biological conditions dictate speed of operation such as tow rates or soaking time for passive gear. To the extent processing constrains intensity, when harvesting and processing are vertically integrated into one production process at sea, then intensity plays a larger role in defining full utilization of variable inputs. Finally, maximum catch and full utilization of variable inputs differ from full utilization of the resource stock, and maximum catch and full utilization of variable inputs at any time face an upper bound dictated by the resource stock, weather, and other technological constraints imposed by the environment.

2.7 Latent capacity

The definition and measurement of capacity and capacity utilization depends on the universe of active participants, i.e. which firms to include in the industry. The definition of the participating firms in a fishing industry is complicated because of the great mobility of vessels – the capital stock. Most fishing industries have a core of active participants, where some are more active than others. However, there are often potential participants that fish elsewhere or on other species that are currently inactive, or active only at low levels of

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[21] The definition of full utilization or full employment of variable factors is closely related to the capital utilization literature. For example, Betancourt (1986) refers to capital utilization as the duration of operations of productive processes. Bosworth and Dawkins (1983) refer to capital utilization as the timing of input flows and in particular to shift work and overtime. Betancourt (1986) observed that the utilization of equipment over a given time period can be varied along two dimensions, duration and intensity (speed). The speed of operations is typically assumed constant and variations in utilization come through variations in duration over a given time period.

variable input utilization, but which could suddenly actively participate if resource stock or market conditions or regulations change. The property rights structure (e.g. open access or regulated open access such as limited entry) and other regulations (e.g. TACs) affect the number of potential participants. The number of potential participants and the duration and intensity of operations of potential and existing participants leads to the issue of latent capacity. Latent capacity could be estimated attributing the full variable input utilization rates of active participants to the currently partially or fully inactive participants and using their capital stock information, for which there is quite frequently information (e.g. vessel size from permit files).

2.8 Multiple outputs and heterogeneous capital stock

Measurement of fishing capacity needs to take account of multiple species or outputs and multiple resource stocks. When there are multiple outputs and production is joint-in-outputs, a problem arises because a primal (output-based) scalar measure of output does not generally exist except under the restrictive conditions of homothetic output separability or changes in outputs in constant proportions giving a ray measure (Segerson and Squires, 1990).[22] When production is non-joint in inputs, measures of capacity and CU can be formed for each separate production process.

Even though theoretical constraints militate against a fully theoretically satisfactory primal measure of capacity and CU in multispecies fisheries with joint production, even with only a single stock of capital, policy makers must still form policies to manage capacity. Moreover, multispecies fisheries, especially those in the temperate latitudes, are usually managed on a species-by-species basis, leading policy makers to want capacity and CU measures on a corresponding species-by-species basis. For instance, fishery managers in the New England groundfish fishery separately manage cod, haddock, and other species.

In these instances, partial capacity and CU measures, denoted y_i^* and CU_i, can be formed (Segerson and Squires, 1990). y_i^* provides the capacity level of output for the *i*th product given the actual output levels for all other products (as well as the stock of capital, input prices, the state of technology, and resource stocks). CU_i is correspondingly defined as $CU_i = y_i^* / y_i$ for any given i. The numerical value of this CU measure will vary across products, and therefore it is not unique for a given firm. Nonetheless, under certain conditions, it might be possible to form a consistent partial CU measure.[23] Consistency of the

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[22] A consistent scalar measure of output in multiproduct firms exists if all outputs are homothetically separable from inputs, and a direct analogue of the single-product primal measure of capacity and CU can be developed for the multiproduct firm (Segerson and Squires, 1990). When the technology is not homothetically separable, Segerson and Squires (1990) suggest two alternative ways of defining a primal CU measure: (1) outputs move along a ray, giving a ray measure of capacity and CU and (2) only output adjusts, giving a partial measure of capacity and CU.

[23] For the economic definition of capacity, let the firm's variable cost function be given by G(y,w,K), where y is a vector of outputs, w is the vector of variable input prices, and K represents one input that is quasi-fixed. Let $\subset G/\subset y_i = G_i$ and $\subset^2 G/\subset y_i \subset K = G_{iK}$. Then from Theorem 1 of Segerson and Squires (1990), if $G_{iK} < 1 \;\forall$ i, exactly one of the following holds: (1) $CU_i > 1$ for all i; (2) $CU_i < 1$ for all i; or (3) $CU_i = 1$ for all i. Given the levels of all other outputs, if $y_i < y_i^*$, then $-G_K < P_K$ (where P_K denotes the rental or services price of K) and there is an incentive to disinvest, i.e. capacity is underutilized. This holds true regardless of the product considered, i.e. which one is allowed to adjust to equate the shadow value and the price of capital K. Thus, the question of whether the firm faces expansionary or contractionary forces has the same answer regardless of which product is used to measure capacity utilization (Segerson and Squires, 1990). The full CU measure = 1 implies $CU_i = 1$ for all i. Finally, the partial and full CU measures could converge at different rates (e.g. if costs are relatively insensitive to changes in output).

partial CU measure when applying the technological-engineering approach and a single stock of capital has yet to be evaluated in the literature.

When there are both multiple outputs and multiple (quasi-) fixed factors, measures of capacity and CU become problematic (Berndt and Fuss, 1986).[24] However, in fisheries and other natural resource industries with stock-flow production technologies, and when the resource stock is conceived of as natural capital stock (i.e. as quasi-fixed or fixed inputs), capacity and CU can be found recognizing that these are short-run. Each species output flows from a corresponding resource stock. The estimates of capacity and CU can be made conditional upon the existing (or target) resource stocks, given a single stock of man-made capital. The resource stocks can alternatively be conceived as technological constraints, like the state of technology, and capacity and CU measured conditional upon their levels. Either conceptualization of the resource stocks gives equivalent empirical results. When a heterogeneous man-made capital stock is considered, the issue of multiple quasi-fixed or fixed factors once again raises its head.

2.9 Multiple fisheries and the level of aggregation

The issue arises of what capacity to measure when there are multiple fisheries or multiple resource stocks harvested by different gear types. In general, multispecies fisheries and multiple fisheries can be approached as multiproduct industries (Kirkley and Squires, 1999; Gréboval and Munro, 1999). The TWG concluded that stock-by-stock, fleet-by-fleet, and region-by-region approaches are all required (FAO, 1998b).

The level of spatial, species, and gear aggregation affects the results. The more broadly based the analysis, such as a major regional fishery across all gear types instead of a more narrowly defined one, the more the effects of fleet interaction and mobility are incorporated. More broadly based analyses might indicate lower or even zero excess capacity, since high-value species might show excess capacity relative to MSY but are counter-balanced by under-capacity relative to MSY lower-value species.[25] For example, world-wide, many demersal (bottom dwelling) fisheries are generally believed to face excess capacity but lower-valued pelagic (surface dwelling) species may face under-capacity (FAO, 1998a).[26]

[24] With the technological-engineering approach to capacity and a single output for example, CU may equal one, seemingly indicating full capacity, but when in fact one fixed factor may be fully utilized, while the other is not. Alternatively, in the economic approach to capacity, capacity corresponds to the tangency point of the short- and long-run average cost curves, where the short-run average cost curve depends on all fixed factors. This tangency occurs when the shadow prices and service/rental prices of each fixed input are each equal, and capacity utilization is defined as the output level satisfying the equality of shadow and actual total costs (Morrison, 1993: p. 65). Nonetheless, its interpretation can be unclear with multiple fixed factors, since it is possible for capacity utilization to equal one (shadow and total costs are the same) even if the actual prices of the fixed factors do not equal their shadow values (e.g. if there are offsetting effects). The implications of this for investment incentives are unclear, since a unique measure of capacity output may not exist in this context even with only a single output (Morrison, 1993: p. 65).

[25] Klein (1960) discussed whether measures of capacity output suffer from aggregation problems. For example, capacity outputs for firms might all be increasing and yet industry capacity output may not be consistent with the sum of the firm's individual capacity outputs because of, say, downward sloping industry demand, or upward sloping supply curves for inputs (Morrison, 1993: p. 72). Moreover, firm-level data can only be aggregated to the industry level under very stringent conditions (van Daal and Merkies, 1984; Morrison, 1993: Chapter 10).

[26] Production from most of the high-value species, and from demersal stocks in particular, has levelled off since the mid-1970s, with the world-wide growth in landings since then, except for tuna and cephalopods, accounted for by increased landings of lower-value species, much of which are reduced to fish meal (FAO, 1998b). The recent global analysis by Grainger and Garcia (1996) indicates that about 40 percent of the global resource stock, often of lower value, may have allowed for increased catch.

Highly aggregated analyses, such as global or regional, might best describe the issue and indicate approximate orders of magnitude, whereas capacity management might best be served by disaggregated analyses with finer resolution (FAO, 1998a). Aggregated analyses may also be relevant for highly mobile tuna stocks and fisheries, but not efficacious across fishing areas or fisheries that are spatially distinct or sufficiently technologically distinct (FAO, 1998a).

3. MEASURING FISHING CAPACITY

There are a number of approaches to assess fishing capacity. The two most promising approaches for widespread, tractable application correspond to the technological-economic definition that focuses upon capacity output and does not require cost data. This best serve the current FAO-led efforts to globally manage fishing capacity and the requirements of member nations to develop national capacity management plans. Both approaches are nonparametric in that they do not entail statistical analysis. These are the peak-to-peak method of Klein (1960), and output- and input-oriented data envelopment analysis (DEA) approach developed by Färe *et al*. (1989, 1994) and proposed for fisheries by Kirkley and Squires (1999).

The peak-to-peak approach is best suited when data are especially parsimonious, such as when the data are limited to catch and vessel numbers.[27] The approach permits determining the capacity output and the potential level of capital which might be targeted for reduction in decommissioning schemes, although it does not provide any information to indicate the actual operating units to be decommissioned (Kirkley and Squires, 1999). Ballard and Roberts (1977) and Garcia and Newton (1997) are the most prominent applications of the peak-to-peak method in fisheries.

The stochastic production frontier provides another option, since it gives the maximum possible output (Kalirajan and Salim, 1997; Kirkley and Squires, 1999). To conform to the technological-engineering approach to capacity, the frontier should be estimated with the stock, not the flow, of capital and with full utilization of variable inputs, not the observed level of use. The stochastic frontier approach does not readily accommodate multiple outputs.

3.1 Data envelopment analysis

DEA is a nonparametric or mathematical programming technique to determine optimal solutions given a set of constraints (Charnes *et al.,* 1994). DEA can be used to calculate capacity and CU using the approach of Färe *et al.* (1989, 1994).[28] The DEA

[27] The peak-to-peak method (also called trend line through peaks, Klein and Long, 1973) defines capacity by estimating the observed relationship between catch and fleet size. Periods with the highest ratio of catch to the capital stock provide measures of full capacity (maximum attainable output). Estimates of maximum attainable output for the most recent years are obtained by extrapolating the most recent output-capital peak and multiplying by the capital stock in the selected recent years. Capacity output is compared to actual output levels in different time periods to give measures of CU. Catch levels in all years can be adjusted for productivity levels. The method is most seriously limited by the problem that vessel tonnage or numbers are only a rough measure of capital stock, the analysis ignores other economic inputs (it essentially utilizes the average productivity of capital), and it ignores differences across gear types (which can change over time). Ballard and Roberts (1977), Garcia and Newton (1997), and Kirkley and Squires (1999) give further discussion, including its weaknesses.

[28] Klein and Long (1973: p. 746) describe an earlier approach using linear programming to measure the technological-engineering definition of capacity, "*... as the bottleneck point in expansion along a given ray corresponding to a fixed product mix*." When one product hits such a bottleneck, all others dependent on it for intermediate input are restricted at less than full CU. This provides a maximum output point while preserving a given product mix.

approach determines the maximal or capacity output given that the variable factors are unbounded or unrestrained and only the fixed factors and state of technology constrain output. Based on an output orientation (i.e. output is allowed to change while inputs are held constant), capacity output is determined by solving a simple linear programming problem. The maximum possible output or capacity corresponds to the output which could be produced given full and efficient utilization of variable inputs, but constrained by the fixed factors, the state of technology, and when included, the resource stock.

The difference between observed and frontier output gives the excess capacity for that resource stock in an output-oriented approach, but may be biased downward because of the possible inefficiency in production. In many fisheries, however, observed output is usually the TAC. Thus, both measures of excess capacity should be considered.

DEA has several unique advantages (Kirkley and Squires, 1999). DEA can estimate capacity under constraints including TACs, by-catch (incidental catch of species other than those intended), regional and/or size distributions of vessels, restrictions on fishing time, and socio-economic concerns such as minimum employment levels. DEA readily accommodates multiple outputs and multiple inputs, zero-valued output levels, and nondiscretionary inputs and outputs. DEA can also determine the maximum potential level of effort or variable inputs in general and their optimal utilization rate. The analysis accepts virtually all data possibilities, ranging from the most parsimonious (catch levels, number of trips, and vessel numbers) to the most complete (a full suite of cost data). With cost data, DEA can be used to estimate the least-cost (cost minimizing) number of vessels and fleet configuration. It can also measure capacity to any desired biomass or TAC. DEA also allows both the input- and output-oriented approach.

The DEA approach to capacity measurement effectively converts the multiple products into a single composite output because there is a radial expansion of outputs (outputs are in fixed proportions for different input levels). This gives the ray measure of capacity and CU considered by Segerson and Squires (1990, 1992, and 1995), and implicitly imposes Leontief separability among the outputs.

The heterogeneous capital stock represents multiple quasi-fixed or fixed factors.[29] By specifying a heterogeneous capital stock, the specification does not necessarily *a priori* denote any individual piece of capital as binding or fully utilized, and in fact, not all fixed factors necessarily will bind. Instead, the data can determine the individual component of the heterogeneous capital stock that binds on a firm-by-firm basis. For instance, the vessel length might bind for one firm while engine horsepower might bind for another firm.

In two different ways, the DEA approach effectively converts the heterogeneous capital stock (multiple fixed or quasi-fixed factors) into a single measure of the capital stock (composite factor) to solve the indeterminancy problem raised by Berndt and Fuss (1986). First, when the DEA measure of capacity is output-oriented, i.e. the maximum output given (quasi-) fixed inputs, the (quasi-) fixed inputs or heterogeneous capital stock are held constant at observed levels, and as discussed above, that individual component of the heterogeneous capital stock that is fully utilized (binding) is the individual capital stock that determines capacity. Second, and perhaps more importantly, the DEA measure of capacity entails a radial

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[29] These factors can be captured by different proxy variables, each of which measures one of the capital components. These proxy variables can include those that resource managers denote as most important at capturing production and which are most easily regulated, such as vessel length or gross registered tonnage and main engine horsepower.

expansion of outputs and inputs, that is, outputs are in fixed proportions for any output levels and inputs are in fixed proportions for any input levels. When (quasi-) fixed inputs are in fixed proportions, an aggregate fixed input or capital stock is formed (Leontief separability). This effectively converts the multiple (quasi-) fixed factors into a composite measure.

Other issues that could be considered within the DEA framework include calculation of capacity output under various by-catch mitigation or habitat restoration policies. Adding by-catch simply requires reformulating the problem such that by-catch is treated as an undesirable output; this requires subvector disposability constraints.[30]

3.2. DEA and vessel decommissioning

Capacity reduction programmes are conceived in terms of reducing vessel numbers and the associated fishing power, such as for example, through vessel buybacks. The target capacity level, such as TAC, needs to be directly and explicitly linked to the appropriate and superfluous numbers of vessels and their composition (vessel sizes, regional distribution, engine power, gear type, and so forth).

The need for vessel decommissioning in capacity reduction programmes can be directly addressed using the DEA approach (Kirkley and Squires, 1999). Because DEA can be either output- or input-oriented, different aspects of vessel decommissioning can be addressed. The input-based measure considers how inputs may be reduced relative to a desired output level, such as a TAC.[31] Hence, it would allow determining the optimal vessel or fleet configuration and actual vessels that should be decommissioned in a fishery corresponding to a TAC. The output-based measure indicates how output could be expanded to reach the maximum possible output level, given the capital stock and full utilization of variable inputs. The output-oriented DEA measure allows fishery managers to identify the level of output and vessels which would maximize output subject to given full utilization of variable inputs and fixed factors and (optionally) resource constraints. Hence, it can be used to identify operating units (individual vessels or vessel size classes) that can be decommissioned. By rearranging observations in terms of some criterion, such as capacity by region and vessel size class, the number of operating units can be determined by adding the capacity of each operating unit until the total reaches the target.[32] Moreover, given a TAC, the output-based measure could yield a precautionary level of total inputs and vessels that yield maximum technical efficiency.

3.3 The DEA framework

Following Färe *et al.* (1989), let there be $j = 1,...,J$ observations or firms in an industry producing a scalar output $u^j \in R_+$ by using a vector of inputs $x^j \in R_+^N$. We also assume that

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[30] Disposability generally refers to the ability to stockpile or discard or dispose of unwanted commodities (Färe *et al.,* 1994). The private disposal cost distinguishes two types of disposability. Strong disposability refers to the ability to dispose of an unwanted commodity with no private cost. Weak disposability refers to the ability to dispose of an unwanted commodity at positive private cost. Thus, joint reduction of a bad output entails scaling back production of a good output. Strong disposability implies weak disposability but not vice versa.

[31] In an input-oriented approach, an infeasible solution is possible without constant returns to scale. A TAC is the target flow from a corresponding resource stock. Unless the resource stock level is in excess of that corresponding to the TAC, the resource stock should be held constant as a nondiscretionary input or a technological constraint. The variable inputs would be scaled under all circumstances. If the capital stock(s) is not scaled back, it should be specified as a nondiscretionary input(s).

[32] The dual economic measures of CU allow direct estimation of the optimal number of vessels corresponding to the TAC.

for each n, $\sum_{j=1}^{J} x_n^j > 0$, and for each j, $\sum_{n=1}^{N} x_n^j > 0$. The first assumption states that each input is used by some firm. The second assumption indicates that each firm uses some input. A remaining assumption is that each firm produces some output, $u^j > 0$ for all j.

The following output-oriented data envelopment analysis (DEA) problem calculates Johansen's notion of capacity (Färe *et al.,* 1989, 1994):

$$\begin{aligned}
&\max_{\theta\lambda z}\ \theta \\
&\text{s.t. } \theta u_j \leq \sum_{j=1}^{J} z_j u_j \\
&x_{jn} \geq \sum_{j=1}^{J} z_j x_{jn},\ n \in \alpha \\
&\lambda_j x_{jn} = \sum_{j=1}^{J} z_j x_{jn},\ n \in \hat{\alpha} \\
&z_j \geq 0,\ \lambda_{jn} \geq 0\ \forall\ n \in \hat{\alpha}
\end{aligned} \tag{1}$$

The variable factors are denoted by $\hat{\alpha}$, the fixed factors are denoted by α and the z_j define the reference technology. Problem (1) enables full utilization of the variable inputs and constrains output with the fixed factors. Moreover, the vector λ is a measure of the ratio of the optimal use of the variable inputs (Färe *et al.,* 1989, 1994). λ gives the capacity utilization rate of the n^{th} variable input for the j^{th} firm for $x_{jn} > 0$, $n \in \hat{\alpha}$. Problem (1) imposes constant returns to scale, but it is a simple matter to impose variable returns to scale (i.e. variable returns to scale requires the convexity constraint $\Sigma z_j=1$.

The parameter θ is the reciprocal of an output distance function and is an output-oriented measure of technical efficiency relative to capacity production, $\theta \geq 1.0$. It provides a measure of the possible (radial) increase in output if firms operate efficiently given the fixed factors, and their production is not limited by the availability of the variable factors of production (e.g. a value of 1.50 indicates that the capacity output equals 1.5 times the current observed output). If * denotes an optimum, then $\theta^*_j u^j$ equals the maximum amount of u^j that can be produced given observed levels of fixed factors α and full utilization of variable inputs $\hat{\alpha}$ capacity output for output u^j.

The CU measure of observed output divided by capacity output may be downward biased because the numerator in the traditional CU measure, observed output, may be inefficiently produced. Färe *et al.* (1989) demonstrate that an unbiased measure of CU may be obtained by dividing an output-oriented measure of technical efficiency corresponding to observed variable and fixed factor input usage by the technical efficiency measure corresponding to capacity output (i.e. the solution to problem (1) in which variable inputs $\hat{\alpha}$ are fully utilized).

To obtain a measure of TE corresponding to observed input usage, Färe *et al.* (1989) suggest that TE of the jth firm, ($\theta(x^j)$), may be obtained as a solution to a linear programming problem:

$$\max_{\theta\lambda z} \theta$$
$$\text{s.t. } \theta u_j \leq \sum_{j=1}^{J} z_j u_j$$
$$x_{jn} \geq \sum_{j=1}^{J} z_j x_{jn} \ \forall n \tag{2}$$
$$z_j \geq 0$$

where the input vector x includes both the fixed and variable inputs.

Problem (1) provides a measure of TE, θ_1, which corresponds to full capacity production. Problem (2) provides a measure of TE, θ_2, which corresponds to technically efficient production given the usage of the variable inputs. The ratio of the two θs, θ_2/θ_1, is an unbiased measure of capacity utilization (Färe *et al.,* 1989). Solutions to problems (1) and (2) provide estimates of technical efficiency, capacity, capacity utilization, and optimal input utilization relative to a best practice frontier.[33] The solutions are not indicative of absolute efficiency and capacity.

The optimal levels of the fixed factors (which would approximately correspond to the long-run level of capacity) can be calculated under constant returns to scale. Alternatively, it is possible to assess the optimum levels of the fixed and variable factors that correspond to scale efficiency and use those levels as benchmarks for assessing capacity in the long-run. We defer these other possible approaches to future research because there is no comparative basis upon which to evaluate the corresponding results. More important, though, is that even if the approach cannot provide measures of capacity and capacity utilization for the long-run, it can still provide measures useful for determining the potential capacity removed with vessel reduction programmes. Also, it is highly probable that any capacity reduction programme implemented by resource managers would have additional constraints on the existing vessels such that capacity would not be allowed to increase in a short to intermediate time period.

4. CONCLUDING REMARKS

The economic issue of excess capacity, its biological twin of overfishing, and their management are the single dominant issues in world fisheries today. They are currently the subject of considerable attention at the national and international levels. Nonetheless, considerable confusion has reigned over a definition and a tractable means of measuring capacity and excess capacity in fishing industries.

The paper provides both technological-engineering and economic definitions of capacity and excess capacity in fishing industries. The paper recommends the technological-engineering approaches to measuring capacity and excess capacity. Either output- or input-oriented approaches are possible. The paper provides definitions and a tractable approach to measurement using Data Envelopment Analysis.

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[33] The variable input utilization rate measures the ratio of optimal variable input usage to actual variable input usage, where the optimum variable input usage is that variable input level which gives full technical efficiency at the full capacity output level (Färe *et al.,* 1994). If the ratio of the optimum variable input level to the observed variable input level exceeds 1.0 in value, there is a shortage of the i^{th} variable input currently employed and the firm should expand use of that input. If the ratio is less than 1.0 in value, there is a surplus of the i^{th} variable input currently employed and the firm should reduce use of that input. If the ratio equals 1.0, the actual usage of the i^{th} variable input equals the optimal usage of the i^{th} variable input.

This paper applied the engineering-technological definition of fishing capacity, as the short-run maximal output given the capital stock and with and without resource stocks, to the Northwest Atlantic sea scallop fishery to estimate capacity in the harvesting sector. The paper calculated the excess capacity and corresponding number of vessels that should be removed from the fishery to satisfy a target level of fishing capacity and socio-economic goals for the distribution of decommissioned vessels.

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