

433/2

# Measuring and assessing capacity in fisheries

2. Issues and methods



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FAO  
FISHERIES  
TECHNICAL  
PAPER

433/2

2. Issues and methods

by

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ISBN 92-5-105015-5

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## PREPARATION OF THIS DOCUMENT

In 1998, FAO organized a Technical Working Group (TWG) to discuss issues related to fishing capacity. Major issues discussed included measurement and control methods for managing and reducing capacity. The FAO meeting also served as a basis for the development of an International Plan of Action (IPOA) for the Management of Fishing Capacity. The FAO Committee on Fisheries adopted the IPOA in February 1999. A subsequent FAO Technical Consultation was held in Mexico City in 1999. The purpose of that meeting was to better define capacity and capacity utilization in fisheries, and to examine methods or develop general guidelines that might be used to estimate capacity and excess capacity in fisheries.

Since the 1988 meeting, considerable activity has been undertaken by FAO in studying fishing capacity. This has culminated in several reports, including:

- Report of the Technical Working Group (TWG) meeting on the Management of Fishing Capacity (FAO Fisheries Report No. 586, 1998).
- Selected papers from the TWG Meeting (FAO Fisheries Technical Paper No. 386, 1999).
- International Plan of Action on the Measurement of Fishing Capacity (1999).
- Report of the Technical Consultation on the Measurement of Fishing Capacity (FAO Fisheries Report 615, 2000).
- A review of policy and technical issues involved in managing capacity (FAO Fisheries Technical Paper No. 409, 2001).
- Report on the Expert Consultation on Catalysing the Transition away from Overcapacity in Marine Capture Fisheries (FAO Fisheries Report No. 691, 2002).
- Selected papers from the Technical Consultation on the Measurement of Fishing Capacity (FAO Fisheries Technical Paper 443, 2003).

This current report is part of this ongoing commitment to improving methods for assessing and managing fishing capacity. The report is in two volumes, published separately. Part 1 provides an overview of basic concepts for the assessment and management of fishing capacity. Part 2 provides more details on methods for measuring and assessing capacity. The first volume is aimed at managers and policy-makers who need to have an understanding of the key concepts but are not likely to be involved in capacity assessment directly. The second volume is aimed at fisheries economists and scientists who are likely to be involved in the process of measuring and assessing fishing capacity.

### ***Distribution:***

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Pascoe, S.; Kirkley, J.E.; Gréboval, D.; Morrison-Paul, C.J.  
**Measuring and assessing capacity in fisheries. 2. Issues and methods.**  
*FAO Fisheries Technical Paper*. No. 433/2. Rome, FAO. 2003. 130p.

### ABSTRACT

This Fisheries Technical Paper provides guidance for the measurement and assessment of fishing capacity, with the aim of facilitating the implementation of the International Plan of Action (IPOA) for the Management of Fishing Capacity. It provides a discussion and overview of the various concepts of capacity and capacity utilization and potential methods for estimating capacity discussed at the FAO Technical Consultation on the Measurement of Fishing Capacity held in Mexico City from 29 November to 3 December 1999. The Technical Paper also introduces some more recent methodologies for examining capacity in fisheries. Its specific objective is to provide the information necessary for developing a widely accepted definition of capacity for fisheries as well as sufficient detail about various methods for estimating capacity to permit an empirical assessment of fishing capacity conditional on the types of data typically available for fisheries. The Technical Paper initially discusses concepts and issues necessary for understanding capacity and capacity utilization in fisheries. It then discusses the primary methods often used to estimate capacity. The Technical Paper also provides empirical examples of how the various approaches can be used to estimate and assess capacity. Finally, a potential framework for assessing overcapacity is presented and discussed.

## FOREWORD

Government officials and fishery scientists from around the world long ago recognized that unrestricted entry into a fishery would result in fishing fleets having the ability to harvest in excess of sustainable levels. Overcapacity is now recognized as a major and global problem for maintaining socially and economically viable fisheries (FAO, 1999). In the absence of appropriate restrictions on harvesting activities, fishing fleets could easily deplete valuable fishery resources and generate considerable economic waste. These are the basic problems – resource depletion and economic waste – created by overcapacity in fisheries.

Managing fishing capacity first requires information on current levels of overcapacity and underutilized capacity in the fisheries. This Fisheries Technical Paper provides guidance for measuring and assessing fishing capacity. It is primarily intended for use by fisheries managers, economists, and multi-disciplinary research teams interested in the management of fishing capacity and related measurement issues. The Technical Paper provides a discussion and overview of the various concepts of capacity and capacity utilization and potential methods for estimating capacity discussed at the Mexico City Technical Consultation in 1999. The Technical Paper also introduces some more recent methodologies for examining capacity in fisheries. The major objectives of this Technical Paper are to provide the following: (1) information necessary for developing a widely accepted definition of capacity for fisheries; and (2) sufficient detail about various methods for estimating capacity to permit an empirical assessment of fishing capacity conditional on the types of fisheries data typically available. Initially, the Technical Paper discusses concepts and issues necessary for understanding capacity and capacity utilization in fisheries. It then discusses the various methods frequently used to estimate capacity. Empirical examples also are provided to illustrate how various approaches may be used to estimate and assess capacity and capacity utilization in fisheries. Last, a potential framework for assessing overcapacity is presented and discussed.

Although economics serves as the principal analytical framework used by the authors, the concepts, approaches and methods proposed reflect a rather general approach to the measurement, assessment and management of fishing capacity.

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## 1. INTRODUCTION

### 1.1 Background

Many of the major fishery resources of the world are currently being exploited by an excess number of vessels and are in a state of decline due to overfishing (FAO, 1997). This has been caused, in part, by the historically unrestricted expansion of fishing effort permitted under open access regimes, which characterized fisheries management between 1950 and 1990. Even after the widespread adoption of various controlled access schemes, effective fishing effort still increased as vessels adopted new technology. New and larger vessels and the adoption of more sophisticated technology have enhanced the ability of many of the world's fishing fleets to harvest fishery resources. The combination of increases in the number of vessels, improvement in efficiency and expansion of effort has resulted in excess capacity in many world fisheries. Fishery resources, although renewable, are finite or limited in size, and only so much can be removed without jeopardizing the resource. Once the rate of removal reaches a certain level or biological threshold, the resource declines in abundance or experiences other problems. Alternatively, even in the absence of biological problems, an excessive rate of removal may subsequently cause serious social and economic problems.

Fisheries management measures are applied in most fisheries around the world in an attempt to counter the propensity to overexploit the resource. Until recently, most regulations used to manage fisheries have been command and control type. These types of regulations specify not only how much is to be caught, but also how to catch it. The more common types of command and control regulations include catch quotas, size limits, and restrictions on fishing effort or some aspect that influences effective fishing effort. In general, these types of restrictions may be considered as output or input controls. Such restrictions, while possibly realizing biological objectives of management,<sup>1</sup> do not address the open access nature of fisheries, and thus do not generally reduce excess capacity. Indeed, failure of these restrictions often leads to the imposition of even more restrictions, which increases production costs for fishers while failing to address the underlying problem of excess harvesting capacity.

Early attempts to directly address excess capacity in fisheries included limited access or controlled access schemes (Scott, 2000). Typically, limits were imposed on the number of operating units or vessels allowed to operate in a fishery. These limited entry programmes, however, also were found to be inadequate for controlling expanding capacity. Fishers simply engaged in capital stuffing by increasing their capital stock (e.g. larger engines, more electronics and more efficient gear). Capacity reduction programmes were subsequently introduced into many fisheries, generally in the form of publicly funded buyback programmes. These programmes offered temporary respite from the problems of excess capacity, but as the underlying problem of inadequate property rights was not addressed, capacity would again increase through increased capital investment.

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<sup>1</sup>Throughout the world, fisheries management and regulation have typically addressed resource problems first and social and economic issues next. The primary objective of management has traditionally been to protect or restore resource levels. In contrast, social and economic objectives have traditionally not been viewed, in practice, by managers as the primary objective of fisheries management and regulation, except for those fisheries for which a large number of participants engage in subsistence fishing or food security is of a major concern. In recent years, however, there has been an increasing awareness by managers of the need to more thoroughly consider the social and economic ramifications of management.

Individual transferable quotas, or ITQs, which represent a quasi-private property right management regime, were subsequently offered as a way to address excess capacity and biological problems (Anderson, 2000). ITQs, however, are not without problems, and for some fisheries and social institutions, ITQs either may not resolve the problem of excess capacity or may prove inappropriate (Scott, 2000; Arnason, 2000; Anderson, 2000; McCay, 2000; Shotton, 2000). Given the extent of excess capacity in most fisheries, it is unlikely that many regulatory regimes will realize stated management goals and objectives without experiencing at least some social and economic costs, especially in the short run.

Although there is increasing evidence indicating that excess capacity has begun to diminish because of alternative management and regulatory regimes, there also remain many fishing fleets with substantial excess capacity (FAO, 1997). These fleets have the capability to harvest well in excess of sustainable levels. The imbalance between the ability of the world's fishing fleets to harvest fishery resources and the ability of fishery resources to sustain such harvest levels is the major problem currently facing world fisheries. With harvest levels in many fisheries exceeding the maximum sustainable yield (MSY) or other desired target levels, managing fishing capacity is critical to ensure continued sustainability of resource and harvest levels.

In 1995, the Code of Conduct for Responsible Fisheries (CCRF) was adopted by the FAO Conference. The Code of Conduct for Responsible Fisheries recognizes that excess capacity is a major impediment to sustainable fishing. In particular, Article 6.3 of the CCRF recommends 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 resource and their sustainable utilization.*" Further, Article 7.1.8 of the CCRF states that "*States should take measures to prevent or eliminate excess fishing capacity and should ensure that levels of fishing effort are commensurate with the sustainable use of fishery resources as a means of ensuring the effectiveness of conservation and management measures*" (FAO, 1995).

In 1998, a technical working group (the La Jolla working group) was convened by the FAO to consider the management of fishing capacity (FAO, 1998; Gréboval, 2003). Subsequent to the La Jolla working group meeting and several FAO technical consultations, the Committee on Fisheries (COFI) adopted an International Plan of Action (IPOA) for the Management of Fishing Capacity (FAO, 1999a). The plan calls for all member states to achieve efficient, equitable and transparent management of fishing capacity by 2005 (and preferably, by 2003). Guidelines on the "Management of Fishing Capacity" have been developed separately to assist in this process (Cunningham and Gréboval, 2001).

A major action specified by the IPOA was the assessment and monitoring of fishing capacity. In particular, the IPOA recommended that states should perform the following (FAO, 1999a):

- *proceed, by the end of 2000, with a preliminary assessment of the fishing capacity deployed at the national level in relation to all the fleets of principal fisheries and update this exercise periodically (Section 1, Paragraph 13);*
- *proceed, by the end of 2001, with the systematic identification of national fisheries and fleets requiring urgent measures and update this analysis periodically (Section 1, Paragraph 14); and*

- *cooperate, within the same time frame, in the organization of similar preliminary assessments of fishing capacity at the regional level (within the relevant regional fisheries organizations or in collaboration with them, as appropriate) and at the global level (in collaboration with FAO) for transboundary, straddling, highly migratory and high seas fisheries, as well as in the identification of regional or global fisheries and fleets requiring urgent measures (Section 1, Paragraph 15).*

In December 1999, a Technical Consultation on the Measurement of Fishing Capacity was held in Mexico City to define capacity and develop methods for measuring and assessing fishing capacity (FAO, 2000). Fishing capacity was subsequently defined as follows: *the amount of fish (or fishing effort) that can be produced over a period of time (e.g. a year or a fishing season) by a vessel or a fleet if fully utilized and for a given resource condition.* Full utilization in this context means normal but unrestricted use, rather than some physical or engineering maximum.

The FAO (2000) concept of capacity is a technical concept and relatively void of economic content; that is, it is not directly related to economic decision making behaviour (e.g. cost minimization or profit maximization). This concept, however, does implicitly reflect economic decision-making behaviour because empirical data used to estimate this notion of capacity reflect the consequences of decision-making behaviour. Kirkley, Morrison-Paul and Squires (2002) term this concept of capacity as a “technological-economic” measure of capacity output.

## **1.2 Key concepts used in the document**

In many industries, concepts relating to capacity are well defined. For example, the capacity of a car factory is the total number of cars that could be produced if the factory was fully utilized. That is to say, both capital and labour were operating at their maximum level, the latter being defined in terms of normal working practices (e.g. in terms of hours per shift and number of shifts per day). A particular problem arises in fisheries management tied to the fact that a key input into the production process – the fish stock itself – is not controllable by the individual producer and can change over time. A further problem unique to fisheries is that the use of this input is generally costless to the fisher. In the absence of well defined property rights, such as those partially existing under ITQs, incentives are created for individuals to try to increase their share of the limited resource. Such incentives not only affect their own future production, but the future production of others in the industry. These incentives lead to an increased level of capital in the industry over and above that which might be expected to develop in non-resource-based industries and a situation in which increased levels of investment decrease, rather than increase, longer term output. This leads to the often used description of the state of many fisheries: too many boats, not enough fish.

These unique problems have led to the standard concepts of capacity as adopted in most industries being confused in fisheries literature, and new terms introduced to try and overcome the definitional problems arising from variable fish stock. As a result, the concepts of capacity in fisheries (as will be seen in this document) involve subtleties that are not required in the analysis of capacity in most industries, and a number of definitions are often used that may not exist or may differ from those used in the traditional literature on capacity. In particular, the need to distinguish between short- and long-term measures of excess capacity has resulted in different terminology being adopted. In the case of fisheries, these

have been defined as excess capacity and overcapacity, respectively. Similarly, the concept of target capacity is unique to fisheries. Conventions also exist in fisheries to measure capacity in terms of inputs as well as outputs. In this document the concepts often used in fisheries literature are adopted, which can differ from those used in studies of capacity in other industries. In this section, a simple intuitive outline of these key concepts as they relate to fisheries is provided. More precise specifications are given in the following chapters.

The concept of capacity, defined in FAO (2000) and generally adopted in the fisheries literature, is primarily a short-run concept as it relates to the underlying resource base (i.e. the state of the stock). In its basic form, *capacity output* is the maximum level of output that can be produced by the *capacity base* if it is fully utilized. The *capacity base* represents the fixed inputs used in the harvesting process, and also could be considered an input-based measure of capacity. Fixed inputs are those that cannot be readily adjusted in the short term (e.g. the fishing season). At a basic level, these might be the number of vessels, but in some fisheries the number of traps or nets may also form part of the capacity base. The capacity base is also associated with the level of capitalization in the fishery. This is a measure of the total investment, which is presented in terms of vessels, gear, or other equipment.

In simple terms, capacity output can be interpreted as the maximum catch that could be taken by the current fleet (the capacity base) if it was fully utilized (i.e. operated at the maximum level of fishing effort that could be expected under normal working conditions). Implicit in the measure are current stock conditions. With higher or lower stock levels, the maximum catch would be higher or lower also, and capacity output would rise or fall.

The *utilization rate* can be associated with the effort level. If a vessel is under-utilized, it is employing less effort (e.g. days fished) than it could, relative to other boats of the same size. As a consequence, its catch is less than would occur if it was operating at the same level of effort as other, similar boats. The rate of capacity utilization, therefore, at a very basic level is related to the level of effort employed by the vessel and also the difference between the current catch and the catch if fully utilized. Different measures of capacity utilization are related to these different aspects (i.e. effort levels or catch levels), as will be seen in subsequent chapters.

Catch in most fisheries depends upon the total level of fishing effort, normally expressed as a combination of vessel numbers and days fished. If many boats are operating at less than full capacity, similar levels of effort can be produced by fewer boats operating at full capacity. As a result, not all vessels are required to take the allowable level of catch if they operate at full capacity. The concept of *excess capacity* relates to the difference between the potential catch if all vessels are fully utilized and the current catch. For management purposes, excess capacity also can be interpreted as the difference between the number of vessels that exist in the fishery at the moment and the number that could take the same level of catch if fully utilized.<sup>2</sup> It is a short-term measure only, because it is related to current stock conditions. Under different stock conditions, a different number of vessels may be required to take the optimal catch level.

The concepts of capacity, capacity utilization and excess capacity are short-term measures, because they are related to the current stock level. The objectives of fisheries management

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<sup>2</sup>This is a simplification of the definition of excess capacity, as will be seen in subsequent chapters.

are often more long term in nature. For example, objectives may include obtaining the maximum sustainable yield from the fishery. If this differs from the current yield, then it is likely that stock conditions also vary, and hence, measures of capacity, capacity utilization and excess capacity tell us little about how much adjustment may be needed in the fishery in the short run to achieve management objectives. An alternative concept – *target capacity* – relates to the level of output and/or levels of effort and capital that achieve the longer term goals of fisheries management. A concept unique to fisheries analysis – *overcapacity* – has been introduced in the literature to describe the longer term concept of excess capacity. Overcapacity relates to the difference between “current” capacity (either in terms of effort, vessels, or expected catch given the long-term stock level) and the target level of capacity. It is a longer term indicator of how much adjustment may be required in the fishery, and it takes into account the changes in stock levels that would occur as a result of this adjustment.

The link between the concepts of excess capacity and overcapacity is not clear and the concepts are often confused. In other industries, there is no distinction between the two. However, in the case of fisheries where, unlike many other industries, production is influenced by an input over which the fisher has little control – the fish stock – some distinction needs to be made. It is possible for excess capacity to exist in the short term given current stock conditions, particularly if stocks are depleted, but all vessels may be required to catch the optimal yield when stocks have recovered. Conversely, it is possible for all vessels to operate at full capacity in the short term (so no apparent excess capacity exists), but the number of vessels may still be too high to take the target catch level at full capacity over the long run if fish stocks are at optimal levels (so overcapacity still exists).

The terms *short term* and *long term* have been used throughout the document. For purposes of this document, *short term* refers to the current fishing season or year. During this period, only some inputs are variable (e.g. days fished or crew number). The *long term* refers to the period over which both the stocks have adjusted to their target level, and inputs that are fixed in the short term (e.g. vessel numbers) also are able to vary.

The measurement of these concepts introduces additional complications. Further, the concepts may take on different meanings when considered from different perspectives. These complications and alternative interpretations are detailed in the chapters following.

### **1.3 The need for consistent estimates of capacity**

Fisheries management involves balancing inputs and outputs in order to achieve a particular objective or set of objectives. These objectives may include sustainability of the resource, economic efficiency and social considerations (e.g. preserving fishing communities). The process of balancing inputs and outputs requires links to be made between each. If such links can be established, theoretically the level of outputs from a fishery could be controlled through limits on the level of inputs, or the level of inputs employed in a fishery could be controlled through restrictions on the level of output. Establishing such links, however, is not straightforward; different combinations of inputs can be used to produce a wide variety of outputs. Restricting some inputs may lead to expanding the use of other unrestricted inputs, resulting in an inefficient mix of inputs and little output, or catch, reduction (Dupont, 1991). Restricting outputs directly may lead to a reduction in some inputs, and the underutilization of other (fixed) inputs, resulting in inefficient input usage. Fisheries managers therefore need

to continually assess the level of inputs and outputs employed in fishing, and manage such levels accordingly to balance associated responses with the potential of the resource.

The measurement of capacity provides an estimate of the productive potential of the fleet and the extent to which the current level of inputs is being fully utilized. Many countries have developed a range of capacity indicators, mostly based on physical attributes of the fleet. Key indicators of capacity that have been applied are measures such as gross tonnage (a measure of the volume of the vessel), engine power, and number of boats. In some countries, engineering measures such as vessel capacity units, generally based on a combination of characteristics, also have been developed. However, for countries with large artisanal fleets where the use of physical capital is limited (e.g. canoes rather than large mechanized vessels) and of less importance than labour inputs, such measures may have little meaning. The role of fixed versus variable factors must be carefully considered in their interpretation.

More generally, a difficulty in using these measures is that they are not consistent between countries, making international comparison problematic. This is particularly relevant where several countries and several heterogeneous fleet types (e.g. canoes and trawlers) share common stocks. Identifying a common measure of fishing capacity that can be aggregated over different fleet segments, and potentially different species in multispecies fisheries, is consequently essential for sound management of shared stocks.

#### **1.4 Objective of the document**

The objective of the document is to help national fisheries agencies and administrations derive appropriate measures of capacity and assess the level, if any, of excess capacity in their fisheries. Measures of capacity and assessment of excess capacity offer information critical for determining appropriate capacity management programmes. To this end, the document provides a conceptual framework for measuring and assessing fishing capacity, and it introduces and explains approaches for measuring fishing capacity, which likely will have the greatest empirical applicability, particularly given the limited fisheries data typically available.

The conceptual framework provides a non-technical description of how different measures of capacity and capacity utilization may be used to assess the degree (if any) of overcapacity and excess capacity in different types of fisheries. This foundation will help resource managers better determine which fleet segments or fisheries are most in need of management action. In this overview, key concepts briefly alluded to above are more fully elaborated, and their roles in understanding capacity issues discussed, for the purpose of allowing managers, biologists, technicians and economists to use a common language when assessing capacity and developing capacity management plans.

The methods for measuring capacity discussed in the second part of these guidelines are based on the methods recommended by the Mexico City consultation and more recent developments. Both simple (i.e. pragmatic but potentially less reliable) and somewhat more complex methods for capacity measurement are overviewed. Even more complex methods for estimating capacity are also available, but because of data limitations, these methods generally cannot be used to estimate fishing capacity (e.g. one might use a dual cost function to estimate a formal economic measure of capacity). These more complex measures are mentioned in the document, but details of the methods are omitted. References for further

exploration of these methods are provided, however, to allow individual states to gain a more thorough understanding of alternatives. It is anticipated that the measures described in this document will better enable states to more easily comply with the reporting requirements of the “International Plan of Action for the Management of Fishing Capacity.”

Measures presented in this document should enable states to undertake a “stock-take” of the levels of capacity in each of their fisheries. These measures, however, provide only a snapshot of capacity, capacity utilization and excess capacity at the fishery and national level. This is because the measures are static and do not directly incorporate uncertainty (e.g. what appears as excess capacity today or given current conditions may not be excess capacity tomorrow, or under a different set of circumstances than expected).<sup>3</sup> It is difficult also to impute what would happen if environmental or economic conditions or regulatory strategies in a fishery – which affect the measures and assessments of capacity and excess capacity – were to change. For example, price or stock level changes may result in a reallocation of fishing activity to other stocks or fisheries, or regulations imposed on one fishery may result in a transfer of fishing activity into another fishery.

Although methods that bring dynamics and expectations into these models and allow direct consideration of the impact of reallocation on a fishery (or at national level) may be developed, they are typically quite complex to implement. This is especially the case for latent effort (effort that could be expended in a fishery, but is not because of other reasons). When a vessel can operate in more than one fishery, it may be extremely difficult to assign effort to a particular fishery, and thus, more complicated to assess capacity and capacity utilization. Using methods that incorporate both dynamics and expectations as a base to guide policy also requires incorporating explicit knowledge about constraints on fisheries, since their direct application may generate infeasible solutions. For example, Färe, Grosskopf and Li (1992) offer one approach for estimating capacity of an industry when fixed and variable factors can be changed or reallocated. Without imposing realistic constraints on reallocation, however, the approach yields estimates consistent with proposing extremely large capital platforms (e.g. a fishery with one very large vessel). Imputing potential expected technological, economic and environmental conditions from observed data might, therefore, be somewhat arbitrary. Using simpler static methods, updated over time to accommodate changes and thus trace dynamic adjustments, seems a desirable solution.

The measures outlined in this document have limitations, as do any measurement methods. Within our discussions of various approaches to the conceptualization and measurement of capacity and capacity utilization, we attempt to identify these limitations in order to facilitate the most justifiable possible construction, interpretation and use of the measures. Fisheries managers should view the measures as overall indicators and additionally consider possible dynamics and other complicating factors (e.g. the potential allocation of fishing activity) when developing capacity management plans.

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<sup>3</sup>Discussions about dynamic and stochastic measures of capacity are available in Fousekis and Stefanou (1996), Fagnart, Licandro and Sneesens (1997) and Fagnart, Licandro and Portier (1999).



## 2. CAPACITY, RELATED CONCEPTS AND FISHERIES

### 2.1 Capacity and related concepts

The concept of capacity can be quite difficult to define and even more cumbersome to understand. There are numerous definitions of capacity, and several bases upon which to define it. The most widely used concept of capacity is the maximum potential production of an output or group of outputs by a producing unit, firm, or industry, given technology, capital stock and other factors of production. By definition, capacity is a short-run concept, since at least one input (usually the capital stock) and technology are held fixed at some level. There are at least three bases upon which to consider the concept of capacity.

First, there is an engineering concept of capacity. This concept of capacity defines a theoretical maximum rather than a real world, practical maxima (e.g. the name plate rating on an electric power generator or the maximum power rating on an engine) (Coelli, Grifell-Tatje, and Perelman, 2001). The engineering concept, however, is not a particularly useful concept for managers of fisheries and is not further considered in this Technical Report.

Another notion of capacity is the “pure physical” or “technological” notion of capacity. The physical or technological concept of capacity is the maximum potential output a producing unit, firm, or industry could produce, given technology, capital stock and other factors of production, but without any limits on the factors of production that can be changed (e.g. labour and energy) in the short run.

A third concept is the economic concept of capacity. As broadly interpreted, the economic concept of capacity is the output level that would be produced in order to satisfy some underlying economic behavioural objective, such as profit maximization or cost minimization (Morrison, 1985; Coelli, Grifell-Tatje and Perelman, 2001). This notion defines capacity as an economically-derived optimum level of output.

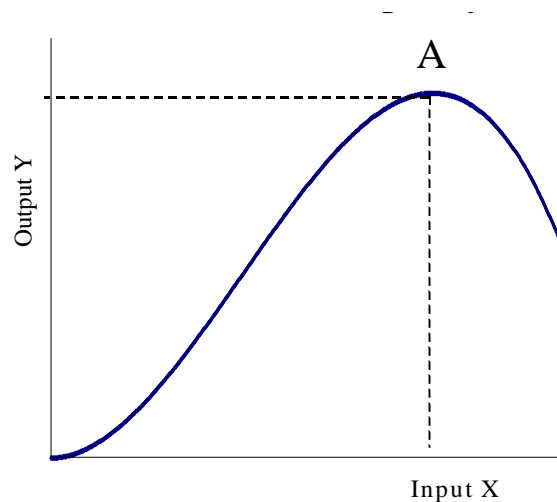
Regardless of whether or not capacity is defined according to an engineering maximum, a technological or purely physical maximum, or an economic optimum, capacity refers to a potential output level (e.g. the maximum potential number of automobiles a car manufacturer could produce, or the number of automobiles that must be produced in order to maximize profits). Even though all of the concepts of capacity refer to potential output, the various interpretations can be confusing to understand.

To help explain these concepts of capacity, we introduce the concept of a production function and some basic notation. Let  $Y$  be a single output;  $X$ , a variable factor of production; and  $Z$ , a fixed factor of production. A variable factor of production is an input whose level may be varied or easily changed in the short run (e.g. fuel and labour). A fixed factor is an input that cannot easily be changed in the short run (e.g. capital such as equipment and machinery). The production technology or production frontier,  $g$ , defines the maximum output attainable from a given set of economic inputs. The technology may be specified in mathematical form as  $Y = g(X, Z)$ .<sup>4</sup>

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<sup>4</sup>The mathematical specification of the production technology is not the most generalized specification of the technology. For more general specifications, see Chambers (1988) and Fare, Grosskopf and Lovell (1994).

The production function or technology may exhibit various relationships between inputs and output. Of particular concern is how the level of output changes in response to changes in the levels of variable inputs. In general, it might be expected that output would initially rise at an increasing level given increases in the variable input (Figure 1). The rate of increase in output, however, would likely reach a maximum (point A), because output would start to be limited by the fixed factor and increases in variable input use would only modestly increase total output. At some level of production, output would be as high as possible and increasing inputs would actually decrease the level of output.<sup>5</sup>



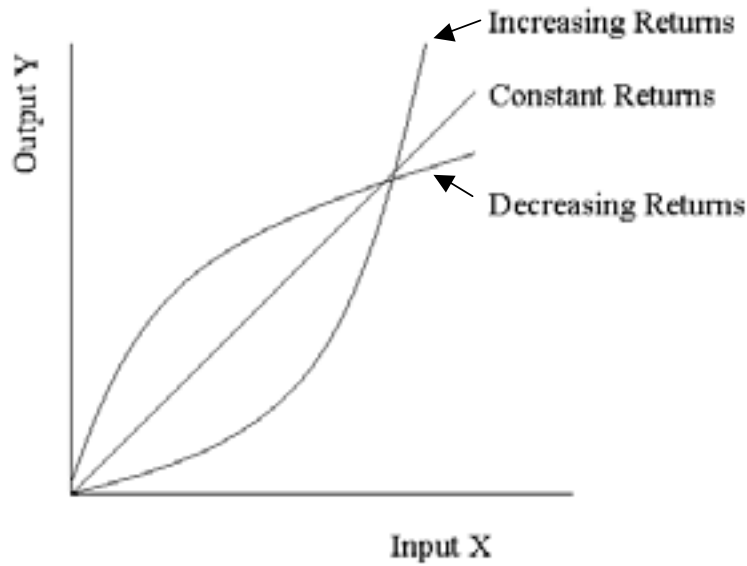
**Figure 1 – The classic production function**

The technological concept of capacity, as proposed by Johansen (1968), can be understood by viewing Figure 1. Johansen defined capacity as the maximum possible output that could be produced given technology, fixed factors and no limitations on the availability of variable production factors. The maximum output occurs at Point A in Figure 1. At the maximum or capacity level of output, inputs are fully utilized (i.e. they are used at levels yielding maximum output).

Also of particular concern is whether or not the technology exhibits increasing, decreasing, constant, or variable returns to scale. Returns to scale, however, are a long-run concept as it implies that there are no fixed inputs (i.e. the levels of all inputs can be changed). Technology is said to exhibit increasing, decreasing, or constant returns to scale if a proportional increase in all inputs results in a more than, less than, or same proportional increase in output (Figure 2). Variable returns to scale exist when returns to scale changes with input levels. For example, smaller units may experience increasing returns to scale, while larger units experience decreasing returns.

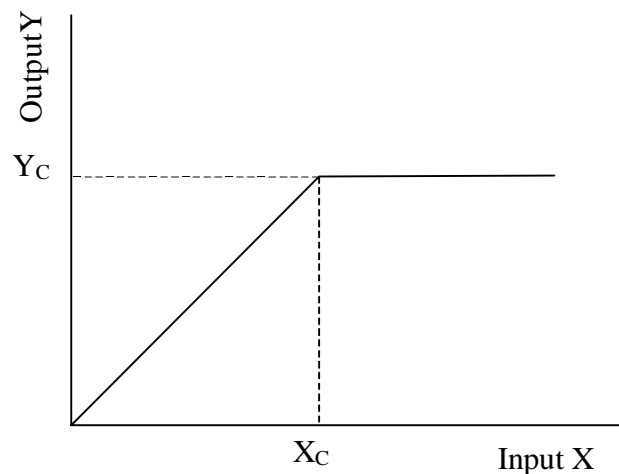
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<sup>5</sup>The relationships discussed pertain to what is usually referred to as the classic production function. With this production function, there are three stages of production, which may be characterized in terms of the average product or the ratio of total output to the level of the variable input. There are numerous other specifications, which do not assume the three stages of production.



**Figure 2 – Returns to scale<sup>6</sup>**

Färe (1984) considered Johansen’s definition of capacity a “strong” definition of capacity. This technological maximum, however, is not likely to be a particularly useful concept of capacity, since it would likely not be produced under customary and usual operating procedures. Färe subsequently offered a “weak” definition of capacity, which is similar to Johansen’s definition, but only requires that output be bounded as opposed to requiring the existence of a maximum (Figure 3). In Figure 3, capacity output,  $Y_C$ , is produced using  $X_C$  units of the variable factors of production; the fixed inputs, however, bind or limit output to  $Y_C$ . This weaker concept of capacity output explicitly recognizes restrictions on production and may better indicate customary and usual operating procedures.



**Figure 3 – Capacity output for the weak definition of capacity**

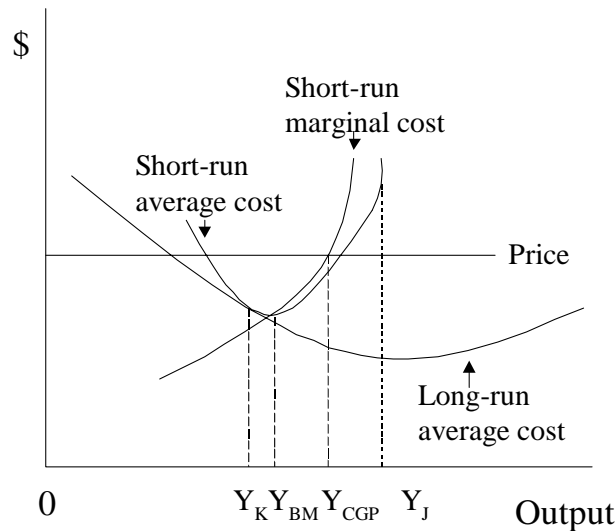
<sup>6</sup>Returns to scale depicted in Figure 2 assume extremely restrictive forms of technology. More complex forms are illustrated in Coelli, Rao and Battese (1998).

The various technological concepts of capacity output, while being useful concepts of capacity, can be misleading. Most important is that these technological concepts may suggest capacity output levels for which profits are negative or lower than they could be, given some alternative level of production. As a consequence, economists have attempted to develop more economically meaningful measures of capacity (Coelli, Grifell-Tatje and Perelman, 2001). Explaining these various economic concepts of capacity output, however, requires a considerably different framework. First, rather than defining capacity output in terms of a physical or technological maximum, it must be defined in terms of an output level that satisfies some underlying behavioural objective (e.g. the output level produced when total cost is minimized, or the output level produced when profit is maximized). Second, rather than deriving capacity output directly from production relationships, it is derived relative to economic relationships (e.g. cost, revenue, or profit relationships).

Klein (1960) and Berndt and Morrison (1981) developed economic concepts of capacity based on the short-run cost function. Klein defined capacity output as the level of output corresponding to a tangency between short-run and long-run average cost curves. Berndt and Morrison defined capacity output as the level of output corresponding to the minimum point of a short-run average cost curve. Coelli, Grifell-Tatje and Perelman (2001) offer a definition of capacity output based on static profit maximizing behaviour; they define capacity output as the level of output corresponding to profit maximization. Färe, Grosskopf and Kirkley (2000) offer definitions of capacity output based on revenue maximizing and cost minimizing behaviour. More recently, economists have developed economic measures of capacity output assuming dynamic profit maximization (Fousekis and Stefanou, 1996; Fagnart, Licandro and Portier, 1999).

Static economic concepts can be easily illustrated in graphic form. Consider Figure 4, which depicts short- and long-run average cost curves, the short-run marginal cost curve and the price level facing a firm or producing unit. The short-run average cost curve is the cost per unit of production given the presence of fixed inputs. The long-run average cost curve is the cost per unit of production when all inputs are variable. Marginal cost equals the change in cost associated with increasing production by one unit. The usual distinction between short run and long run is related to the feasibility of adjusting input levels. The short run pertains to a period during which the level of one or more inputs cannot be changed (Ferguson, 1975). The long run pertains to a period during which the levels of all inputs can be changed.

In Figure 4, four concepts of capacity output are depicted. Capacity output as defined by Klein is  $Y_K$ ; the capacity output of Berndt and Morrison is depicted by  $Y_{BM}$ ; the Johansen concept of capacity output is given by  $Y_J$ ; and the static, short-run, profit maximizing capacity concept of Coelli, Grifell-Tatje and Perelman equals  $Y_{CGP}$ . The Johansen concept of capacity output is a technological concept and represents the highest level of output. The profit maximizing capacity output occurs at the point at which price equals marginal cost. Capacity output as defined by Klein is lower than the other concepts. Capacity output as defined by Berndt and Morrison is higher than the capacity output defined by Klein; the two concepts are equal, however, when technology exhibits long-run constant returns to scale.



**Figure 4 – Economic concepts of capacity output**

(YK = Klein; YBM = Berndt and Morrison; YCGP = Coelli, Grifell-Tatje and Perelman; and YJ = Johansen)

## 2.2 Capacity utilization, capital utilization and variable input utilization

An important concept related to capacity is capacity utilization (CU), or the amount of productive capital and inputs being utilized to produce a given output, relative to the level of output that could be produced if the capital stock, other fixed inputs, and variable inputs were fully utilized. Alternatively, capacity utilization is a measure of the actual utilization of the capital stock, other fixed inputs, and variable inputs relative to some desired or maximum potential utilization. Most often, CU is defined and measured as the ratio of observed or actual output ( $Y_O$ ) to capacity output ( $Y_C$ ). If the technological notion of capacity output is assumed, CU is always less than or equal to one in value. If the technologically-based CU is less than one, excess productive capacity exists; that is, either production could be increased with no change in actual fixed and variable input usage, or fixed and variable input levels could be reduced with no change in the production level. If CU equals one, productive capital, other fixed inputs and variable inputs are fully utilized. If the economic concept of capacity is considered, CU is not restricted to being less than or equal to one in value; in this case, CU can be greater than one in value. That is, actual output can be larger than desired economic output. If the economic concept of CU is less than one in value, excess capacity exists, or the input base is said to be under-utilized. If CU is greater than one in value, there is an inadequate utilization of capital, other fixed inputs, and variable inputs, or the input base is said to be overutilized. If CU equals one, capacity is fully utilized and all production inputs have reached their full equilibrium levels.

It is important not to confuse capital utilization with capacity utilization. Too often, particularly in natural resource-based industries, policy-makers conclude that an industry has excess capacity because it is over-capitalized. That is, the existing stock of capital is higher than necessary to produce a given desired level of output. Capital utilization is defined as the ratio of the desired stock of capital to the actual stock of capital and measures the utilization of a given capital stock. Capital utilization also may be defined as the ratio of the services of capital to the stock of capital (Schworm, 1977). Capacity utilization refers to the utilization of all inputs and not just the stock of capital. Berndt and Fuss (1989) demonstrated, however, that the two concepts are equivalent if there is one and only one fixed input and production is

characterized by constant returns to scale. Although constant returns to scale may be appropriate for many industries or firms, the existence of one and only one capital input is likely to be unrealistic.

A concept related to capacity and capital utilization is the variable input utilization rate. Färe, Grosskopf and Kokkenlenberg (1989) appear to have introduced this concept to the economics literature. They define the variable input utilization rate as the ratio of the optimal use of a variable input to the observed, or actual, use. The optimum may refer to a variety of objectives, such as cost minimization or profit maximization or even output maximization. The optimum equates to the levels required to produce the optimum from the variable inputs. If the utilization rate is greater than one in value for a particular variable input, it means that the firm or producing unit has a shortage of that variable input. If the utilization rate is less than one in value, the firm or producing unit has a surplus of the variable input.

### **2.3 Capacity in fisheries**

Fisheries involve common-pool resources, where yields are rivalrous and use is only partially excludable because agents are unable to contract to exclude others. As a consequence, the market fails to properly allocate firms or vessels to a fishery, and excessive levels of inputs are employed to exploit it. The fishery is then over-capitalized and has too much harvesting capacity. Alternatively, fishing fleets end up with the capability to harvest well in excess of sustainable levels. Too high a level of capacity equates to over-investment in stock resources (e.g. vessels and gear) and variable inputs. Resources tend to be over-exploited or at levels that cannot be sustained, and profits and economic rents tend towards zero. This is the “Tragedy of the Commons” problem discussed in Hardin (1968).

The history of fisheries economics, starting as early as Jens Warming (1911), has stressed the likelihood that fisheries will, in general, suffer from overcapitalization and too high a level of capacity. Yet, there has been little research attention given to actually assessing the levels of overcapitalization and capacity in fisheries. Clark, Clarke and Munro (1979) and Conrad and Clark (1987) provide an exhaustive discussion on the derivation of the optimal capital stock in a fishery, which they equate to capacity. These two works, however, actually address the issue of overcapitalization and not capacity. This is because solutions are offered in terms of capital stock and ignore full utilization of other fixed factors and variable inputs.

Defining the concepts of capacity and capacity utilization for traditional industries is difficult enough, but for fisheries it presents a more daunting task. The complexity is compounded by the fact that production depends upon a natural resource stock (i.e. the biomass or abundance of fish), which has its own regenerative properties that must be considered when defining and assessing capacity in fisheries. The resource stock introduces a constraint to the capital stock, which is recognized as the basis for existing capacity rigidities. In addition, ill-structured, incomplete, or severely attenuated property rights, regulatory structure and other factors further exacerbate the complexity of defining and measuring capacity and capacity utilization in fisheries.

Clear definitions and measures of capacity and CU, however, are fundamental to facilitating an understanding of capacity issues, and eventually, to helping develop capacity reduction programmes. The Food and Agriculture Organization (FAO) and the United States National Marine Fisheries Service (henceforth referred to as the National Oceanic and Atmospheric

Administration, or NOAA, Fisheries) have generally agreed upon two concepts of capacity in fisheries. One concept is excess capacity, which characterizes the potential output level relative to the observed output level in the short run. Alternatively, *excess capacity is defined as the difference between the maximum potential output – given technology, current resource conditions and full and efficient utilization of capital stock, other fixed and variable factors – and the observed output*. The definition, although appearing to be equivalent to the technological definition, does not preclude consideration of the economic concept of capacity. The other concept, and the one which appears to be of greatest concern to resource managers, is overcapacity. *Overcapacity equals the difference between the maximum potential output that could be produced – given technology, desired resource conditions, and full and efficient utilization of capital stock, other fixed and variable input – and a desired optimum level of output* (e.g. the maximum sustainable yield, MSY, or maximum economic yield, MEY). The concept of overcapacity is, therefore, a long-run concept. By definition, it also does not preclude consideration of the economic concept of capacity.

The distinction between the two concepts is quite important for fishery managers concerned about reducing capacity in fisheries. Excess capacity is a short-run problem which can possibly self correct. That is, excess capacity may occur when shifts in supply and demand cause disequilibrium in the market, and firms end up having the capability to produce too much, given input and output prices. In this situation, firms can adjust their capital and variable inputs to either increase or decrease production. In contrast, overcapacity usually occurs because the market fails to efficiently allocate inputs and outputs. Firms cannot prevent other individuals from harvesting the resource, and there are no incentives to conserve inputs or outputs. With overcapacity, there a level of excess capacity persists. In this Technical Report, both concepts are presented, because it may only be possible to estimate excess capacity or some modified concept of overcapacity. This is because the empirical data available on fisheries may not reflect production activities during periods of desired resource conditions. The major emphasis of this report, however, is overcapacity.

Overcapacity typically results in overexploitation of resources and the inefficient use of the resource, capital stock, and all productive factors involved in the fishing activity. From an economic viewpoint, the same – if not greater – catches could be taken using fewer inputs, and consequently, at a lower cost. Alternatively, a smaller fleet could land the same level of catch at a substantially reduced cost. Reducing economic waste would generate additional profits, which could be used to benefit the entire community.

Resource managers historically have emphasized reducing the capital stock (i.e. overcapitalization) and not really reducing capacity, per se. Concurrently, though, they have also been concerned about the optimum utilization of the capital stock, the corresponding level of fishing effort or variable inputs, and the gear types. Thus, they have been partially concerned about overcapacity. The historical emphasis on reducing the capital stock or number of vessels (i.e. overcapitalization), along with concerns about production costs, however, have resulted in managers also desiring to measure capacity in terms of inputs (e.g. the number of vessels that could harvest the MSY if the capital and variable inputs were fully utilized and the resource was at the MSY level). These concerns have, subsequently, resulted in an input-based concept of capacity for fisheries. The input-based concept of capacity is defined as the number of vessels, or gear, required to harvest the capacity output. Similar to the notions of short- (excess) and long-run (over) capacity, are definitions of input capacity. For the short-run case of excess capacity, input capacity would be defined as the difference

between the actual number of vessels harvesting a given output and the number of vessels required to harvest the capacity output. For the long-run or overcapacity case, input capacity would be defined as the difference between the number of vessels harvesting a resource – given desired resource conditions – and the number of vessels required to harvest a desired optimum level (e.g. MSY). Both of these concepts require the assumption of full input utilization.

It also is possible to think of the two concepts of capacity – input- and output-based – as dual to one another. If one knows the level of either excess or overcapacity and the full utilization levels of capital stock and variable inputs, it is possible to determine the level of the capital stock (i.e. number of vessels or gear) required to harvest a specified level of output.

There remains another notion of input capacity. In this case, the emphasis is on the minimum level of capital stock or fixed inputs required to produce a given output (e.g. MSY). In general, this concept of input capacity may be referred to as a dual or input- (cost) based, versus an output-based, concept of capacity. This dual notion is not the same as that previously discussed. In this case, input capacity refers to the minimum number of vessels operating at full utilization of the capital stock and the variable inputs required to harvest a specified level of output. In the former case, input capacity simply referred to the number of vessels required to harvest the capacity output if capital stock and variable inputs were fully utilized.

The presence of excess or overcapacity may be quite costly to society in terms of foregone profits, inefficient production and loss of alternative opportunities. Reducing either excess or overcapacity, however, also may be quite costly, both in financial and social terms. The loss of employment in the short run through capacity reduction often counters many fisheries management plans, the objectives of which may be to maintain employment or viable fishing communities (Charles, 1989). The effective management of capacity, therefore, not only requires a measure or indicator of excess or overcapacity, but also careful consideration of its appropriate measurement and use for policy guidance in the context of target biomass stocks and output levels, or other objectives of fisheries management plans. In addition, implementation of any formal capacity reduction programme needs to be cognizant of developing an appropriate timeline for capacity reduction.

## **2.4 Excess capacity, overcapacity and overfishing**

The concepts of excess and overcapacity in fisheries can perhaps be illustrated best using the simple but widely used surplus production framework of Schaefer (1954). It is offered that the Schaefer model or framework is extremely limited and probably not applicable to many fisheries (Hilborn and Walters, 1992).<sup>7</sup> It is, nevertheless, a model that is very familiar to resource managers and fisheries scientists and is widely used to discuss economic aspects of fisheries. The Schaefer model will therefore be used throughout this Technical Report to discuss capacity and related fisheries issues.

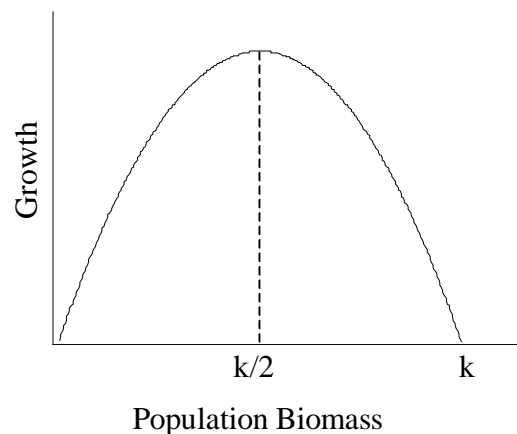
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<sup>7</sup>Conrad and Clark (1987) and Hilborn and Walters (1992) present considerably more complex biological and bio-economic models. Alternative dynamic specifications appear in the literature on dynamic pool models. Brock and Riffenburgh (1963) and Clark (1976) have shown that the logistic model may be inadequate for many types of schooling fish.



Prior to introducing the Schaefer model, however, it will be helpful to introduce some basic notation. Let  $C$  equal industry-wide or fleet-wide catch;  $E$  equal fishing effort, which is a combination of the number of vessels or capital stock,  $K$ , and the level of variable inputs,  $V$  (e.g. days fished);  $B$  is the population or biomass of the resource (throughout this report, biomass is used to indicate the level of the resource population); and  $q$  is the catchability coefficient (a scalar measure of the proportion of the stock that is removed with each unit of fishing effort). For a given set of biomass a production technology (i.e. the short term), catch is determined by  $C = qEB$ .

The simple surplus production model of Schaefer (1954) is a long-run sustainable yield function, which is derived assuming the simple logistic growth equation and the short-run yield function,  $C = qEB$ . Under this surplus production framework, it is assumed that there is some annual rate of growth ( $G$ ) of a population given an existing population biomass ( $B$ ) (Figure 5). As population increases, growth also increases up to some limit, which is established by food availability and the area of the water body. After realizing this maximum, growth continues but at a reduced level. Finally, there is some population level at which growth becomes zero, and this is referred to as the environmental carrying capacity ( $k$ ) (Cunningham, Dunn and Whitmarsh, 1985). The long-run sustainable yield or production model of Schaefer assumes a logistic growth model, which is of the form  $G = rB(1-B/k)$ , where  $r$  represents the intrinsic rate of growth. Growth is maximized in such a model at half the environmental carrying capacity.

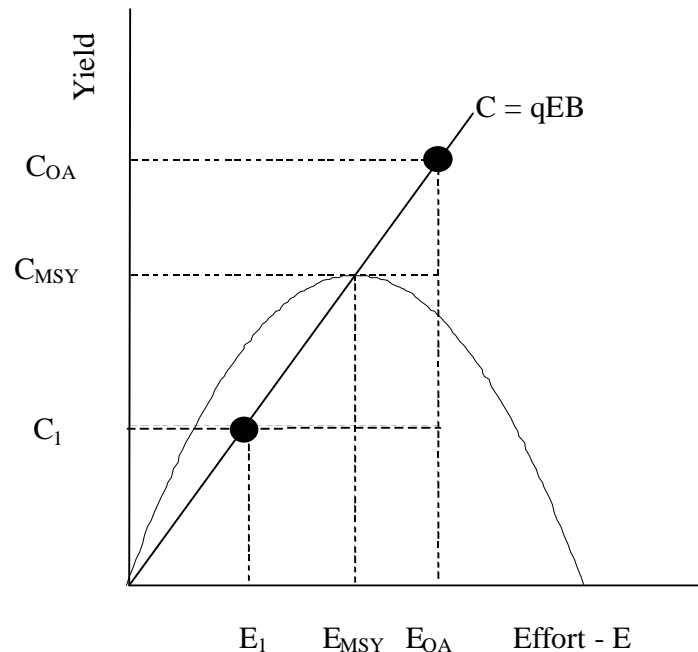


**Figure 5 – The logistic growth curve**

To derive the sustainable yield function, we introduce the short-run yield or production function,  $C = qEB$ . Assuming the logistic growth equation adequately depicts growth, a long-run sustainable yield function may be derived by equating growth to removals from fishing. We have the equilibrium relationship  $G = rB(1-B/k) - qEB$ , which will equal zero. Solving in terms of the sustainable yield or catch ( $C_S$ ) gives us the long-run sustainable yield function of Schaefer:  $C_S = qkE(1-qE/r)$ , or more conveniently,  $C_S = \alpha E - \beta E^2$ , where  $\alpha = qk$  and  $\beta = q^2k/r$ . The sustainable yield function of Schaefer is then a parabola (Figure 6).<sup>8</sup> The origin of the

<sup>8</sup> Alternative functional forms of the long-run sustainable yield function are possible. Different short-run yield functions or different growth functions yield different long-run sustainable yield functions. Pella and Tomlinson (1969) allow for raising the second-order term of the traditional growth function to some arbitrary power. Similarly, the use of a short-run transcendental or translog production function results in different long-run sustainable yield curves. Also, sustainable yield curves for some types of species, such as shrimp, may be characterized by sustainable yield curves with high sustainable yields over a wide range of fishing effort levels.

sustainable yield curve corresponds to the environmental carrying capacity level of the population. As sustainable yield increases, population decreases. Yield increases until it reaches a maximum, which is referred to as the maximum sustainable yield, or MSY. The MSY equals the maximum growth; it is the largest level of catch that can be harvested on average per period of time (e.g. per year). For catch levels to the right of MSY, growth and, subsequently, sustainable yield decline.



**Figure 6 – The sustainable yield curve**

Using the sustainable yield function of Schaefer, the concepts of excess and overcapacity can be illustrated (Figure 6). Assume that the fishery is unregulated (i.e. open access) and the level of the population ( $B$ ) supports MSY. Also assume that the objective of management is a harvest level equal to MSY, and that  $E_{OA}$  is the full utilization level of capital stock and variable inputs for the fleet. Allow the level of effort to equal  $E_{OA}$ , and thus, the short-run catch equals  $C_{OA}$ . At this level of effort and catch, there is overcapacity equal to  $C_{OA} - C_{MSY}$ . In contrast, assume that the fleet is not fully utilized and instead operates at  $E_I$  units of effort. The fleet lands  $C_I$  units of catch. The fleet could, however, catch  $C_{OA}$  at  $E_{OA}$  units of effort; the difference between  $C_{OA}$  and  $C_I$  equals excess capacity.<sup>9</sup> A primary distinction between overcapacity and excess capacity is the time domain and an underlying stated objective of management. Excess capacity is defined and assessed relative to the short run; overcapacity in this case is defined and assessed relative to the long-run sustainable yield function and the objective of MSY.

The previous discussion of excess and overcapacity, unfortunately, is a bit misleading in that it better illustrates issues associated with overcapitalization. Normally, excess capacity is defined relative to an existing capital stock and potential output; that is, the maximum potential output given technology, fixed factors, and no limits on availability of the variable

<sup>9</sup>As presently illustrated, excess capacity is defined relative to a level of landings interior to the long-run sustainable yield. It could just as easily be characterized relative to landings in excess of MSY but lower than  $C_{OA}$ .

factors. In our example above, the capital stock (i.e. the number of vessels) was assumed to be held constant, with only the variable inputs changing. Both our short- and long-run yield curves permit changes in number of vessels. We would thus have a capacity output level for each level of vessels. If we assume, however, that the number of vessels is constant for all levels of effort and only allow the level of the variable inputs to change, the above depictions of excess and overcapacity illustrate the two measures. Alternatively, if we ignore the rigorous theoretical definition of capacity, we can loosely interpret the concepts of excess and overcapacity as the differences between  $C_{OA}$  and  $C_I$  and  $C_{OA}$  and  $C_{MSY}$ . This is but one of many problems encountered in defining and assessing excess and overcapacity in fisheries.

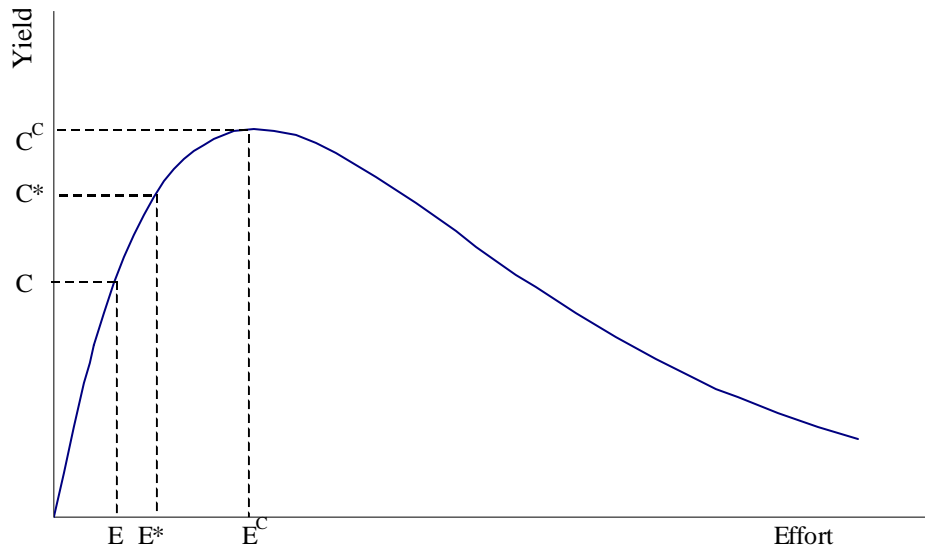
We also may consider excess and overcapacity in terms of the input base –  $E$ . In this case, excess capacity is the difference between  $E_{OA}$  and  $E_I$ ; overcapacity is the difference between  $E_{OA}$  and  $E_{MSY}$ . This is basically the mirror image, or dual to the output measure. This is not the economic dual, however, relative to the definition of capacity consistent with dual specifications of technology (e.g. cost, revenue, or profit functions).

## 2.5 Economic implications of excess and overcapacity

Excess and overcapacity are typically associated with economic waste. Simply put, more inputs are being expended than are necessary to harvest a given quantity of fish; cost is not minimized; profits are not maximized; and society is not receiving the maximum possible benefit. Remembering that excess capacity is a short-run concept and overcapacity is a long-run concept, and is defined relative to either a desired resource condition or level of production, we need to consider two different frameworks for illustrating the implications of excess and overcapacity.

In the case of excess capacity, we consider a slightly different short-run yield function,  $C = qE^\beta B^\alpha E$ , where  $\beta$  is less than one in value and  $\alpha$  is negative. We also follow the example of Coelli, Grifell-Tatje and Perelman (2001), which describes the notion of excess capacity relative to the behavioural objective of maximizing short-run profits. The technology, as depicted, has a maximum potential or capacity output of  $C^C$  (Figure 7). It is further assumed that  $E$  is comprised of the level of capital invested in the fleet (e.g. the number of vessels),  $K$ , which is assumed to be constant, and the variable input per vessel,  $V$ , (e.g. number of days fished). For further simplicity, we assume that  $V$  is the same for all vessels, but can be varied (e.g. for a fleet of 100 vessels,  $V$  could be 10 days or 20 days, but would be the same for all vessels). We also assume that  $C^*$  represents that catch which maximizes short-run profits. We let  $C$  be a level of production. The level of effort is assumed to change only through variable input usage.

If the objective of the fleet was to maximize short-run profits (output and input levels of  $C^*$  and  $E^*$ ), but the fleet produced at the capacity output level ( $C^C$ ), it would be over-utilizing the variable inputs and would have excess capacity relative to the optimum production level. In this case, the fleet would not realize the maximum profit. If the fleet produced at  $C^I$ , variable input and capital stock would be under-utilized, and short-run profits would still not be maximized. Alternatively, if we consider only the technological concept of capacity output, we would conclude that the fishery had excess capacity if actual production equaled  $C^I$ , given that the fleet had a potential maximum output of  $C^C$ .

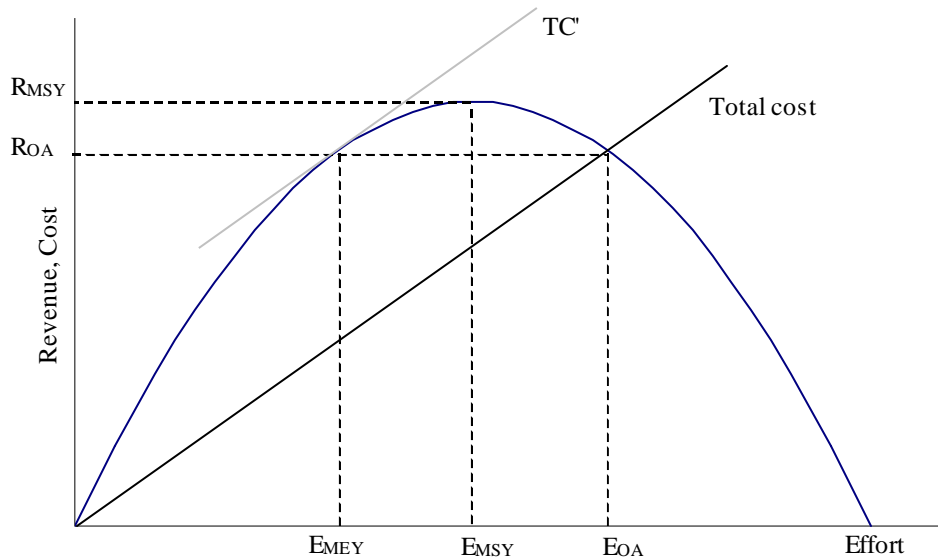


**Figure 7 – Excess capacity and variable input utilization**

The potential waste associated with overcapacity may be explored and illustrated by considering the sustainable *economic* benefits from fishing associated with the costs of production, and recognizing that overcapacity also implies inefficient use of existing vessels due to short-run rigidities, most likely associated with regulations. For the purpose of illustration, we use the sustainable yield model of Schaefer to formulate a simple bio-economic model of a fishery. For additional simplicity, we assume a constant output (fish) price and a constant average cost of fishing. By multiplying the constant fish price by the sustainable output, we obtain a sustainable revenue curve, or as correctly titled in Cunningham, Dunn and Whitmarsh (1985), a “revenue product curve” (Figure 8). We next impose a total cost curve on the sustainable revenue curve. In so doing, we assume that total cost equals the product of the average price of a unit of fishing effort and the level of fishing effort.<sup>10</sup> Such a model allows us to broadly conceptualize the relationship between economic waste and overcapacity.

In an unregulated fishery with free and open access, fishing boats will enter the fishery as long as the resulting profits – Revenue (R) less total cost (TC) – are greater than those that could be earned in the next best alternative activity. The foregone profits in the alternative activities are considered the opportunity cost of entering the fishery, and economic profits are said to exist when the profits are greater than the opportunity cost of fishing. Hence, boats enter the fishery up to the point where economic profits cease to exist. At this point, fishers are earning the same level of returns on their investment and labour as they might in the next best alternative industry with equivalent risk. This return is the ‘normal’ profits that are the minimum level of returns required to keep capital in the fishery. If the returns were greater than these ‘normal’ returns, additional investment (and therefore effort) flows into the fishery. Conversely, if returns fall below this level, investment (and effort) moves out of the fishery. The returns that can be earned elsewhere in the economy are considered the opportunity cost of staying in the fishery. Economic profits are those that are achieved over and above the opportunity cost, or the ‘normal’ returns.

<sup>10</sup>If price varies with output, the shape of the sustainable revenue curve would be quite different. A linear total cost function has been assumed, but it is possible for the cost function to be non-linear.



**Figure 8 – Economic implications of overcapacity in a fishery**

In Figure 8, ‘normal’ profits are earned when total revenue equals total costs, at which point total revenue is  $R_{OA}$ . The economic measure of total cost includes the opportunity cost, so economic profit is zero at this point. The resulting current fleet size is  $E_{OA}$ , and we refer to this as the open access equilibrium fleet level. Also depicted in Figure 8, the open access equilibrium results in biological overfishing. If the total cost curve had intersected the revenue curve to the left of MSY, however, biological overfishing would not occur, but there would still be considerable economic waste in the form of technical and economic inefficiency.

The same level of revenue ( $R_{OA}$ ) could be realized at a lower cost, however. In fact, fleet size or effort could be reduced from  $E_{OA}$  to  $E_{MEY}$  with no change in revenue.<sup>11</sup> Relative to the revenue level of  $R_{OA}$  and the objective of maximizing profits, there is overcapacity of  $E_{OA} - E_{MEY}$ . A reduction of effort from  $E_{OA}$  to  $E_{MEY}$  creates the possibility for economic profit, which is given by the difference between the revenue and costs at  $E_{MEY}$ . The potential increase in profit, however, requires that the resource stock regenerate. But in the absence of additional regulations, it is likely that the existing vessel operators will attempt to realize profit by increasing their effort per period, which will subsequently increase the total cost, until eventually total revenue equals total cost (Anderson, 1977). Decreasing fishing effort or capacity in the absence of other regulations, therefore, does not guarantee that profits will be positive.

In Figure 8,  $R_{OA}$  also equals the revenue corresponding to maximum economic yield (MEY). Maximum economic yield is the level of output at which economic profit is maximized. The fact that revenue,  $R_{OA}$ , equals the revenue corresponding to maximum economic yield is purely an artefact of the cost assumptions used in the figure. The point of maximum economic profits can be found where the slope of the cost curve (indicated by the line TC' in Figure 8) is equal to the slope of the revenue curve. A higher or lower average cost per unit of

<sup>11</sup>The total cost curve has been drawn to intersect the sustainable revenue curve to the right of the MSY level. It is possible for total cost to intersect the sustainable revenue curve either to the left of the MSY level or exactly at the MSY level. In either case, the open access equilibrium level of profit would still be zero.

effort (giving a steeper or flatter total cost curve) would have resulted in the revenue associated with MEY being lower or higher respectively than that at the open access equilibrium.

In Figure 8, MEY occurs at a level of effort equal to  $E_{MEY}$ , which is below  $E_{MSY}$ . If the objective of fisheries management was to maximize long-term sustainable profit, there would be overcapacity relative to the fleet size and input utilization levels required to harvest MSY. Fishing activity that produces the maximum sustainable yield is above that which produces maximum economic yield. This form of bio-economic overcapacity – from an economic perspective – can exist even when maximum sustainable yield is taken at least cost.<sup>12</sup>

## 2.6 The bio-economic model, practical limitations, and assessing overcapacity

The preceding discussion, based on the bio-economic model, illustrated various notions or concepts of overcapacity. Overcapacity was illustrated or characterized relative to bio-economic and biological optimums and the open access equilibrium. In some sense, the situation characterized as overcapacity (the levels of capital and effort corresponding to the open access and maximum economic yield or maximum sustainable yield) could be misleading. This is because the discussion emphasized the determination of the optimum capital stock (fleet size required to harvest either MSY or MEY) over capacity, which requires consideration of full utilization of existing capital stock, other fixed factors and variable inputs.

In some sense, however, the extent of overcapacity can be measured in terms of the difference between the current fleet size ( $K$ , or the level of capital invested) and the fleet size that would generate maximum sustainable yield ( $K_{MSY}$ ), or maximum economic yield ( $K_{MEY}$ ), assuming full utilization of the variable inputs. The notion of overcapacity previously discussed, however, might better be called overcapitalization, since the emphasis is on determining the optimum fleet size required to harvest either MSY or MEY. Alternatively, if overcapacity is initially determined relative to output levels and the capital stock or number of vessels, and we assume full variable input utilization, it is possible to define and assess overcapacity in terms of the capital stock or number of vessels.

However, the issue of determining the optimum capital stock versus optimum capacity may only be of interest to economic theoreticians. Stock conditions, or the size of the fish population and long-run adjustments of resource conditions to varying levels of effort, pose considerable problems for assessing and reducing overcapacity. Alternatively, standard bio-economic models may pose limitations for determining overcapacity and providing a basis for formulating capacity reduction programmes.

Consider again Figure 8, which assumes long-run stock levels and no inefficient use of inputs or capacity for the current biomass stock. At levels of effort higher than  $E_{MSY}$ , the fleet exerts enough pressure on the resource that the stock can no longer support the MSY harvest level. Both the cost of fishing and the level of effort are higher than necessary to realize the

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<sup>12</sup>This conclusion is based on the simplistic assumption of zero discounting, no uncertainty, the form of the technology and long-run sustainable yield curve, and price being constant. Clark, Clarke and Munro (1979), Charles and Munro (1985) and Conrad and Clark (1987) provide conditions for different conclusions. Conrad and Clark note, however, that the optimal level of fishing effort will at least be less than the open access level of fishing effort.

sustainable revenue,  $R$ . At the higher level of effort,  $E_{OA}$ , the stock is sustainable but lower than its potential maximum level, which corresponds to the population size necessary to support MSY. The number of vessels, however, could be reduced in order to achieve either  $E_{MEY}$  or  $E_{MSY}$ , and the same or even a higher harvest level could eventually be realized. At  $E_{OA}$ , though, too many boats are in the fishery and stock levels are too low relative to levels desired by management or society. If the total level of effort was reduced to  $E_{MEY}$  or  $E_{MSY}$  relative to  $E_{OA}$ , stock levels would increase but overcapacity would remain until the resource regenerated itself to a level that supports either MEY or MSY.

Determining and reducing the level of overcapacity in a fishery also could easily be complicated by erroneous assumptions about the logistic growth model or short-run yield functions. Initially, assume that the simple logistic curve represents the true biological potential, and technology is the standard short-run model ( $C = qEB$ ). Maximum economic yield is produced with a fleet size exactly 50 percent smaller than the fleet size corresponding to the open access equilibrium level (this is a feature of the standard surplus production model and the assumed form of the short-run production function). This conclusion, however, also requires the stock to rebuild to a level necessary to support maximum economic yield. Given assumptions about the logistic growth curve and the short-run yield function, managers would subsequently conclude that the fleet should be reduced by 50 percent to realize the MEY level of harvest. If the short-run yield function took a different form, however, (e.g.  $C = qE^{0.7}B$  or  $C = qE^{0.4}B^{0.3}$ ), the reduction necessary to produce MEY might be quite different than 50 percent. It is thus important that careful attention be given to the bio-economic framework used to assess overcapacity.

Reducing overcapacity also may be quite difficult if the price of fish is sufficiently high (assuming a constant price), or the cost of fishing is very low. In this case, the intersection of the total cost (TC) and total revenue (TR) curves could be far to the right of the sustainable yield curve. Fish stock could be seriously overfished, relative to desired target levels, or even pushed toward extinction, with  $E$  nearing a level that reduces sustainable yield to zero – the level of effort that also extinguishes the stock. This is often referred to as  $E_{MAX}$ , but not the  $E_{MAX}$  concept of fishing mortality (Cunningham, Dunn and Whitmarsh, 1985). This could imply a very large gap between  $E$  and either  $E_{MSY}$  or  $E_{MEY}$ , and very high costs of reducing the implied overcapacity by stock regeneration.

In general, the bio-economic model indicates that overcapacity would occur in the absence of appropriate regulatory strategies. Fishing effort would become excessive and the resource would eventually be over-harvested relative to desired stock levels.<sup>13</sup> Even with such a simplistic framework, establishing the extent of the gap between the existing fleet level and a target level of  $E$  such as  $E_{MSY}$  or  $E_{MEY}$  would generally require information on current fleet size, current harvest, maximum sustainable harvest and associated minimum fleet size. In addition, the growth curve for the biomass must be known. For economic measures of excess capacity, information on the production and cost structure of the industry, as well as the price of the output, also would be required. Although simple assumptions such as those built into the logistic growth and linear cost and short-run yield curves may facilitate such analysis, they are unlikely to be realistic for any particular fishery.<sup>14</sup>

<sup>13</sup>An obvious exception to this conclusion, of course, would occur when the total cost curve intersects the revenue product curve (sustainable revenue curve) either at MSY or to the left of MSY.

<sup>14</sup>A wide range of alternative specifications or frameworks exist for constructing bio-economic models. See, for example, Deriso (1980), Conrad and Clark (1987), and Hilborn and Walters (1992).

Also, at the existing biomass stock level  $B$ , the scenario represented in Figure 8 by the generation of revenues,  $R_{OA}$ , associated with fleet,  $E_{OA}$ , does not imply that any additional catch (output) may be produced. That is, given the overfished stock, the fleet effort level  $E$  is required – being the least cost or efficient level – to harvest the corresponding biomass growth. The only time the smaller fleet implied by, say,  $E_{MEY}$ , could produce the maximum economic yield level of catch,  $C_{MEY}$ , is after regeneration of the stock. Representing the existence of overcapacity or non-optimal capacity utilization at a *given* stock level requires further consideration of the impacts of regulations or other restrictions upon competitive factors that cause production to be carried out at less than optimal cost levels.

In practice, fishing fleets are typically subject to a number of constraints that limit their level of activity. In particular, constraints include management-imposed restrictions on catch (e.g. total allowable, or TAC, controls), gear, nominal fishing effort, areas and seasons. In the former case, fishing must cease on the species once its quota has been filled. The more common types of seasonal and area restrictions, respectively, are seasonal limits on either effort or catch and restrictions on areas that may be fished. We may generally view such restrictions as command and control type regulations, which are imposed on either outputs or inputs, or both.

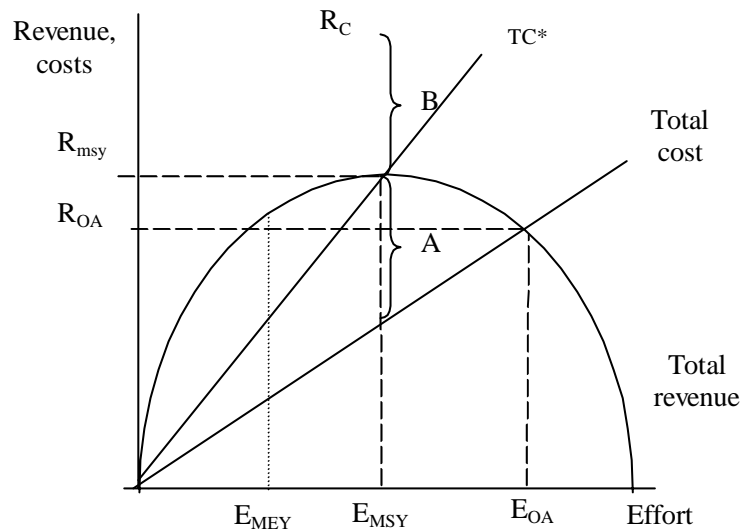
Output regulations, which directly restrict the amount of catch from the fishery, are usually imposed to allow the stock level to rebuild or to keep it from further decline. Output restrictions, however, also imply limits on how much  $F$  may be applied to catch fish, and thus, limit input utilization. Restrictions on the level of output may curb the excessive harvest of the stock, or overfishing, but at the same time they also may generate excess capacity at existing stock levels. This is because open access motivations remain for any individual vessel to expand fishing effort as long as positive profits are generated (average revenue exceeds average cost). If the bio-economic framework is used to determine overcapacity, the impacts of regulatory factors must be taken into account to further conceptualize and understand the concepts of overcapacity capacity and non-optimal capacity utilization.

## 2.7 Sub-optimal levels of capacity, capital and variable input utilization

The concept of capacity utilization, even in fisheries, is relatively easy to understand. In its simplest form, it is simply the ratio of observed or technically efficient output to capacity output, where capacity output is defined in terms of either a maximum potential or economically optimum level of output. The concept may become a bit complicated to understand and calculate, however, because of related but different concepts of utilization. Almost from the beginning of FAO's initiative to define and assess capacity in fisheries, there has existed substantial confusion about the differences between capital utilization, capacity utilization, and variable input utilization. The three are related but not equivalent concepts. In this section, we attempt to illustrate the three concepts and related problems, again using the simple bio-economic model of Schaefer.

To begin, consider a fishery operating at the open access equilibrium level, which is characterized by a level of effort equal to  $E_{OA}$  and revenue equal to  $R_{OA}$  (Figure 9). Total cost ( $TC$ ) for this initial situation is depicted by the total cost curve. This equilibrium is sub-optimal because the same level of revenue and catch could be realized with reduced fishing effort.





**Figure 9 – Non-optimal capacity utilization with cost inefficiency**

We now assume that regulations have been imposed to increase the stock to the MSY level. A total allowable catch (TAC) is set at the corresponding biomass growth rate. Competition exists, then, among boats to catch as much of this TAC as possible, but movement toward  $E_{OA}$  is curtailed by regulation. Vessel owners, however, will keep investing in technology to remain as competitive as possible in order to catch a large share of the TAC. In this case, instead of moving toward  $E_{OA}$ , the  $TC$  curve will shift upward so the  $TC^*$  curve, including non-optimal use of capital inputs, intersects the revenue curve at the TAC level of  $R_{MSY}$  (Figure 9). This short-run cost curve, incorporating non-optimal utilization of fixed inputs, is higher than  $TC$  due to cost inefficiencies from over-investment in fixed inputs that are not being used effectively to produce the allowed catch. Thus, costs are high and profits are negligible even at the maximum sustainable yield. Further development of this overcapacity concept requires a distinction to be made between variable (effort) input use,  $V$ , and the fixed capital component that is at sub-optimal levels,  $K$ , that make up the overall input base,  $E$ .<sup>15</sup>

In this case, the TAC ( $C_{MSY}$ ) is being caught, although not at minimum costs because each boat could potentially catch more if it was able to use its capacity at full potential. No further investment is generated to compete more effectively, because no profit motive exists. Average revenue ( $AR$ ) equals average cost ( $AC$ ), or total revenue equals total cost, and again, more capital exists in the fleet than is necessary to catch the TAC.<sup>16</sup> In terms of inputs, the extent of existing overcapacity can therefore be represented as the difference in effective  $E$

<sup>15</sup>In the short run, capital and equipment are generally viewed as fixed or quasi-fixed inputs; that is, they cannot be increased or decreased. For example, a vessel size cannot be changed in the short-run. Over the long run, however, capital and equipment may be viewed as variable inputs. They can be changed. A vessel owner, for example, can purchase a larger vessel. From an economic perspective, the long-run competitive equilibrium for an industry occurs at the point of minimum long-run average cost. This occurs because firms enter an industry and eventually force the price received by producers to equal minimum average cost. At that point, there is no incentive for entry or exit.

<sup>16</sup>This does not mean, however, that there is no incentive to make new investments. Fishers will likely invest in technology that may allow them to more effectively harvest a share of the catch, and this will increase the level of capital in the fishery.

(or capital,  $K$ ), implied by the gap between  $TC$  and  $TC^*$ . In actuality, however, this situation depicts capital, and not capacity, utilization. Determining the level of excess capital in the fishery requires imputing the capital or fleet level associated with  $TC$  (the proportion that would contract  $0-R_{MSY}$  or  $0-TC^*$  to  $0-TC$  (gap A), thus reaching minimum input costs). If we seek to directly determine the reduction in capital stock required to eliminate overcapacity, which also incorporates full utilization of the variable inputs and capital stock, we need an input-oriented or dual measure of capacity utilization. Alternatively, we need a measure of capacity utilization expressed in terms of the possible contraction of fixed capital inputs (vessels and power characteristics) but still capable of harvesting the current output level.

In contrast, determining potential catch if the current fleet was fully utilized would require adding the potential product from efficiently using this overcapacity for fishing purposes to the output or catch currently generated.<sup>17</sup> This loosely implies (depending on scale economies and boat productivity, as elaborated below) addition of the  $TC-TC^*$  gap above the revenue curve, which implies a full capacity utilization harvest level and, thus, revenues ( $R_C$ ) that would greatly exceed  $TAC=C_{MSY}$ , or  $R_{MSY}$  (gap B). The difference between the implied potential catch,  $C_C$ , and  $C_{MSY}$ , provides an output-oriented or primal measure of capacity utilization, which is consistent with the traditional concept of capacity utilization. This, in turn, implies a level of (variable) effort applied to the existing capacity base (or vessels) that exceeds what is currently exhibited in the fishery but would be consistent with full use of existing capacity. The difference between these two effort levels represents a capacity utilization indicator that is input-based, but output-oriented—a variable input utilization measure. The potential level of catch, however, would not be sustainable over the long run, and the stock would likely decrease. Nevertheless, the concept of capacity output can provide valuable information about the level of capital stock that should be removed from the fleet so that management goals and objectives are realized.

These three measures – the dual input-oriented measure, the primal output-oriented measure, and the variable input-based measure corresponding to the capacity output level – result in different utilization (CU) indicators. The dual input-oriented measure indicates how much the existing fleet could be contracted to a level of capital,  $K_C$ , from the observed level,  $K$ , and still generate the same level of harvest,  $CU_K=K_C/K$ , assuming the full utilization level of the variable inputs. The output measure implies how much more output could potentially be produced with the given fleet if regulations – or other motives for producing at inefficient cost levels – were removed, and variable effort levels were correspondingly increased. This potential or capacity output level,  $C_C$ , can be compared to observed (or target) catch,  $C$ , to construct a capacity utilization measure  $CU_C=C/C_C$ . The input-based measure of full utilization of the existing capacity indicates how much (variable) effort,  $E$ , would have to be increased to reach  $C_C$ ,  $E_C$ , resulting in the capacity utilization measure  $CU_V=E/E_C$ , where  $V$  (and  $E$ ) denote variable inputs.<sup>18</sup>

<sup>17</sup>This notion of capacity output, primal, is strictly a short-run concept. It assumes that the capital stock or fleet is given. It is a measure of the potential output that could be produced given resource conditions, technology, capital stock, and full utilization of the variable factors (the level of variable factors required to produce the capacity output level). Although it is a short-run concept, it provides a valuable reference point for management. If managers have information on the level of capacity output for a given capital stock, they can then determine the level of capital stock that must be reduced from the current fleet to achieve a desired harvest level (e.g. MSY or MEY).

<sup>18</sup>Färe, Grosskopf and Kokkelenberg (1989) refer to the measure as the optimum variable input utilization ratio. It is the ratio of the observed level of variable inputs to the level of the variable inputs required to produce the capacity output.

Of the three concepts of utilization, only the output-oriented concept is actually a measure of capacity utilization. The dual input measure, while providing useful information, is actually a measure of capital utilization. Berndt (1990) defines capital utilization as the ratio of the desired stock of capital to the observed or actual stock of capital, which is the same as  $CU_K = K_C / K$  because “desired” could be equal to either the maximum potential output or the output level desired by management (e.g. the MSY level of output). The variable input utilization measure also is not a measure of capacity utilization. It is simply the ratio of the level of variable input usage required to produce the capacity or target output level, to the observed usage of a given variable input.

Differences among these measures arise not only in terms of perspective, and thus interpretation, but potentially in terms of magnitudes. The magnitudes of these ratios depend on the prevailing stock level, scale economies and the (marginal) productivity of boats (or their characteristics such as horsepower and technology). Importantly, it is these differences that have generated considerable confusion among resource managers and researchers about capacity utilization and capacity output in fisheries. The present emphasis of management is on reducing overcapacity in fisheries. Reducing overcapacity requires reducing the capital stock or number of vessels in a fishing fleet. To determine the potential reduction in the capital stock, however, requires information about the full utilization of the variable inputs by the existing capital. There has been a tendency by managers and fisheries scientists to focus only on the level of the capital stock (usually number of vessels) that must be reduced, without realizing that the desired level of the capital stock reduction is determined by the capacity or potential output and full utilization of the variable inputs. Thus, a key requirement to implement or quantify measures implied by the above analysis is an explicit link between inputs ( $V$  and  $K$ , or  $E$  overall) and output ( $C$ ), particularly for estimating long-term sustainable yields. This requires knowledge or estimation of the underlying production relationship.

## **2.8 Short-run constraints and further considerations for assessing capacity**

Estimation of capacity and capacity utilization requires recognition of constraints that fundamentally underlie the problem of excess and overcapacity, since the deviation between  $TC^*$  and  $TC$  arises due to short-run rigidities and resulting non-optimal use of fixed inputs. That is, the existence of overcapacity, or lack of full capacity utilization, requires some restrictions or constraints on production or activity levels. In addition to the regulatory constraints raised as a motivating factor for the existence of excess and overcapacity, other constraints also may affect excess and overcapacity and capacity utilization. For example, onshore processing constraints may limit the level of fishing activity. If processors are unable to process more than a given quantity of fish per unit of time, this places a limit on the ability of the fleet to sell the fish they catch. In turn, this effectively limits the level of fishing activity and possibly results in higher costs of production than necessary for a given catch level.

At the individual boat level, breakdowns and subsequent repairs reduce the time available for fishing. In all cases, very few boats would be able to operate on every available day of the fishery, due to maintenance and repair requirements, unloading and re-provisioning, and rest and family commitments of the skipper and crew. This emphasizes the importance of

distinguishing the maximum possible production from a given fleet, or capital stock,  $K$ , from the optimum or feasible production resulting from customary and usual operating procedures.

Older boats also may be subject to more breakdowns and therefore operate for fewer days than newer boats. Similarly, older skippers may fish for fewer days than younger skippers. This raises the issue of how to consider fleet heterogeneity, which must be recognized to effectively impute the impacts of  $K$  reductions, when assessing capacity and CU. These impacts will depend upon different boat characteristics and, thus, vessel or capital productivity. If licenses were transferred to newer boats with younger skippers, total fishing activity and subsequent catch could increase. These variations in productivity for different components of the capital stock should be taken into account or controlled for when estimating capacity levels and utilization, and particularly when guiding capacity reductions.

Fish stocks, or existing biomass levels, impose another constraint on production. In general, the potential catch from the existing fleet (or capital/capacity) will be greater at higher stock levels (at least at the levels observed for currently over-exploited stocks). The reduction in  $E$  ( $K$  combined with variable effort  $V$ ), associated with a movement toward  $E_{MSY}$  or  $E_{MEY}$ , thus, requires the stock to regenerate in order to reach desired catch levels such as MSY or MEY. This implies both that current biomass stock levels will affect measured short-run potential capacity output or input levels, and that imputing these levels for more optimal long-run stock levels is important for determining long-run or overcapacity. Long-run adjustments to accommodate stock regeneration, and associated capacity reductions that do not yield short-run benefits, also must be taken into account when constructing and using capacity utilization measures to manage fisheries.

There are also potential issues related to uncertainty and time. Resource levels and market conditions typically change over time and, thus, it may be necessary to have sufficient harvesting capacity to take advantage of such changes. That is, in most fisheries stock sizes fluctuate from year to year. As a result, complete capacity utilization under all conditions is not possible. In poor years the capital could not be fully utilized, while in good years the capital would be insufficient to achieve an efficient level of catch, given resource conditions. Some underutilization of capital is desirable under average conditions to enable the fleets to efficiently exploit the fluctuating resource. This should be accommodated in the definition of customary and usual operating procedures, which emphasizes the importance of imputing an optimum rather than maximum utilization of capacity. The extent to which capacity underutilization is efficient, however, varies from fishery to fishery and depends to a large extent on economic factors (i.e. the costs of maintaining an under-utilized capital stock in average and poor years, against the benefits of fully exploiting the capital stock in good years).<sup>19</sup>

In summary, full utilization of capacity for a fishery is determined by the *potential* catch or fleet levels if all fixed inputs (e.g. the boats and associated technological capital, or the capacity base) are utilized optimally, given prevailing stock and market conditions. The difference between these optimal or potential and existing levels depends on short-run constraints, which cause the existing total cost level,  $TC^*$ , to exceed  $TC$ , because capacity or capital stock levels,  $K$ , are higher than required to produce prevailing (allowed) catch levels.

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<sup>19</sup>This notion is explored in the context of excess capacity resulting from future expectations, as distinguished from that associated with disequilibrium or short-run rigidities, in Morrison (1985a).

Capacity utilization is, thus, essentially a short-term concept, measured as a ratio of actual to potential catch, given the level of fixed inputs. Capital utilization, which equals capacity utilization only if the technology exhibits constant returns to scale and there is only one fixed factor, is measured as the potential contraction of capital inputs from their actual level that could still catch the existing or target catch level, while allowing for variations in economic and environmental conditions due to customary and usual operating procedures and natural stock fluctuations. It is measured as the ratio of the desired capital stock to the actual stock of capital. Schworm (1977) provides an alternate definition or measure of capital utilization - the ratio of capital services to the stock of capital. Variable input utilization equals the ratio of the level of a variable input required to produce the capacity output to the observed or level of the variable input actually used to produce the existing output level. Recognition of the impact of constraints such as those associated with biomass stocks, and of the importance of both short-term fluctuations and long-run adjustment, is important to build into the construction, and also to the interpretation and use of resulting utilization indicators.

## 2.9 Equating input- and output-oriented measures of capacity and utilization

The three types of utilization concepts outlined above – output-oriented measures imputing full utilization of the given capital stock, input-oriented measures capturing the contraction of the capital stock possible to maintain production of existing output levels, and input-based measures representing the variable input use corresponding to capacity output levels – are only equivalent in magnitude under certain restrictive conditions. These restrictions involve scale economies (constant returns to scale - CRS), or input-specific economies or returns, given existing levels of other factors, a single fixed input, and an optimum capital output ratio that is constant over time (Berndt, 1990).

Deviation between the output- and input-oriented utilization measures depends on scale economies; they will only be equivalent if the industry is characterized by constant returns to scale (CRS), (i.e. doubling the quantity of all inputs doubles potential output). As presented earlier, let  $E$  represent the combination of vessel characteristics (i.e. technological capital,  $K$ ) and the variable inputs ( $V$ ) used to generate catch. Given constant returns to scale and our measure of  $E$ , the relationship between  $E$  and catch ( $C$ ) must be proportional for a particular biomass stock level ( $B$ ). The formulation of  $E$  implicitly requires that the combination of the capital stock ( $K$ , or the fixed inputs) and  $V$  underlying the measure of total effort, or  $E$ , is proportional, or that the contribution of each input to catch is the same for all scales of operation (Squires, 1987). This latter conclusion is related to aggregation theory, which stipulates that an aggregate input should increase by the same proportion as the components that make up the aggregate (e.g. if  $K$  and  $V$  both double, then  $E$  should double).

The difference between output- and (variable) input-based measures involves the returns to *variable* inputs, given the existing capital base, that result from an expansion in scale of production with the capital factors fixed. That is, both of these measures involve imputing the potential for expansion of output, given fixed inputs, but one is expressed in terms of catch and the other, in terms of (variable) effort levels (i.e. the full utilization level of inputs required to produce the capacity output). The measurement issue in this context is thus based upon returns to a particular input, rather than returns to scale, and the measures will only be numerically the same with constant returns to the variable input.

For many fisheries (and many other industries), the notion that these relationships are constant or proportional may be incorrect. Economies or returns to scale are likely to be variable and deviate across inputs. In addition, the returns to the variable inputs, which also can be measured by output elasticities, are not likely to be constant. In fact, the returns to the variable inputs are likely to be diminishing. For example, doubling boat size, engine power, and variable input usage in many fisheries would likely result in catch increasing by less than the rate of increase in all factors of production. In other fisheries, however, it is possible that a doubling of effort might more than double catch. In contrast, reducing the existing capacity base or fixed input level by half could decrease the potential catch by either less or more than 50 percent. The doubling of variable effort levels, given the existing capacity base, might be expected to result in less than a doubling of catch if fishers are operating economically. Diminishing returns would arise not only from the existence of fixed capital levels, but also from other fundamental constraints such as biomass stock levels. Diminishing returns also are implied by the existence of some optimal level of utilization, or application of variable effort to the existing capital stock in the fishery. But since production with excess capacity is, by definition, being carried out at non-optimal levels, increasing returns to variable effort could also prevail.

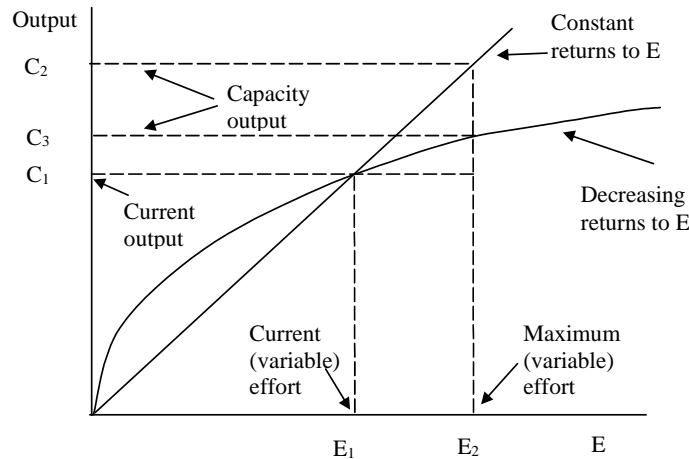
It also is likely that greater crowding in fisheries as overall effort levels rise will result in a *less* than proportional increase in the level of output, which implies diminishing returns to both capital and variable inputs. The notion of crowding is typically recognized as a congestion or technological externality. As a consequence, potential catch will not increase by as much as potential effort, particularly if the increased effort involves higher variable effort levels applied to a given capacity base. In this case, (variable) input-based measures of capacity utilization indicating the increased effort required to reach capacity output will imply a larger gap between existing and optimal levels than the corresponding output-based measures.

More specifically, the proportion that catch or output,  $C$ , can be expanded given the existing capital stock,  $K$ , is constrained by decreasing returns to (variable) effort.<sup>20</sup> This particular primal concept of capacity output is based on Gold's (1955) and Johansen's (1968) definitions of capacity output, which are identical. Simply, the technology must be of such a form that a maximum level of production exists; Coelli, Grifell-Tatje and Perelman (2001) refer to this as the strong concept of capacity. Coelli, Grifell-Tatje and Perelman (2001) also note, however, that for some functional forms (such as the Cobb-Douglas or multiplicative form of the short-run yield function) having diminishing returns to scale, the weak concept of capacity offered by Färe (1984) must be used. This is simply because such functional forms do not experience a maximum. Rather, output asymptotically approaches a maximum as the levels of variable inputs approach infinity.

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<sup>20</sup>Färe (1984) and Färe, Grosslopf and Kokkelenberg (1989) introduce the notion that output is bounded by a fixed input. This can apply to either constant or variable returns to scale (i.e. diminishing returns to the variable input are not required). Coelli, Grifell-Tatje and Perelman (2001) provide additional discussion about the capacity concept of Färe; more formally, this concept of capacity is referred to as the weak concept of capacity, whereas the Johansen concept is referred to as the strong concept of capacity. With the Färe concept, production is bounded by the fixed input, and additional levels of variable inputs do not increase output. (In Figure 10, for example, once  $E_2$  was reached, assuming  $E_2$  equalled the full utilization level of the variable input, the output would remain unchanged regardless of the level of the variable inputs.)

We use the weak concept of capacity output to illustrate the difference between an output-oriented and an input-oriented measure of capacity utilization. If we assumed that the production technology had a global maximum output, and output decreased for higher levels of effort, we might consider the strong definition of capacity output. We further assume, given the weak concept of capacity output, that for effort level  $E_2$ , capacity output is bounded or limited by the fixed input base (Figure 10). In such a case, the level of variable inputs determines the overall level of effort.



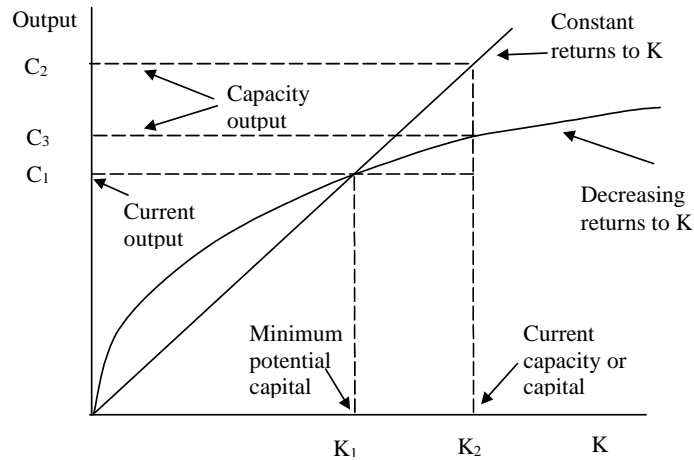
**Figure 10 – Returns to E and capacity utilization, output orientation**

With diminishing returns to effort ( $E$ ), let the capacity output equal  $C_3$ ; for constant returns to effort, let the capacity output equal  $C_2$ . Given diminishing returns to the variable input, there is a gap between catch,  $C_1$ , and the imputed potential or capacity output level,  $C_3$  that is smaller than that associated with constant returns to scale. The output-oriented capacity utilization measure,  $C_1/C_3$ , is closer to one than that based on the variable input or  $E$ , which equals  $E_1/E_2$ . If constant returns to  $E$  existed, the implied capacity output,  $C_2$ , and the associated variable input use,  $E_2$ , would result in identical capacity utilization ratios,  $C_1/C_2 = E_1/E_2$ .

A similar diagram can be used to illustrate the input-oriented measure of utilization implied by contraction of the existing capacity base, given current catch  $C=C_1$  (Figure 11). Note that this concept, however, really indicates capital utilization rather than capacity utilization. We consider the case of one fixed input to illustrate the potential differences between estimates of capacity output, when based on a measure of capital utilization, given different returns to scale. In this case, the input represented on the horizontal axis is the capacity base or capital stock,  $K$ .<sup>21</sup> If the current level of capital is one of excess capital, the levels of  $K$  and  $C$  will not be consistent with economic optimization and catch  $C=C_1$  will be produced with a capital stock of  $K_2$ . Imputing the contraction of  $K$  required to produce  $C$  at least cost, or optimally, thus reproduces point  $K_1$ , which is on both the constant and decreasing returns frontiers. The corresponding capital utilization measure is thus  $K_1/K_2$ . Since this measure does not imply any change in output, no scale economy or returns to  $K$  impact is imbedded in the measure,

<sup>21</sup>The returns to  $K$  here involve only the  $C$ - $K$  relationship. However, assuming that variable inputs are not constraining the relationship, returns to  $K$  and to “scale” are essentially equivalent. That is, if variable input or effort use is represented in this diagram, decreasing returns would be expressed in terms of short-run returns rather than scale economies. The latter implies a movement along long-run cost curves, whereas, by definition, in a situation of excess capacity the relevant cost curve is short run.

so it is independent of the form of these economies. It will differ from the output-based measure, however, depending on the extent of decreasing returns.



**Figure 11 – Returns to E and capacity utilization, input-orientation**

The ratio,  $K_1/K_2$ , is equivalent to the output measure,  $C_1/C_2$ , that represents the (inverse of the) expansion of catch that could potentially (or optimally) be supported by  $K_2$ , given constant returns to scale. However, with decreasing returns to scale, the output-based measure of capacity utilization is greater than the equivalent measure based on  $K$ :  $C_1/C_3 > K_1/K_2$ . This implies a smaller potential expansion of catch than if constant returns existed, and thus a greater adjustment of  $K$  than  $C$  to reach the “potential” or capacity input,  $K_C$  ( $K_1$ ), or output levels,  $C_C$  ( $C_3$ ). The deviation between these values may be measured only with information on the extent of returns to  $K$  and on scale economies if variable inputs adjust correspondingly. Such information may be generated through quantitative estimation, such as through a parametric model, although the resulting evidence of scale economies may be difficult to interpret since actual (variable) inputs are typically not well measured but instead broadly represented as “effort”.

It also is possible that output- and input-oriented measures of capacity output may differ because of their dependence on the state of the biomass. The biomass, or stock, is an underlying constraint or rigidity affecting potential catch. Imputation of potential or capacity catch and associated variable input levels therefore depends on existing biomass ( $B$ ) levels, unless this potential is explicitly evaluated in terms of short-run potential, given the existing biomass. Over the long run, expanding catch levels implies changes in the stock.

Input-oriented utilization measures based on  $K$  contraction for a given  $C$  are independent of assumptions about the biomass, because assessment of capacity is made with existing output, and the associated stock, as a reference point. This is similar to the qualification raised for scale economies, since simulating potential catch levels may involve extrapolating catch and associated stock levels outside the range of existing observations, rather than evaluating relationships at existing scale (catch) and thus stock levels. This implies both that input-oriented measures reduce the difficulty of recognizing complex stock-flow issues associated with catch and both input and biomass stocks, and that to measure potential output we would not want to extrapolate beyond observed and, thus, feasible catch levels, particularly at the boat or trip level.



However, even though input-based measures reduce the potential for convoluting capacity and scale economy or stock issues and measures, identifying the input contraction that could be made and still support the existing level of output requires significant information about the productive process. In addition, the answer to this question also would differ if evaluated at different biomass stock levels. In particular, it requires information about the relationships among inputs and outputs (the production function, and resulting marginal and average productivities of inputs), the constraints imposed by biomass levels, and the potential future impact of technological progress (technical change or shifts in the production function).

Overall, output- and input-oriented capacity utilization measures are not directly comparable without corresponding estimates of scale economies and their input-specific components, and estimates of the dependencies of these relationships on the biomass. Output-oriented measures impute the potential or “optimal” output or catch possible to produce given the existing capital/vessel base, or capacity. Since this implies expansion of scale and harvest levels, it raises problems associated with scale economies and biomass dependencies. Input-oriented measures represent the potential contraction in existing capital or capacity that would still support production of existing catch levels. This requires recognition of varying vessel productivities, but does not imply changes in scale, and thus stock, if evaluated in the short run. Constructing either type of measure requires information to be generated about productive possibilities of inputs, and substitutability. However, since the different measures provide alternative complementary perspectives on the state of the fishery, they are all useful to construct to assess and manage capacity.

## **2.10 Additional difficulties in capacity measurement and assessment**

In practice (and as already evident from the qualifications presented in the previous two subsections), the conditions assumed in the simple illustrative examples presented in the previous sections were overly simplistic. They provide an adequate basis for illustrating concepts, but they would likely be too limiting for an empirical analysis and assessment of capacity output and capacity utilization in fisheries. Many of the issues alluded to relate to stock characteristics (heterogeneity), the form of the short- and long-run technology, and rigidities or expectations (short- as contrasted to long-run behaviour).

A fundamental issue, which should be addressed for construction, interpretation, and use of capacity and capacity utilization measures for micro-management, concerns the fact that boats are not homogeneous in cost structure and activity. Vessel operations typically involve different lengths of time, types of gear, technologies and cost structures, and often target a range of different species. As a result, the selection of boats to remove from a fishery must be based on appropriate criteria established by managers. A removal or capacity reduction strategy that does not adequately consider the heterogeneity of the fleet could greatly affect the level of output and the potential economic benefits that are generated. It is important to a capacity reduction programme, therefore, that overall measures of capacity utilization for the vessels in the fishery be generated, but also, individual boat measures of productivity, efficiency and utilization, calculated. This latter step, however, may be quite difficult since data may not reveal differences among vessels. For example, if boats are assumed homogeneous, removing the most economically efficient (i.e. least cost per unit of output, or largest level of output for given input levels) vessels could result in maximum sustainable

yield being achieved with few economic benefits being generated.<sup>22</sup> Similarly, removing the least technically efficient boats (in terms of catching ability) may result in a reduction in fleet size with either no change or only a minimal change in the potential output from the remaining fleet. The estimation and analysis of capacity should therefore consider boat-specific capital and other input characteristics relating to the efficiency of operations and catch.

Latent effort must also be considered when focusing on the overall fleet level. Individuals or firm owners may possess licenses to fish, but for various reasons they are not currently operating in a particular fishery. These vessel owners could, however, easily renew their activities in an existing fishery. Alternatively, individuals may own a permit to fish in a fishery, but the permit is for a vessel that has been destroyed. In this latter case, the holder of the permit may be able to purchase a new vessel and reactivate the permit for the fishery. In either case, the effective capacity base could increase. These possibilities also need to be considered when calculating capacity output and capacity utilization measures for a fleet.

Multiple species or multiple product fisheries also present problems for calculating and analyzing capacity and capacity utilization. Many fisheries of the world involve the capture of more than one species (i.e. a multispecies fishery), or the landing of more than one product (multiple product fishery).<sup>23</sup> In the case of multispecies or multiple product fisheries, technical and economic interactions usually occur (e.g. the capture of one species affects the capture of another species, or the price level of one species affects the capture of other species). If these potential interactions are not adequately considered in an analysis of capacity, it may not be possible to determine the optimal or desired least cost or profit maximizing fleet. In order to adequately calculate and assess capacity in either multispecies or multiple product fisheries, it is very important to explicitly incorporate potential technical and economic interactions into the calculation and analysis of capacity.

Determining the respective adjustment period poses another potential problem for calculating a concept of capacity useful to resource managers. That is, should calculations be based only on the short run, or should more attention be given to determining capacity output over the long run? The presence of excess or overcapacity capacity implies that fisheries are not in a long-run equilibrium, or that short-run rigidities are driving observed costs. If a fishery is not in long-run equilibrium, it will not be possible to observe long-term catch rates. Managers, however, typically desire information on capacity relative to the long-run or desired resource levels. Methods for calculating capacity should, therefore, be capable of determining the potential long-run output expansion, or input contraction, using available or mostly short-term information. Implications for a long-run adjustment of the capacity base and biomass stock, as well as future technical change, also need to be considered in the calculation of capacity output, however. They have important ramifications for determining the capital stock or capacity base for a fishery.

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<sup>22</sup>Gates, Holland and Gudmundsson (1996) demonstrated that it is critical to know the general level of efficiency of each vessel, particularly for buyback programmes. Buyback programmes in the United States generally have removed the least efficient vessels, and thus not substantially reduced capacity. Walden, Kirkley and Kitts (2002) provide an analysis of the level of capacity reduced in the New England groundfish buyback programme.

<sup>23</sup>A multispecies fishery is one in which more than one species is caught. A multiple product fishery may involve either multiple-species or a single species (e.g. many single species fisheries involve some level of price discrimination based on size or sex of the product being landed).

For the purpose of estimating capacity output, it is also important to account for the impacts of short-run fluctuations and expectations on production and apparent excess and overcapacity. Excess capacity in the short term may actually be desirable, in terms of feasibly maximizing the benefits derived from fishing. Having excess capacity in the short run may permit cost efficient adjustments to the capacity base in the long run (i.e. it may be less expensive to purchase vessels in the present than it is to purchase them in the future). Fluctuations in either stock abundance or biomass are typical of many fisheries. Having seemingly excess capacity in one period when stocks are low may not actually equate to overcapacity in a period when stock abundance or biomass is high. Simply put, vessel operations with adequate capacity may be able to take advantage of high resource levels, even though they have excess capacity when resource levels are low. Harvesting at this higher level may yield higher net benefits to society than would be realized by harvesting levels corresponding to a lower capacity base. A measure of fisheries capacity also should recognize the existence of physical and motivational limitations; for example, required maintenance and personal choices considered to be part of customary and usual operating procedures.

One possible way to better consider the long-run notion of capacity, given various short-run issues, is to base the calculation and analysis of capacity output, capacity utilization and the capital base on information reflecting several years of operations. Alternatively, averages may be used to actually assess capacity output and capital and capacity utilization, as was recently done in Walden, Kirkley and Kitts (2003). The use of information over several years should permit a calculation of capacity output that somewhat reduces the influence of stock fluctuations, while also better reflecting customary and usual operating procedures. The use of several years of information also should permit a distinction to be made between “desirable” excess capacity (that exists for economic reasons and accounts for fluctuations in stocks and market conditions, or normal physical limitations such as required maintenance) and “undesirable” excess capacity (capacity levels that are higher than the economically desirable or optimal level).

Calculating concepts of capacity and capacity utilization, which will be useful for capacity reduction programmes, therefore may be quite complicated. It should be evident that the basic bio-economic framework presented in Sections 2.3 through 2.5 is too restrictive or simplistic for developing useful measures of capacity and capacity utilization. The purpose of presenting that framework, however, was to illustrate basic concepts related to capacity and capacity utilization. A considerably more complicated analytical framework needs to be developed; the framework or method to be used will, however, primarily depend upon available data. That is, if appropriate economic data are available, an economic concept of capacity should be calculated. These estimates should be based on economic measures presented in the literature (e.g. Morrison and Berndt, 1981; Morrison, 1985a, b; and Berndt, 1990) and more recent research developments, such as Fousekis and Stefanou (1996), Fagnart, Licandro and Portier (1999), Färe, Grosskopf and Kirkley (2000), and Coelli, Grifell-Tatje and Perelman (2001). If only primal (outputs and inputs) related data are available, then the technological economic concept of capacity is all that can be estimated. In the absence of any empirical data, it is likely that a survey will have to be designed and implemented to calculate capacity output, because it will likely be the most consistent measure.

In subsequent sections of these guidelines, we present concepts of capacity output and capacity utilization and methods for estimating these concepts when data are primarily limited to observations on input and output levels. It is recognized that several member states of the European Union, the United States, and other nations have initiated large-scale economic data collection programmes, but such data are not available for all fisheries and all nations. Methods requiring only primal data thus are likely to have the broadest current applicability. There is, however, an increasing body of literature on dynamic measures of capacity output using both cost and profit functions, or the assumption that producers maximize profit or minimize cost.<sup>24</sup> An excellent treatment of ways to estimate and analyze the economic concepts of capacity and capacity utilization in fisheries when only data on output prices and levels and input quantities are available appears in Segerson and Squires (1990, 1993, and 1995). The approach, however, is quite complicated and requires an understanding of duality theory and virtual prices. For the most part, we ignore this more recent literature, and instead refer readers to the more recent references focusing on economic measures.

### 3. MEASUREMENT OF CAPACITY AND CAPACITY UTILIZATION

Several nations already have developed measures of capacity output based on the physical attributes of the fleet and implemented capacity reduction policies based on these capacity measures. See, for example, Kirkley *et al.* (2002) for an analysis of five United States-managed fisheries and Walden, Kirkley and Kitts (2003) for analysis of the United States Northeast Groundfish Fishery Buyback Programme. Of primary concern to most fisheries managers is the optimum utilization of the capital employed in the fishery (Kirkley and Squires, 1999). Fisheries managers need to know the fleet size and configuration that achieves the objectives defined by the management plans and policies of their respective nations. These usually equate (implicitly or explicitly) to some target level of output, which is often based on biological concerns. To this end, measurement of the capacity base and capacity output for a fleet or fishery is essential for comparison to these targets, representation of full capacity utilization, and management of capacity.

To provide an aggregate measure of capacity output or capacity utilization, it is necessary to deal with issues that arise for the aggregation of output, input, and stock measures, even if input-based measures are used that are not as dependent on the additional issues of scale economies and stock levels. The units are generally non-homogeneous, and restrictive assumptions may be necessary to aggregate or proxy them if characteristics cannot be measured and subsequently used to form aggregates. If the underlying simplifications and assumptions are not valid, and in most cases they are unlikely to be valid, the resulting aggregate measures may be distorted. In addition, there are serious theoretical issues related to aggregation. See, for example, Daal and Merckies (1984); Corns (1992); Dervaux, Kerstens and Leleu (2000); and Färe *et al.* (2000). It is therefore important to carefully consider how to measure the capacity base and input and output quantities in order to facilitate their applicability to management decisions.

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<sup>24</sup>Methods for estimating both static and dynamic economic concepts of capacity are discussed in Clark, Clarke and Munro (1979), Morrison (1985a,b), Conrad and Clark (1987), Grøn (1994a,b), Fousekis and Stefanou (1996), Fagnart, Licandro and Portier (1999), Higgins and Thistle (2000), and Coelli, Grifell-Tatje and Perelman (2001).

### 3.1 Input stock or capacity and effort measures

Constructing capacity utilization (CU) measures based on either an input or output perspective requires representation of the *fixed* stock of inputs comprising *capacity*, or the capacity base. This typically involves measuring the number or characteristics of the vessels, or the capital stock, in which case the capacity utilization measures expressed in terms of inputs are equivalent to capital utilization measures.<sup>25</sup> If other stocks also make up the capacity base and are assumed immobile and thus fixed (e.g. labour, which includes skipper and crew and the fish stock level, if capacity utilization is expressed for a given fish stock level), a broader interpretation of available capacity is implied.

For effective management, measures of the capacity base should take into account varying characteristics across vessels or fleet segments. That is, different productivities of alternative types of (fixed) inputs must be recognized and measured for appropriate capacity and capacity utilization analysis. This may be accomplished by identifying vessel characteristics that determine the overall “fishing power” of a given vessel and combination of vessels at the sub-fleet or fleet level. Estimation of capacity utilization may then be carried out separately for units with similar characteristics in terms of fishing activity (e.g. gear type used, fishing area, target species), or by explicitly controlling for (or taking into account) different productive contributions stemming from variations in such characteristics.

The application of *variable* inputs to the capacity base determines the potential output that may be produced from the existing capacity base. As presented above, this *capacity output* is compared to existing output levels to construct output-oriented capacity utilization measures, and the implied variable effort levels required to reach this potential output are compared to existing effort levels to generate input-based (but output-oriented) “variable input utilization” measures.<sup>26</sup> Alternatively, the potential contraction in the capacity base that could still support existing catch or output levels may be imputed and compared to the existing capacity or capital level to construct directly input-oriented capacity utilization measures. Both of these input-based measures are sometimes referred to as capital utilization measures, although capital utilization may be expressed from either an output or input orientation; it just requires that only capital inputs comprise the capacity base.

Construction of capacity utilization measures, therefore, first requires defining and characterizing the inputs and outputs used for production, and then distinguishing between the inputs making up the capacity base (the fixed inputs) and those that could adapt to produce capacity or full-utilization output from this base (the variable inputs).

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<sup>25</sup>Capital utilization measures can be used to determine capacity utilization measures only if there is a single stock of capital, the technology exhibits constant returns to scale, and the optimal capital output ratio of constant over time (Berndt, 1999). A single capital stock, when there are multiple stocks and equipment, may be possible if conditions necessary for aggregating over all capital stocks and fixed inputs characterize the technology (e.g. weak or strong separability).

<sup>26</sup>Färe, Grosskopf and Kokkelenberg (1989), and more recently, Kirkley, Morrison-Paul and Squires (2002) advanced the notion of an unbiased measure of capacity utilization. This unbiased measure uses the technically efficient output level rather than the observed output level to calculate capacity utilization. By using the unbiased measure, it is possible to determine whether or not the capacity output level is not being realized because of inefficient production or inadequate use of the variable inputs.

### 3.1.1 Vessel units: fixed inputs, or the capacity base

The key (fixed) input capacity indicator is some measure of the stock of capital. This might include, at the most basic level, the number of boats in the fishery. Kendrick (1961), however, demonstrated that the number of operating units (e.g. plants) is an inadequate indicator of the capital stock; Kirkley and Squires (1986) demonstrated this was also the case for fisheries. Other measures have been developed that capture not only the number of boats in the fishery, but also the size of these boats, including measures of total gross tonnage, hold capacity or total engine power in the fleet. These latter measures characterize the fixed input or capacity base in terms of their productive characteristics. These measures recognize that a small fleet of large boats may have the same, if not greater, harvesting potential than a large fleet of small vessels. The FAO Mexico City consultation developed a comprehensive list of major capacity characteristics by gear type, which illustrates the potential array of different possible characteristics (Table 1).

**Table 1 – Major capacity characteristics by gear type**

Gear type	Capacity characteristics
All gears	Number of vessels, licenses, participants, or gear units (which ever is relevant); length of trip; number of trips per year or season; potential number of trips per year or season; total catch including discards; level of mechanization
Beach nets	As for all gears, plus total length of nets
Handline	As for all gears, plus number of lines employed
Set nets	As for all gears, plus total length of net, average set time
Traps	As for all gears, plus number of traps, average soak time
Diving	As for all gears
Purse seine	As for all gears, plus time searching; use of fish aggregating or fish finding aids such as fish aggregating devices (FADs), airplanes and sonar; average sets per trip; vessel gross tonnage or other volumetric measures; engine power (kW); fish hold capacity
Longline	As for all gears, plus average hooks per set, average sets per trip; average soak time; use of fish finding aids; vessel gross tonnage or other volumetric measures; engine power (kW); fish hold capacity
Gill net	As for all gears, plus type of net, total length and depth of net, mesh size; average set time; average sets per trip; use of fish finding aids; vessel gross tonnage or other volumetric measures; engine power (kW); fish hold capacity
Trawl/dredge	As for all gears, plus gear dimensions (e.g. head-rope length, beam length); mesh size; tow time; average tows per trip; use of fish finding aids; vessel gross tonnage or other volumetric measures; engine power (kW); fish hold capacity

Source: FAO (2000).

Several nations have developed composite measures of capacity based on the physical characteristics of the vessels, such as boat size and engine power. These measures attempt to equate capacity to fishing power (Kirkley and Squires, 1999).<sup>27</sup> An assumption of such measures is that fishers are able to substitute among inputs, and hence an appropriate measure of capacity requires the combination, rather than individual quantities, of inputs to be represented. For example, in the United Kingdom, input-based vessel capacity is measured using Vessel Capacity Units (VCUs). These are defined as follows:

$$VCU = l \times b + 0.45kW$$

<sup>27</sup> An extensive listing of studies for which researchers have attempted to measure capacity in terms of fishing power is provided in Kirkley and Squires (1999). Hannesson (1987, 1993) appears to offer the earliest and most comprehensive treatment of using fishing power as a basis to determine capacity output; Hannesson, however, focused on fishing effort, as measured by the cost of capital invested in fishing equipment.

where  $l$  is the length of the boat (in metres),  $b$  is the breadth (in metres), and  $kW$  is the engine power (in kilowatts). This is essentially a simple hedonic formula relating “effective” capital units to their characteristics. This particular formula was derived from an econometric analysis of the Scottish North Sea trawlers, and was found to explain between 70 and 80 percent of the differences in earnings between boats (United Kingdom Fisheries Department, 1988).<sup>28</sup> While derived on the basis of the North Sea trawlers, the formula has been applied to all boats operating in all United Kingdom fisheries regardless of the gear type or target species. VCUs are estimated for each individual boat in the fishery and aggregated to give a total (fixed or stock) input capacity, or “effective” capital capacity measure, at the national level. In Australia, a similar measure was developed for the purposes of capacity management. However, unlike the United Kingdom, the units are non-transferable between fisheries. While intuitively appealing, such a measure can create severe distortions if applied to all fisheries for capacity management, because the relative importance of the boat size and engine power varies from fishery to fishery and its estimated contribution may crucially depend on the available data.

A preferred measure of the capital stock in a fishery is the economic value of the capital stock (Bell, 1967; Kirkley and Squires, 1986). The economic value of the capital stock can greatly ease the problems associated with aggregating over different types of capital and equipment and over different capital platforms (e.g. vessels). In addition, shadow values or rental prices can be obtained for different attributes of the capital stock, which reflect differences in the productivity of the various attributes. An economic measure of the capital stock for a fleet can then be obtained by aggregating the market values, insurance values, replacement values, or the actual investment values of the vessels.<sup>29</sup> In theory, these measures should capture the differences in fixed input combinations (including difficult to quantify inputs such as levels of technology) on the assumption that the market value or one of the other measures of the capital stock reflects the productive capacity. In practice, however, financial values of the inputs may provide misleading indicators, particularly since financial depreciation may not correspond to a reduction in the productive capacity of the input. Such measures also preclude the ability to distinguish among the contributions of different types of investments.

For many fisheries, however, information necessary for constructing an economic value of the capital stock is not available. In this case, it may be possible to consider the differential capital productivities by explicitly incorporating different capital characteristics into the analysis as individual production determinants, or inputs; that is, the components of (fixed) input capacity may be measured separately. The capacity base, therefore, is recognized to have different quality-adjusted or effective levels depending not only on total boat numbers, but also on total gross tonnage and total engine power and, perhaps, on other indicators of “power” if available. An alternative framework to adequately deal with quality differences and varying characteristics, while also constructing an economic measure of the capital stock, is to combine different types of capital goods by weighting each type by its average compensation (National Academy of Sciences, 1979; Kirkley and Squires, 1986). In this way,

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<sup>28</sup>The original model was based on a Dutch study of North Sea beam trawlers. This model was applied to Scottish boats. However, the econometric analysis was undertaken in logarithmic form, i.e.  $\ln(\text{earnings}) = f(\ln[\text{VCU}])$  (UK Fisheries Department, 1988).

<sup>29</sup>Kirkley and Squires (1986), using a sample, estimated the value of the capital stock using a hedonic approach, in which vessel values or acquisition prices were regressed against vessel characteristics. The statistical estimates were subsequently used to estimate the value of vessels of the fleet.

it is possible to develop an aggregate measure of the capital stock. The information necessary for developing this latter measure of the capital stock, however, is seldom available for fisheries. Measures based on the physical indicators of the capital stock and fishing power may be estimated as separate indicators of capacity either at the boat or the fleet level. However, aggregating to the fleet may be difficult to accomplish without direct estimation of the varying productivities of the capital characteristics, potentially through the empirical representation of the production function relationship required for direct capacity utilization measurement.

### 3.1.2 “Effort” units: variable inputs applied to the capacity base, or overall effort

Effort is an abstract concept that consists of many elements, including time fished, the level of inputs, level of technology and the skill of the skipper and crew. Effort is typically represented as a combined measure of fixed (vessel) and variable (crew, fuel, days) components.<sup>30</sup> Effort may be viewed as an aggregate input (e.g. we combine labour and capital services with fuel and call it fishing effort). Alternatively, we may view fishing effort as an intermediate output in a two-stage, non-separable technology, in which factors of production (e.g. fuel, capital and labour) are used to produce an intermediate product (e.g. effort) in stage one, and then used as an input to produce a final product in stage two (Pollak and Wales, 1987). However, the fixed input stocks making up the capital base (capacity) must be distinguished from the variable inputs applied to this base (effort) to represent non-optimal utilization of capacity. These variable inputs are typically summarized simply as days fished or days at sea, which represents the combination of inputs applied to the capacity base to generate catch, assuming that they are applied in some constant proportion. This is often done since many of the actual inputs are difficult to quantify, both conceptually and due to limitations in available data. Effort is thus generally measured in terms of time spent fishing or days at sea (days or hours fished per boat, or nominal effort).<sup>31</sup>

This measure is, however, often standardized to account for differences in relative fishing power, such as those due to differences in boat size, skipper and crew skill, and level of technology (effective effort). Such standardized measures of the relative performance of different boats compensate for heterogeneity in the fleet. Standardized measures of effort are often constructed by normalizing effort by multiplying the ratio of the catch per unit effort of an existing vessel to the catch per unit effort of a reference vessel or gear, although a range of methods have been used to calculate relative fishing power (Gulland, 1956; Comitimi and Huang, 1967; Pope, 1975; Ricker, 1975; Hilborn and Ledbetter, 1985; and Hilborn and Walters, 1992). Kirkley and Strand (1984) provide a discussion of economic approaches to standardizing effort (e.g. cost, revenue and technical efficiency measures are used to standardize nominal fishing effort).

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<sup>30</sup>The concept of fishing effort originates from the biological literature on fisheries; the notion that a single variable, such as fishing effort, represents the influences of all inputs on output is related to the economic concepts of separability and aggregation. The notion of fishing effort may also be viewed as though it is an intermediate output of a two-stage production process (Pollak and Wales, 1987). General theoretical information about separability and aggregation is available in Blackorby, Primont and Russell (1978). Squires (1987) provides a detailed discussion about the construction of an economic concept of fishing effort.

<sup>31</sup>Kirkley and Squires (1999) provide a discussion on different measures of effort, which include time fishing vs. time at sea, or for some fisheries, number of trap or pot pulls, etc.



While the measure of total effective effort in a fishery is generally equivalent to that of total nominal effort for the particular time period in which fishing powers were estimated, changes in the composition of the existing fleet will result in a divergence between the nominal and effective measure of effort. For example, if the least efficient boats (in terms of catch per unit of nominal effort) were removed from the fishery, effective effort would decrease by less than nominal effort. This notion of standardized effort, however, is also a *combination* of the variable (E, effort) and fixed (K, capital) inputs that determine overall productivity, and it is necessary to distinguish their contributions *separately* for direct evaluation of capacity and capacity utilization in a fishery.

An alternative version of a standardized unit of effort is one that is expressed in terms of vessel features, rather than time fished, and thus is based on fixed rather than variable inputs. In this case, performance is related to a particular feature of the boat, such as engine power, so that a standardized unit of effort can be derived, say, by multiplying the engine power by days fished to produce a hybrid measure (i.e. kW days fished).

Measures of fishing power based on a single feature to adjust for the “effectiveness” of the capital stock can generally be readily derived for all fleet segments and fisheries, and thus provide a relatively easy foundation on which to aggregate across boats. However, while such a measure is likely to be related to the harvesting capacity for similar types of vessels, it may not be readily comparable across fleet segments (Ricker, 1975). For example, larger trawlers use bigger engines and are likely to catch more per day than smaller trawlers with smaller engines (i.e. some proportionality may be assumed between relative engine power and catch rates). In contrast, vessels using similar engines but different gear may achieve significantly different catch rates when operating in a given fishery. Measures of fishing power based on a single feature are, therefore, less accurate when comparing fleet segments within a fishery than standardized effort units based on more inclusive measures of fishing power. This also makes them less representative of the true mix of a variety of vessel characteristics. It seems that such characteristics might better be measured and represented in terms of their specific productivities (catch rates), to distinguish their individual impacts on catch for both specific vessels and the fleet as a whole.

The previously discussed standardization techniques have limitations.<sup>32</sup> The standardization process is quite fishery-specific, so aggregation of standardized effort units across fisheries is seldom appropriate. It also does not readily allow for the application of production-oriented methods for constructing capacity measures. Such standardization may nevertheless be required for other purposes. In particular, estimation of fishing powers as a way of standardizing effort between different fleet segments within a given fishery is the basis for developing the biological or bio-economic models of fisheries that would be required for the estimation of target capacity levels. These methods may also be useful when data are especially limited. In particular, information on catch rates is necessary for the explicit estimation of fishing power but, in some cases, is not available at the individual boat or even fleet segment level. Measures of characteristics or even nominal levels of the fixed and variable inputs may also not be available. In these cases, the simpler standardized measures may be used to represent “effort,” and can be estimated at the fleet segment, fishery or national level without taking boat-specific characteristics into account. Results derived from

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<sup>32</sup>Pope (1975) provides probably the most comprehensive, and still up to date, discussion about methods for estimating fishing effort and fishing power.

this approach, however, would require careful interpretation. The qualifications above about the importance of representing a variety of specific input characteristics and their contributions to catch in order to more justifiably identify variations across boats or fleet segments must be taken into account when using such measures to guide policy.

The overall level of effort,  $E$ , for a fleet is a complex combination of variable “effort” in terms of days, crew, fuel, and other variable inputs ( $V$ ), and the services of capital and equipment embodied in the vessels ( $K$ ). Again, this presumes that the condition of separability, which is required for constructing an appropriate aggregate, characterizes the technology.<sup>33</sup> This combination may not be expressed as a standardized measure for the representation of capacity and capacity utilization, since full capacity input-based measures are defined in terms of  $K$ , given catch levels, *or* in terms of  $E$ , given the capacity, or capital stock. And this distinction between fixed and variable inputs is necessary to generate total input measures for any level of aggregation – that is, for boat, sub-fleet, or fleet-level measures of inputs and resulting capacity and capacity utilization.

If appropriate data are available, output-oriented measures of capacity and effort may be developed and used instead to focus on the distinction between vessel characteristics comprising the capacity base, or fixed inputs, and effort or variable inputs applied to the base. Recognition of different boat, and ultimately fleet, characteristics, must be built into the process of capacity and CU estimation, in order to control for fishery-specific input relationships. This is important for identifying either the amount by which the capacity base could be reduced and still generate existing catch or TAC levels, or the output that the existing capacity base could potentially support. An output-oriented measure also facilitates justifiable aggregation of boat-level characteristics to analyze the potential power of the fleet as a whole, and to help determine the optimum fleet configuration when there are heterogeneous operating units.

The underlying productive relationships can be expressed in this case in terms of a production function relating output produced to the fixed and variable inputs applied (and their characteristics). For multiple output fisheries, these relationships may be expressed in terms of more general functions, such as a distance function, stochastic multiple output distance function, or polar coordinates (Löthgren, 1997). If the data are available to quantify these relationships, measurement methodologies that identify the specific contributions or productivities of capital stock and variable inputs may be applied, which is important for establishing the capacity level embodied in the capital stock. Analysis of the underlying production technology allows a detailed evaluation of the true power of the input stock, and the implications in terms of catch rates of reducing the physical capital stock, required for measuring and assessing capacity, capacity output and capacity utilization.

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<sup>33</sup>Separability is the condition of independence of the marginal rate of substitution (the ratio of the marginal product of one input,  $X_1$ , to the marginal product of another input,  $X_2$ ) between two inputs from other inputs (e.g.  $X_3$ ). In words, separability implies that relationships between outputs or inputs in one group of outputs or inputs and those of another group are through an aggregate effect (e.g. the combining of cod and haddock into groundfish, or capital, fuel, and labour into fishing effort, implies there is no unique interaction between the individual outputs of an output group, or for a single output, and the individual inputs of an input group). The marginal product is simply the change in output associated with the change in an input by one unit. The conditions for aggregating over firms or vessels to construct a composite output or input for a fleet are considerably more complex. (See, for example, Daal and Merkies, 1984.)

## 3.2 Capacity utilization definitions

Capacity utilization is defined more precisely in this section in relation to output, effort and input.

### 3.2.1 Output-oriented capacity utilization measures

The general definition of capacity output given in Section 1.1 can be modified to the specific definition of capacity output: *the maximum amount of catch that can be produced in a given unit of time (e.g. year or fishing season) with existing plant and equipment under customary and usual working conditions, provided that the availability of variable factors of production is not restricted.* In this case, the variable factors of production include days (or hours) fished, labour, quantities of gear, etcetera, which are separately identified from the capital or capacity base defined in terms of vessel characteristics. Hence, capacity output is fundamentally determined by the capacity base and is directly related to the corresponding full utilization level of variable inputs or “potential effort”, although the relationship is not necessarily proportional. This basic definition, however, is consistent with the strong concept of capacity output offered by Johansen (1968) and discussed in Coelli, Grifell-Tatje and Perelman (2001). The weaker concept, in which output is bounded or limited because of fixed factors, is generally used in this volume; this is especially the case when the primal or technological-economic concept of capacity output is used.

Determining capacity output requires imputing the catch that would be generated if all boats (available capital or capacity) operated at maximum potential effort levels (say, days or hours), given normal working practices (i.e. making allowances for repairs and other normal breaks in or constraints on fishing activity), and the state of the production technology (i.e. the technology required to convert inputs into outputs or produce a product). This requires taking a measure of the existing capacity (capital) and determining the most feasible catch from this capacity base, given the prevailing production technology and environmental/biomass conditions.

Capacity output can be measured at the species level or aggregate fishery level. For effective management of the fishery, measurement of capacity output should be undertaken at the species level where possible. This is important when identifying the extent to which individual species are being over-exploited, or face potential overexploitation.

Capacity utilization (CU), relative to capacity output, is the ratio of the current catch level to the capacity (or potential) catch level, which is interpreted as the extent to which the fixed inputs in the fishery (e.g. capital) are being utilized.<sup>34</sup> That is, for the output (catch) oriented measure,

$$CU_c = \frac{\text{Current catch}}{\text{Capacity catch}}$$

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<sup>34</sup>It also is common practice to use the inverse of the capacity utilization measure. The inverse indicates the amount that output could increase if the existing capacity were to be used “optimally”. In addition, Färe (1984) and Färe, Grosskopf and Kokkelenberg (1989) argue that the technically efficient output level rather than the observed output level should be used in the measure of capacity utilization in order to eliminate distortions in the measure that might be associated with inefficient production.

The measure of capacity utilization ranges from zero to one. Values of CU significantly less than one indicate the existence and extent of excess capacity in the fishery. That is, the current catch could be increased with no change in the fixed input base or capital stock, if operators fully utilized the variable inputs. The proportion by which a fleet could potentially contract and still produce the existing catch level is loosely implied by the CU measure. For example, a measure of 0.75 implies, very loosely, that reducing capacity by about 25 percent would allow the current output level to be produced in an economically optimal manner. As previously discussed, however, the actual magnitude of the measure will depend on scale economies and returns to individual factors.

As previously noted, however, CU measures should be carefully assessed relative to resource and economic conditions. One way to do this, particularly in the absence of detailed economic data, is to develop CU measures under average resource and economic conditions. Measures derived under average conditions should facilitate a better understanding of the severity of excess capacity and promote capacity reduction targets more consistent with the needs of management. Consider, for example, a period during which resource or economic conditions were favourable for increased exploitation. It is likely that an analysis of capacity would suggest a higher level of capacity output than would normally be realized by a fleet or vessel. If a subsequent capacity reduction programme was based on estimates of capacity output obtained during periods supporting high capacity output, the programme might remove too many vessels, particularly relative to customary and usual operating procedures. Similarly, if the capacity reduction programme was based on estimates of capacity output obtained during conditions supporting very low catches, it is possible that the programme would remove too few vessels from the fishery. In order to assess the extent to which capacity underutilization is excessive, it is important to compare CU measures over several years of observation, including periods in which fish stocks were considered “good” or above average, to distinguish stock from utilization fluctuations.

### 3.2.2 *Potential effort and variable input utilization*

Potential effort is the level of effort or levels of all variable inputs required to produce the capacity output, given the existing capital stock. More formally, we can define such a measure of potential effort as follows: *the (variable) effort level corresponding to the maximum amount of catch that can be produced in a given unit of time (e.g. year or fishing season) with existing plant and equipment under customary and usual working conditions but with variable input use unrestricted.*

In the case of fisheries, and because of limited data, days at sea or days fished, or some other measure of fishing effort is typically used to represent the influence of the variable factors of production. If additional data are available, such as person-hours of skipper and crew labour, these other variable factors also should be included in an analysis of variable input utilization. The corresponding input-based (but output-oriented) measure of capacity utilization is typically referred to as the *variable input* utilization ( $CU_v$ ) (Färe, Grosskopf and Kokkelenberg, 1989; Färe, Grosskopf and Lovell, 1994). The measure provides an indication of the level of effort or levels of variable inputs required to produce the capacity output; it is therefore an input-based but output-oriented measure (i.e. it provides a measure of the proportion by which variable inputs should be expanded or contracted relative to capacity output, but the capacity output is a measure of the amount by which output could be

expanded until reaching the maximum potential capacity level). It is formally defined as the ratio of the current to the potential level of effort:

$$CU_v = \frac{\text{Current effort}}{\text{Potential effort}}$$

The input utilization measures may be less than, equal to or greater than one in value. A  $CU_v < 1.0$  implies a shortage of effort relative to the level necessary to produce the capacity output; a  $CU_v > 1.0$  in value implies a surplus of effort relative to the level necessary to produce the capacity output. Färe, Grosskopf and Kokkelenberg (1989) use a somewhat different and possibly confusing terminology for  $CU_v >$  or  $< 1.0$ ; they refer to the case of  $CU_v > 1$  as over-utilized and  $CU_v < 1.0$  as under-utilized.

The variable input utilization measure has also been referred to as a measure of *capital* utilization, since it is a direct measure of the utilization rate of the physical inputs in terms of the application of variable inputs, whereas output-oriented measures of capacity utilization are represented in terms of potential output (catch) from the capacity base. However, any utilization measure where the capacity base is defined solely in terms of capital levels or characteristics may be termed a capital utilization measure. Also, as elaborated above, if the fishery is subject to diminishing returns to effort, the  $CU_v$  measure is likely to be less (further from one) than the  $CU_c$  measure of capacity utilization.

Determining potential effort requires imputing the catch that would be generated if all boats operated at the maximum number of days (or hours, etc.) given normal working practices. Alternatively, and for the weaker concept of capacity output, it would require determining the maximum number of days corresponding to utilization of the fixed factors, such that addition increases in variable input usage did not further increase output. The calculation of either notion of potential effort involves taking a measure of the existing capacity (capital), expressing the maximum feasible output producible from this capacity (given an existing production technology under customary and usual operating conditions), and determining the implied amount of variable inputs. This may in turn imply levels of effort, crew, or other variable inputs, but as noted above this is usually summarized in terms of days fished, with the idea that given amounts of crew and fuel are necessary per day to fish effectively.<sup>35</sup> Although such measures ideally would be constructed at the individual boat or fleet segment level, to take specific vessel characteristics into account, fleet level measures also may be generated through aggregation.

In some cases, measuring potential effort may instead require subjective evaluation of how much input use might be feasible if regulations were removed separately from the impact of customary and usual operating conditions on the definition of “feasible” or “potential” catch or variable input use. This implies approaching the capacity output question initially from the input perspective.

For example, if the fishery has been regulated throughout the period for which data are available, (e.g. through TACs) the potential number of days may not be observed directly. Thus, estimating the number of days that a vessel could operate may require a subjective

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<sup>35</sup>In formal economic terms, levels of variable inputs required, at a minimum, to fish are termed essential inputs (Chambers, 1988).

assessment rather than a simple representation of the maximum catch as that observed within the existing data for a vessel with particular characteristics, but “unrestricted” by variable inputs. To facilitate this, effort units must be expressed in terms of their optimal application to a given capacity base and thus, implicitly (but not directly), in terms of days adapted by a combination of capital characteristics (e.g. kW\*days). Such a perspective helps to determine how many days a boat of a given size could potentially fish if the regulations restricting days at sea were removed; it facilitates representing the “marginal product” of days to determine how days fished might change if it were possible to do so. The potential number of days fished in an unrestricted environment is in this context based on a balance between the productivity of additional days and, potentially, some notion of the costs of the additional days if such an opportunity cost exists.

Generally, the assumption of normal working practices includes that existing gear type/use and engine size cannot be changed, even if restrictions are imposed. This is consistent with the idea that these are part of the capacity base and therefore considered as additional capital characteristics for representing the level of fixed inputs. Depending upon the specific fishery, however, gear use may be a variable input (e.g. change in number of traps or pots), and independent of the amount of overall effort summarized in terms of days. If the quantity of gear currently employed is restricted, possible changes in gear use will need to be reflected in the estimation of potential effort and catch, and further assumptions or subjective evaluations may be necessary. For example, effort in fisheries using static gear (e.g. nets, lines, and pots) could readily expand through increasing the quantity of gear employed, as well as the number of days the gear are employed.

At the fishery level, estimating potential vessel entry or the impact of latent capacity and thus implicitly the associated catch or use of variable input in an entire fishery, also requires consideration of vessels that operate in multiple fisheries. While this effort could, theoretically, be allocated fully to one fishery, it is possible that fishers could allocate their effort across several fisheries. The allocation of effort among fisheries may vary from year to year, based on environmental and economic conditions, and this could be accounted for to assess full utilization.<sup>36</sup> Alternatively, the actual time spent in any one fishery could be considered to be the maximum time that multi-fishery vessels would operate in that fishery under normal working conditions and given existing environmental and economic conditions. In this case, the potential effort of these boats should not be expanded to equate to the potential effort of “full-time” boats, assuming that individual boat activity can be identified. Vessels switch according to opportunities or expectations. If they leave one fishery, conditions in the fishery they left should improve, while conditions in the fishery they entered will likely deteriorate. Estimation of capacity output and capacity utilization for such operations may thus be quite complicated. It may be best to consider the broader economic concepts of capacity and capacity utilization, or at least develop good measures of customary and usual levels of effort and capital stock. When these multi-fishery boats cannot be identified, potential effort is likely to be overestimated.

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<sup>36</sup>Färe, Grosskopf and Kirkley (2000) provided a potential framework for determining capacity output and variable input utilization given that variable and fixed factors of production could be allocated among different fisheries. The approach, while methodologically correct, requires expert knowledge of the various fisheries under consideration. In the absence of expert knowledge about the fisheries, the framework or methodology could suggest incorrect allocations of effort (e.g. an allocation of labour in excess of that permitted by a particular type of fishing vessel).

### 3.2.3 Input-oriented capacity utilization measures

As emphasized in the preceding section, capacity, or the capacity base, is comprised of the fixed input stocks or vessel and vessel characteristics (fishing power) used for production in the fishery. Capacity output is then the level of potential catch, given this fixed input base, while “potential” effort, or full variable input utilization, is the amount of variable inputs (e.g. days) that would be applied to the capacity base to generate capacity output. Such a measure is sometimes called a (variable) input-based measure of full capacity utilization. An input-oriented, or dual, measure of capacity utilization is instead the amount that the (fixed) capacity base, or level of capital, may be contracted to produce the existing or target (e.g. TAC) level of output or catch.

The input-oriented capacity utilization measure may be formalized by first defining a measure of potential capital ( $K$ ) as: *the minimum amount of capital (vessel power) that, in a given unit of time (e.g. year or fishing season), produces the existing or target output under customary and usual working conditions, provided that the availability of variable factors of production is not restricted.* In this context, therefore, we may define an input-oriented capacity utilization measure as follows:<sup>37</sup>

$$CU_K = \frac{\text{Potential } K}{\text{Current } K}$$

where the subscript  $K$  indicates that it is a capital input-oriented measure of capital utilization.

A value of  $CU_K < 1$  indicates the potential capacity or capital contraction that could be achieved and still maintain current (or target) output levels, since the numerator indicates the amount of  $K$  that would be necessary to produce the existing level of output at a full or optimal utilization level.

Any of these capacity utilization measures –  $CU_C$  (or  $CU$ , as usually specified),  $CU_V$ , and  $CU_K$  – can be considered indicators of the degree to which the excess capacity exists in the fishery. All three measures, however, basically relate to the short run. None of the three  $CU$  measures allows for full adjustment of resource conditions, capital stock, equipment, capacity output and variable inputs.<sup>38</sup> All three are defined or calculated conditionally on existing values of some variables (e.g. capacity output is conditional upon no change in the fixed factors; variable input utilization is conditional on capacity output and no change in the fixed factors; and the input utilization for capital,  $CU_K$ , is conditional on no change in output). However, as noted above, they are not necessarily equivalent in magnitude since they are determined relative to different orientations and constraints. In addition, the relationships among output and capital and variable inputs are not likely proportional, which would be

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<sup>37</sup> An alternative, but similar, measure based on a dual cost function is discussed in Morrison (1985a) and Kirkley, Morrison-Paul and Squires (2002).

<sup>38</sup> Even if a given measure allowed for full equilibrium adjustments, it is unlikely that the empirical data would be adequate to estimate a dynamic, long-run equilibrium. This is because it is unlikely that the data would pertain to a period during which the system was in long-run, equilibrium. Clark, Clarke and Munro (1979) and Conrad and Clark (1987) provide methods to determine the long-run equilibrium capacity level, in terms of desired or optimum capital stock. The use of these methods, however, also would require empirical data reflecting the long-run equilibrium.

required for the three measures of CU to be similar. Thus, constructing any of these measures and identifying their variations in terms of magnitude requires knowledge or estimation of the underlying input-output relationships, which provides impetus to move toward estimating methods for computing such measures.

It also is important to emphasize before taking this step that the notions of “maximum”, “minimum” or “potential” catch, effort and capital used above must take into account customary and usual operating procedures, and fluctuations in economic and environmental – in particular, biomass stock – conditions over time. Consistent and excessive underutilization of capital may indicate excess capacity in the fleet, but this must be distinguished from capacity that is required to accommodate, or at least respond to, ideal or peak conditions. Ideally, a well managed fishery would have only sufficient latent effort and capital underutilization under normal conditions to allow for the efficient exploitation of the fishery under "good" conditions, which is what we wish to identify as the optimal or potential level of capacity and capacity utilization.

It should be stressed that construction of any of these measures also raises key issues about the level of analysis, at least in terms of fleet definition. Evaluation of capacity and utilization issues at the boat level, taking into account only the boats already in the fishery, provides an indication of optimal or full utilization levels for this main fleet component. Moving to the full fleet level, however, requires extension of the notion of “potential” output, variable input use, or the current capital stock, to include the latent capacity represented by increased participation of existing vessels in this fishery. Multi-fishery boats also must be properly accounted for in these estimates, so the measurement of latent effort allows only for a “feasible” transfer of effort into the fishery by these boats. While this may not be a problem under the explicit assumption of customary and usual practice, transfer of a license from a multi-fishery boat to a new ‘full-time’ boat may result in an increase in potential effort. Managers also may wish to produce an estimate of potential and latent effort assuming that all licenses are fully active in the fishery, which could provide a ‘worst case’ scenario of potential and latent effort.

#### **4. METHODOLOGIES FOR MEASUREMENT OF CAPACITY UTILIZATION**

##### **4.1 Measurement of capacity output and output-based capacity utilization**

The methods available for deriving both output- and input-based measures of capacity and capacity utilization largely depend upon the level of existing data. (See Appendix A for a discussion of preferred methods for estimating capacity, given different levels of data.) If data are extremely limited or unavailable, surveys and rapid appraisal techniques can be used to derive measures of capacity and capacity utilization. If detailed costs and earnings information are available, it may be possible to estimate various economic, either static or dynamic, concepts of capacity and capacity utilization using a wide array of mathematical or statistical methods. The most typical situation, however, is one in which data are known only on: physical input levels, vessel characteristics, and output levels. Even in this case, it may be possible to use a wide range of mathematical or statistical techniques to estimate capacity and capacity utilization.



#### *4.1.1 Rapid appraisal techniques*

Rapid appraisal (RA) is a participatory research technique developed to obtain data when formal data collection procedures were not practical. The technique often has been used in developing countries where records or information were not available, and the most expeditious method to obtain data was to rely upon the recall of participants in the fishery. The technique places particular emphasis on the collection of local knowledge and combining it with knowledge from outside.

RA is to a large extent an informal method of data collection that has characteristics of both the formal survey and the extraction of information through the use of expert knowledge. The technique is exploratory and highly interactive. It generally involves rapid and progressive learning, with information analyzed and revised in the field to allow further clarification or re-estimation.

The technique largely involves informal interviews conducted with key participants in the fishery. Key participants include fishers, fisher representatives and others who have input into the production process (e.g. head fisher or person in village responsible for “managing” the fishery). The technique is consequently relatively labour-intensive, because a wide range of participants need to be questioned in the field.

For the purpose of capacity measurement, questions can be asked about both current and past catch levels, as well as activity levels and potential activity levels. Where quantitative estimates are not possible, relative estimates can be derived through the use of drawings and diagrams. For example, ten dots may represent current catch while 12 dots represent best-ever catch. Average catch composition can be illustrated through use of a pie chart with the participants, with each segment representing their perception of species composition. Questions also can be asked about how much fishing activity may increase, why the activity is at its current level, and potential constraints that would impose limits on fishing activity.

The information is compiled in the field and quantified as much as possible. The information is supplemented with other quantitative information available (e.g. quantity of sales on a central market can be used as a benchmark). Participants are re-interviewed, and the compiled information is presented for cross-checking and validation purposes. This process may need to be repeated several times. Such repetition allows fine-tuning of estimates to provide values that are believable to the participants in the fishery.

The technique is likely to enable, at the very least, qualitative estimates of capacity and capacity utilization. Depending on the level of knowledge in the fishery, it may be possible to also derive more precise estimates of capacity and capacity utilization, and on a per-species basis.

#### *4.1.2 Surveys and expert opinion*

Surveys can be undertaken to collect subjective but quantitative estimates of capacity. Such surveys are often conducted to assess capacity output in other industries. For example, in the United States, surveys are employed by the Federal Reserve and the United States Census Bureau to estimate capacity and capacity utilization in a number of industries to supplement more directly quantified estimates.

Like RA, this is particularly useful if data are limited or non-existent. Participants can be surveyed to determine their current catch and activity (e.g. days fished) as well as provide subjective estimates of their potential activity and corresponding potential catch. A survey may require less labour than a RA, but it also provides less possibility for feedback and clarification of the analysis with the industry.

Several separate surveys may be required to estimate capacity and potential overcapacity, each directed at different groups in the industry. Individual participants (i.e. fishers) can be asked to estimate their catch, effort and potential effort. From this, an estimate of potential catch (i.e. output capacity) of each individual can be derived (assuming a linear relationship between potential effort and potential catch). In some cases, it may be possible to derive estimates of catch by species. The more disaggregated the data request, the greater the potential for errors to compound, particularly if most of the information provided by the interviewee is being recalled from memory. Ideally, if detailed information is to be collected on a species basis, then some form of logbook programme should be established and fishers record their catches as they occur.

The reliability of survey estimates will vary depending on the degree to which records of current and recent activity are readily available. If the information is based solely on memory (i.e. the fishers do not keep any records), the potential to overestimate (or underestimate) the average catch and potential effort is considerable. As a result, the estimate of capacity output is most likely to be unreliable or highly imprecise. Data collected by such a survey should be regarded as indicative rather than accurate. When fishers maintain good records, potential bias will decrease, and more comprehensive data construction and development are possible.

The reliability of survey estimates will depend also on the size and representativeness of the sample. Ensuring that a wide cross-section of fishers is surveyed will help improve reliability of the estimates. Reliability also will improve with increased sample size, although there is a trade-off between reliability and survey cost. Doubling the sample size will not double the reliability of the results but will smooth potential errors.

Additional information also can be collected from fishers at the same time as the minimum information requirements for capacity estimation. This may include more information on the fishing activity, the boat (e.g. size, engine power if mechanized) and the gear used. Full surveys of fishing activity, including costs and earnings, also can be undertaken. The level of data collected through the survey will depend on the ultimate use of these data, and the cost of acquiring it.

To estimate capacity from the survey information, an estimate of the total number of participants in the fishery is required (unless the survey includes all participants – a census of producers). This may involve a second survey of regional industry representatives (e.g. head fishers) or purchasers. Such a survey could be used to provide estimates of participation rates (i.e. number of boats or individuals) in the fisheries.

Surveys of experts (e.g. biologists, industry representatives) also can be undertaken to provide estimates of capacity output and utilization. This is potentially a more expedient method than collecting a sample from individual participants in the fishery and deriving estimates of capacity from the “bottom up”. However, if expert opinions vary, some

subjective weighting needs to be applied to each opinion to derive a composite estimate, or more formal approaches need to be undertaken. One such formal approach is described under the section outlining methods for assessing target capacity (in Section 5).<sup>39</sup>

#### 4.1.3 *Peak-to-peak analysis*

The peak-to-peak approach assumes a direct relationship between the level of inputs and the level of output. An index of catch-per-unit input (e.g. catch per day or catch per boat) is derived from the data. An assumption is made that peak levels of catch-per-unit input equate to complete capacity utilization. The peaks are assumed to represent years that the fishery was achieving the maximum output in the short run, given harvesting technology and capital stock. Hence, lower catch rates are assumed to indicate underutilization of capacity. Further details on the method, including an example of its application, are presented in Appendix B.

The technique also allows for technological change over time, such that the difference in catch rates between two peak years is assumed to be the result of changes in technology. “Capacity” catch rates in the years between the peaks are estimated as a function of the estimated change in technology between the peaks, which is assumed to be a linear trend. (In recent years, however, researchers have developed quite sophisticated analytical methods to better determine trends in technical progress.) Capacity utilization is then estimated as the ratio of the observed catch rate to the derived “capacity” catch rate. Capacity output is estimated as the product of the level of inputs and the “capacity” catch rate.

An advantage of this technique is that it only requires information about one input and one output. Consequently, it represents the most widely applicable and least demanding of data in all mathematical methods for estimating capacity and capacity utilization (Kirkley and Squires 1999). A disadvantage of the technique, however, is that it does not allow for changes in the stock between years or any other structural changes affecting input-output relationships. Changes in catch rates are assumed to be a function of changes in technology only. A decline in stock size between two peak years would be interpreted as capacity underutilization.

Peak-to-peak analysis has been applied in fisheries by Ballard and Roberts (1977), Ballard and Blomo (1978), and Hsu (2003). Further information on the technique, including the mathematical specification of the approach, also is provided in Kirkley and Squires (1999).

#### 4.1.4 *Stochastic production frontiers (SPF)*

Stochastic production frontiers indicate the maximum expected output for a given set of inputs. They are derived from production theory and are based on the assumption that output is a function of the level of inputs and the efficiency of the producer in using those inputs. Explicit representation of this relationship as a production frontier allows a detailed characterization of input and output relationships and returns that facilitates quantification of the diagrams and equations presented in Section 2.

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<sup>39</sup>Thompson *et al.* (1986) and Tone (1999) offer a framework for consensus-making based on expert opinion. Tone, in particular, offers a framework for deriving quantitative estimates using expert opinion.

A function is statistically estimated that defines the output associated with the best practice use of the inputs, while also recognizing the stochastic nature of the data arising from mis- or un-measured determinants of production. The difference between actual output and the potential output is generally attributed to a combination of inefficiency and random error (i.e. the stochastic element in production). Methods have been developed to separate out the random component from the efficiency component, so that a more realistic assessment of potential output can be achieved. That is, large levels of output that may have occurred through chance rather than as a consequence of normal practice do not overly influence the estimates. As a result, derived measures of capacity output are consistent with the earlier definition that measures output under normal working conditions. Further details of the underlying theory and an example of its use are provided in Appendix C.

SPF methods have been used for the assessment of technical efficiency in a wide range of industries (including fishing). While derived from efficiency theory, these techniques can be readily modified to produce estimates of capacity utilization. This is achieved through incorporating only fixed inputs in the production function, such as boat numbers (in aggregated analyses) or engine power, boat size, or some measure of capital inputs when vessel level data are available. By excluding variable factors of production (e.g. days or hours fished), the frontier output for a given size (for example) of boat is essentially determined by the boats of that size that produced the greatest output, taking into account fluctuations in output levels that might be considered attributable to “luck”. Lower levels of output would indicate a combination of inefficient input use and capacity underutilization.

One advantage of the SPF technique over peak-to-peak analysis is that several inputs in the production process can be incorporated into the analysis. While it is possible to use the technique with a single input and output, it also allows recognition of other available information on the level of fishing inputs or other production determinants. Hence, all available input data can be used in the same analysis to produce a single measure of capacity utilization. This can include information on biomass stock (where available), so that the effects of stock changes can be directly incorporated into the analysis. As a result, low levels of output in some years resulting from low levels of the resource stock will not mistakenly be attributed to underutilization of capacity.

The technique can also be used to estimate changes in efficiency, versus those due to technological change, over time. While peak-to-peak analysis assumed that any change in the catch rate was due to changes in technology, the SPF method can separately identify such changes, as well as those associated with utilization. Independent identification of the impacts from resource stock fluctuations, however, requires incorporating information on stock levels into the analysis in order to distinguish the effects of changes in technology and stock abundance on catch rates. Alternatively, when data are available, the SPF can distinguish between embodied and disembodied technical change.

The technique can be applied to either aggregated (fleet level) data or to the individual fishing vessel level. The latter is the most desirable, although particular care must be taken to separate noise, efficiency and utilization fluctuations separately for estimation at this aggregation level. Capacity and capacity utilization estimated for individual vessels then can be aggregated to the fleet level, although this requires recognition of aggregation issues.

The technique does have some limitations, however. Like peak-to-peak, the standard technique can generally only be used to estimate capacity utilization for a single output.<sup>40</sup> For multispecies fisheries, some form of aggregation, or more complex estimating methods and approximations, may be necessary. The resulting measures of capacity utilization and capacity output may then be difficult to interpret, particularly where fisheries management is undertaken on a species-by-species basis (e.g. using quotas).

Estimation of the frontier also requires one to specify a functional form for the production function. Many functional specifications of the underlying technology impose undesirable or potentially unrealistic restrictions on the underlying production technology (e.g. the Cobb-Douglas, which is a multiplicative function, imposes unitary elasticity of substitution between inputs). However, flexible functional forms, which minimize the number of restrictions imposed on the underlying technology, are widely available. The flexible forms permit parametric evaluation of different properties of the underlying technology, and thus the fact that SPF requires specification of the technology should not be viewed as a substantive limitation of the approach.

Estimation of efficiency and capacity utilization is a relatively complex statistical problem. Fortunately, special software has been developed that makes the econometric estimation of the measures quite straightforward. (See Sena, 1999.) However, there are a range of assumptions that need to be made regarding the specification of the model and distributional assumptions about the measure of capacity utilization, and, being a statistical process, the results may vary considerably from one model to another. Identifying the most appropriate model out of a range of alternative models requires substantial testing. Ideally, the analysis should be undertaken by someone with experience in econometrics who has an appreciation of the potential statistical problems that may occur.

Only limited attempts to estimate stochastic production frontiers for fisheries have been undertaken (Kirkley, Squires and Strand, 1995 and 1998; Cogley, Pascoe and Harris, 1999; Sharma and Leung, 1999; Squires and Kirkley, 1999). These have largely focused on the estimation of efficiency rather than capacity. Kirkley and Squires (1999) and Kirkley, Paul and Squires (2001) provide examples of these techniques applied to capacity estimation.

#### 4.1.5 *Data Envelopment Analysis (DEA)*

Data Envelopment Analysis (DEA) is a mathematical programming technique for estimating technical efficiency and capacity utilization. It is similar to SFP in that it estimates a frontier level of production and measures inefficiency and capacity utilization as deviations from the frontier. Unlike SPF, however, it does not require imposing any particular functional form of the production frontier on the data, and it is able to analyse both single and multiple outputs. Further details on the methodology and an example are presented in Appendix D.

The fact that species-specific measures can be derived allows aggregation of capacity measures across different fleet segments and fisheries for a given species. As a result, capacity estimates can be directly compared to the target capacity measures. Capacity

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<sup>40</sup>More recently, multi-output forms of stochastic production frontiers have been developed but remain highly complex. For a comprehensive summary, see Kumbhakar and Lovell (2000).

utilization measures at the fleet level also provide additional guidance for managers as to where capacity management may be most required.

A drawback of the technique is that it does not take into account random variations in the data.<sup>41</sup> As a result, an above normal catch (due to "luck") would define the frontier and all capacity measures would be made relative to this level of output, which does not correspond to normal operating conditions. Consequently, measures of capacity utilization may be less than what would occur if favourable random elements were removed. Conversely, an "unlucky" vessel would be regarded as operating at well below capacity. This is less problematic, as it is expected that vessel output would be higher under normal conditions. These problems can be eliminated to some extent by averaging the data over a number of years, thus reducing the effects of random variations. In doing so, however, information on changes in capacity utilization over the period being examined is lost.<sup>42</sup>

The data required for a DEA analysis are the same types of data required for SPF. With DEA, however, multiple output technologies may be examined more easily. There is no need to aggregate outputs, and species-specific capacity measures are possible. Like the SPF approach, multiple inputs can also be incorporated in the analysis if available. Moreover, since DEA is a linear-programming-based approach, it is possible to estimate capacity under a wide array of social, biological and economic constraints. For example, total allowable days at sea constraints can be imposed, although this also may be done within SPF by simulation methods. Similarly, where restrictions on gear are in place, their effects on capacity output can be assessed by removing the constraints. Cost and revenue information also can readily be included into the analysis to provide information on economic capacity utilization. (See, for example, Färe, Grosskopf and Kirkley, 2000)

In fisheries, the technique has been applied to the Malaysian purse seine fishery (Kirkley *et al.*, 2003), United States Northwest Atlantic sea scallop fishery (Kirkley *et al.*, 2001), Atlantic inshore groundfish fishery (Hsu, 2003), Pacific salmon fishery (Hsu, 2003), the Danish gillnet fleet (Vestergaard, Squires and Kirkley, 2003), English Channel multispecies multigear fisheries (Pascoe, Coglán and Mardle, 2000; Tingley, Pascoe and Mardle, 2003), the Scottish fleet (Tingley and Pascoe, 2003) and the total world capture fisheries (Hsu, 2003). Additional details on the mathematical specification of the technique are available in Färe, Grosskopf and Lovell (1994), Coelli, Rao and Battese (1998) and Kirkley and Squires (1999).

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<sup>41</sup>The development of stochastic DEA models is currently a key area of research, but operational models are not currently available. Approaches have been developed to capture some of the random variability in data (e.g. chance constrained DEA). Details on some of the recent developments in this area are given in Cooper, Seiford and Tone (2000). Bootstrapping techniques have also been applied to estimate the effects of random variation on the estimates of efficiency and capacity, and methods have been developed to compensate for some of these effects (see Simar and Wilson, 2000).

<sup>42</sup>There is presently considerable research being conducted on stochastic data envelopment analysis. See, for example, Resti (2000), and Ruggiero (2000).