PART 3: OUTPUT BASED MESSURES: DEA AND PEACK-TO-PEAK

MEASURES OF CAPACITY IN A MULTISPECIES DANISH FISHERY

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Abstract: Different measures of capacity utilization (CU) are applied to the Danish Gillnet fleet using the Data Envelopment Analysis (DEA) approach. The potential capacity output is found using the output-orientated measure. The CU measures are the partial capacity utilization measure and the Ray measure (DEA measure). The average CU of the Danish Gillnet fleet was found to be between 0.85 and 0.95 depending on the measure used. Since the Danish Gillnet fleet participates in a multispecies fishery regulated by TACs (output) the excess capacity was also found for each species. The results show higher excess capacity for cod and sole than for other species, which is in accordance with how the fishery developed. The variable input utilization was also estimated. On average, the variable input could have been increased by 27 percent in the period examined. Finally, the results are interpreted with respect to fishing area, port, vessel size and catch composition.

1. INTRODUCTION

Capacity and capacity utilization have been a core issue in fisheries and in the fishery economics literature for several decades. It has long been recognized that, in an open access setting, there will be too many boats in the fleet. The control of capacity has consequently been on the political agenda, since the fisheries in many countries are managed using open-access regulation. In the EU, a Multi Annual Guidance Programme (MAGP) has been in force since 1983 with the main purpose to adjust the fleet to the availability of the resource. Since 1987, the main instrument of this program, in practice, has been to withdraw vessels from the fleets. Several reports have pointed out that a reduction in the size of the fleet of at least 40 percent on average is necessary in order to match the fleet capacity to the availability of the resource. However, these suggestions were only based on biological considerations.

The purpose of the paper is to apply the recently suggested method Data Envelopment Analysis (DEA) (FAO, 1998) to measure capacity and capacity utilization in the Danish gill-net fleet. First, the main issues connecting to the measurement of capacity are briefly discussed. Then, the fishery, regulation and data are described. Finally, the model and the results are presented and discussed.

2. CAPACITY AND DEA - DIFFERENT MEASURES

In the economics literature, capacity is defined in terms of potential output. There are basically two distinct methods of measuring the capacity – a technical-economic approach and a s strictly economic approach (Morrison, 1985). What distinguishes the two notions

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of capacity is how the underlying economic aspects are included to determine the capacity output. In either approach, capacity utilization is then simply actual output divided by capacity (see Morrison, 1985).

In the economics approach, cost-minimizing optimal capacity is defined as the output level at which the short-run average cost curve is tangent to the long-run average cost curve (Klein, 1960; Berndt and Morrison, 1981; Morrison, 1985). Empirically this definition of optimal capacity is difficult to use because detailed cost data is needed to estimate the cost function. While the technical-economic approach can handle problems with limited data, the economic approach requires detailed cost data to be able to estimate the optimal capacity.

In practice a technological-economic approach has been used. Following Johansen (1968), in this approach the capacity output is defined as: "*the maximum amount that can be produced per unit of time with existing plant and equipment provided the availability of variable factors of production is not restricted*".[4] This concept of capacity conforms to that of a full-input point on a production function, with the qualification that capacity represents a *sustainable* maximum level of output (Klein and Long, 1973). In the context of fisheries, this definition corresponds to the maximum catch a vessel can produce if fully utilized given the biomass and the age structure of the fish stock and the present state of technology. It is important to note that this definition does not measure capacity as an output level that can only be realized at prohibited high cost of input usage, and hence be economically unrealistic. The capacity output is measured relative to the observed best practice frontier and hence is not an absolute engineering-derived number. That is, the observed best-practice frontier is established by the existing fleet and reflects economic decisions made by these vessels.

The decision of the level of capacity or vessel size is a long run decision based on, in general, expectations on future production possibilities (e.g. resource stock and regulation), prices and costs. Capacity is at a given point in time fixed, and hence is a short-run concept, and basically it is covered by the definition of Johansen (Prochaska, 1978). The rate of capacity utilization is a short run concept, since with responses in prices, costs or other things the production can be adjusted. The state of technology is given as well as the level of the resource stock.

In fisheries the concept of capacity needs to address several specific issues. The basic additional constraint compared to other areas of applied economics is that the fishermen harvest from a fixed pool of resources where the nature limits the production and the individual fisher's ability to control catches (Prochaska, 1978). Measuring capacity in a renewable resource industry is, therefore, more difficult than in a 'normal' industry because the measure is conditional upon the resource stock. The production technology is stock-flow, in which inputs are applied to the resource stock to yield a flow of catch (output). Hence, if the capacity is measured over a period of time, the measure has to take into account changes in the resource stock as well as changes in the capital stock.

In many cases, the production in fisheries is multiproduct, which influences the selection of empirical methods. Another issue is the mobile nature of the vessel where it is possible to move from fishery to fishery either during a period or from period to period. The

[4] Klein and Long (1973: p. 744) state that, "Full capacity should be defined as an attainable level of output that can be reached under normal input conditions – without lengthening accepted working weeks, and allowing for usual vacations and for normal maintenance."

level of aggregation determines the outcome of the analysis. A high level of aggregation including all fisheries within the year of the whole fleet shows the overall level of capacity utilization. However, the problem is that there may be fisheries with very high CU and fisheries with low CU that can counterbalance so the combined CU result is not alarming. The fisheries with high low CU is typically high value fisheries and hence the most important economically. If the fisheries are technologically distinct they may be treated separately.

In fisheries that are regulated by open-access regulation, i.e. the access to each single fishery is not regulated, a problem called latent capacity might arise. This problem has its origin in the fact that the fishing effort can change allocation between the fisheries during the season. A fishery that has a high CU in one period might have a low CU in the next period because of incoming vessels resulting in other fisheries having a high CU, all things equal. An assessment of the excess capacity in this kind of fisheries has to take the regulation into account. Targeting a decommissioning scheme towards vessels currently in the high value fisheries will not reduce the excess capacity in these fisheries, only the excess capacity in the low value fisheries is reduced.

The empirical method used here is Data Envelopment Analysis (DEA). The DEA approach is a mathematical programming technique in which an optimal solution is determined given a set of constraints. The approach finds the technical efficiency of the firms. This information can then be used to derive the capacity and capacity utilization measure. This method has been used in a wide range of analyses. Traditionally, the method has been used to determine the efficiency within highly regulated sectors, e.g. hospital. The method has several variants. To determine the capacity output and hence the CU, the output-oriented version of DEA is used. The output-oriented version gives the potential output given the current use of inputs, i.e. the frontier production. To use this version consistently with the definition of Johansen only the fixed inputs are bounded at their observed level, allowing the variable inputs to vary. The outcome is a scalar θ_1 showing by how much the production of each firm can be increased, i.e. if the solution is 1.25 the capacity output is 1.25 times observed output. The capacity utilization is then simply 1/1.25 = 0.8.

The value of θ_1 is found by solving:

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\begin{aligned}
&\underset{\theta,z,\lambda}{Max} \quad \theta_1 \\
&\text{subject to} \\
&\theta_1 u_{jm} \le \sum_{j=1}^{J} z_j u_{jm}, \quad m = 1,2,\ldots,M, \\
&\sum_{j=1}^{J} z_j x_{jn} \le x_{jn}, \quad n \in \alpha \\
&\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, \quad n \in \hat{\alpha} \\
&z_j \ge 0, j = 1,2,\ldots,J, \\
&\lambda_{jn} \ge 0, n \in \hat{\alpha}.
\end{aligned} \tag{1}
$$

where u_{jm} is the level of output *m* produced by firm *j* from employing inputs z_n. The inputs are divided into fixed factors, represented by the set α, and variable factors represented by $\hat{\alpha}$. λ_{jn} is a measure of unit *j* n-th variable input utilization rate.

Capacity output is estimated as the production of θ_1 and the level of observed output, given by:

$$CU - observed = \frac{u}{\theta_1 u} \tag{2}$$

This approach provides a ray measure of capacity output and CU in which the multiple outputs are kept in fixed proportions as they are expanded (Segerson and Squires, 1990). The ray measure converts the multiple-output problem to a single-product one by keeping all outputs in fixed proportions. This ray measure corresponds to a Farrell (1957) measure of output-oriented technical efficiency due to the radial expansion of outputs.[5]

Färe *et al.* (1994) noted that this ray CU measure may be biased downward because the observed outputs are not produced technically efficient. A technically efficient measure is obtained by solving a problem where both the variable and fixed inputs are constrained to their current level. The outcome (which can be called θ_2) shows by how much the production can be increased by using the inputs technical efficient. The estimation of θ_2 is given by:

$$\begin{aligned}
&\underset{\theta,z}{Max}\,\theta_2 \\
&s.t. \\
&\theta_2 u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm}, m = 1,2,\ldots,M, \\
&\sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, n = 1,2,\ldots,N, \\
&z_j \geq 0, j = 1,2,\ldots,J.
\end{aligned} \tag{3}$$

The technically efficient output vector is θ_2 multiplied by observed production for each output. The technically efficient or unbiased ray measure of capacity utilization is then:

$$CU_{efficient} = \frac{\theta_2 y}{\theta_1 y} = \frac{\theta_2}{\theta_1} \tag{4}$$

The output-oriented measure can be used in several ways. The capacity output is determined for each vessel. Summing over vessels by a given criteria (e.g. regional or gear-type), the number of vessels required to reach some specified target (e.g. TAC) can be found. In the multispecies case, this can be done for each species.

The input-oriented measure gives the technical efficient input level needed to produce the current level of output. Hence, this measure provides information on the optimal vessel or fleet level and configuration.

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[5] A non-radial expansion of outputs would correspond to Koopman's (1951) notion of technical efficiency.

The variable input utilization outcome measures the ratio of optimal use of input to observed use, where the optimal variable input usage is that variable input level which gives full technical efficiency at the full capacity output level. If the ratio of the optimal variable input level to the observed variable input level exceeds (falls short of) 1.0 in value, there is a shortage (surplus) of the i^{th} variable input currently employed and the firm should expand (contract) use of that input.

3. THE GILLNET FLEET AND FISHERY- BACKGROUND AND DATA

The Danish fisheries are normally divided into human consumption fisheries and industrial fisheries. The Danish human consumption fisheries are composed of many fisheries[6] and are defined as fisheries where no species are landed for industrial purpose. The industrial fisheries are fisheries where some of the species are landed for industrial purpose (processing of meal and oil), meaning that species caught in these fisheries can be landed for human consumption. The human consumption fisheries are, in general, multispecies fisheries, i.e. more than one species are caught in one setting of the gear or in one trip. In several of the fisheries, participants use a range of different gear types (e.g. trawlers, gillnetters, Danish Seiners).

A large part of the Danish human consumption fleet is multipurpose, and can participate in several fisheries during the year, including industrial fisheries. Relative prices between species and factors, regulatory constraints, and biological conditions and change in seasons are factors that determine the choice of fisheries.

The gillnetters participate in the mixed human consumption fishery harvesting round- and flatfish in the North Sea and Skagerrak. The catch composition varies over the year and between fishing grounds. As well as gillnets, the operators also use alternative gears, including trawls and Danish seines. The target species varies over the year and can vary according to the gear type used, but cod, haddock, saithe, plaice and sole are the main species, with cod as the most important species. The mixed human consumption fishery could probably be divided into several fisheries, but this will require very detailed data beyond the scope of this study.

Table 1. Landings in 1993 (Tonnes)

Area	Species				
	Cod	Haddock	Saithe	Plaice	Sole
3AN	11 989			9 127	
3AS	4 469	1 603		1 293	1 430
3BD	10 280		4 310	287	
4AC	19 547	3 582		16 452	1 661
Total	46 285	5 185	4 310	27 159	3 091

Nearly all the gillnetters participate in the fishery in area 4AC (The North Sea) and about half of them also in area 3AN (Skagerrak). Only a few gillnetters take part in the fishery in areas 3AS (Kattegat) and 3BD (The Baltic Sea). The gillnetters target different round- and flatfish.

6 The concept fishery is here defined based on either target species strategy (e.g. lobster fishery) and may consist of single or multiple species targeted and caught or a strategy where a mix of species is caught (e.g. the mixed human consumption fishery). The concept can further be specified based on area and time period (e.g. lobster fishery in Skagerrak in September).

4. THE REGULATION AND THE REGULATORY PROCESS

The EU Council determines every year the total allowable catch (TAC) for quota species in the Exclusive Economic Zones (EEZs) of the EU Member States. A fix scale (called the Principle of relative stability) divides the TACs among the Member States into national quotas. The Member States decide themselves the distribution among fishermen of the allocated quantity. Since there is no banking of national quotas, the Member States will design the regulation, so there is full utilization of their quotas.

The Danish regulation of the fishery[7] for cod, haddock, saithe and sole is based on the Danish share of the TACs divided into quarterly total quotas for the whole fishery, which in turn is divided into rations for a given period,[8] in some cases depending on the size of vessels. However, the number of participating vessels is not regulated for these fisheries, so during the quarter the rations can get smaller or the ration period can be shortened. If the Danish quota for a species is caught before the end of the year, the fishery is simply closed.[9] In addition, the herring and mackerel fisheries are, in principle, regulated by this method.

In the beginning of the year, the Danish Ministry of Fisheries sets both the size of the quarterly quotas and rations based on the experience from former years and based on the size of the total Danish quota. Over the year the Ministry closely monitors the fishery by recording all catches, and if necessary the regulation is changed so that the Danish quota is not overfished. The purpose of the regulation is, in general, to achieve a better distribution of the fisheries over the year and a better utilization of the Danish quotas compared to a free fishery of the quotas. The regulatory instruments quarterly quotas and rations are used to stretch out the fishery over the whole year.

Whether the regulation carried out in 1993 has been a limiting factor (a binding constraint) for the fleet can be investigated in several ways. The TAC and the total catch for the relevant species can be compared. If the catch is close to the TAC (say within ten percent), the regulation could have been a limiting factor. In the North Sea, the total catches of cod, saithe, sole, mackerel, herring and sprat were within ten percent of their respective TAC. Similarly, in Skagerrak, the TACs for cod, plaice, mackerel, and sprat were exploited by over 90 percent.

Examination of how the regulation has changed over the year can also provide insight into which species have been limited due to regulation. If the regulation has been lowered relatively often, then the fishery is being constrained. The regulation for cod in the North Sea, Skagerrak and Kattegat was not changed significantly until November when the rations were reduced for all areas and the ration period shortened for North Sea and Skagerrak. The regulation of haddock in all areas was cancelled in August, while the rations of saithe in all areas was changed several times before the fishery was closed in October. Finally, the regulation of sole in the North Sea indicates limited possibilities. The ration-levels changed several times and the fishery was stopped once, before the fishery finally was closed in November.

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[7] In the regulation context the term ‘fishery’ is not used as in the literature. A ‘cod fishery’ is simply the situation where cod is (a part of) the catch.

[8] It is possible in a number of cases for the fishermen to transfer ration from one period to the next.

[9] Sometimes a fishery is closed if the quarterly quota is caught. The fishery opens then again at the start of the next quarter.

In summary, it can be concluded that the cod and saithe fishery in all the four areas has been constrained by the limited TAC. Sole has been constrained in the North Sea. The TAC for plaice in the Skagerrak was exploited over 90 percent, but no regulation was carried out.

5. OVERALL ACCESS LIMITATION

Access to the Danish fisheries is limited. To participate in the fishery, two authorisations are needed – recognition as a commercial fisherman and a vessel licence, where the former is also a necessary condition for the latter.

To become authorized as a commercial fisherman, two conditions must be fulfilled. Firstly, out of the pervious year personal income over 60 percent must come from fishery. Secondly, the fisher must be a Danish citizenship or have affiliations to Danish fisheries. This authorisation is needed if a person or company wants to conduct commercial fishery and it has, with minor modifications, been a requirement since 1965, at least.

Obtaining a licence to allow the entry of a new vessel (i.e. additional capacity) into the Danish fleet is dependent on two things. Firstly, permission from the Ministry of Fisheries, which in practice only gives permission if either corresponding capacity leaves the fishery or the capacity is directed towards certain species. However, the last possibility is very rarely used. Secondly, the potential licensee must be authorised as a commercial fishermen, and own at least two thirds of the new vessel. In the case of a company owned vessel, at least two-thirds of the company must be owned by persons authorised as commercial fishermen.

The vessel licence follows the vessel, if the new owner(s) fulfils the second condition above, i.e. if the vessel changes ownership at least two thirds of the new owner(s) must be authorised as commercial fishermen.

Capacity in the fishery is nominally measured along six dimensions: GRT, length, width, depth, hold capacity and engine power. These inputs can only be modified with the permission from the Ministry. Further, it is not allowed without permission to rebuild the vessel, for example, to make fishery with beam trawl (only if engine power > 500 HP) and (purse) seine gear possible. It should be pointed out that the capacity of vessels could be changed in other directions than the six mentioned above, e.g. through improvement of storage or catch technology.

The purpose of the regulation is to harmonise the total capacity of the fleet to the fishing possibilities. It is clear from the above interpretation of the legislation that the regulation of the total existing capacity is based on control of the capacity of the individual vessels. This system can regulate the individual vessels fishing possibilities, but the system cannot control the total fishing effort in the fisheries, because the access to each fishery, in general, is non-regulated. The most economically attractive fisheries will attract effort and each fisherman will try to fulfil his ration first, because once the quarterly quota is exhausted the fishery is stopped. As a result, the overall limited access to the Danish fishery and limited possibilities to extend the existing capacity will not reduce the overcapacity in the most profitable fisheries, but may only reduce the effort expended in the least attractive fisheries. From an efficiency viewpoint, the result is (still) that too much effort is attracted into certain fisheries. Therefore, the situation where the overall capacity problem is solved on the sector level, but not in certain fisheries can emerge.

6. DATA

For the purposes of the analysis, only gillnetters greater than 20 GRT were examined, 69 vessels in total. For each vessel, the available data[10] were on a trip level for 1993 and consist of information on:

- the volume and value of the landed catch of cod, haddock, saithe, plaice, sole and other species (added together);
- the month of landing; and
- the fishing area.

The trip information allows for a division of the annual fishery activity based on month and area. The gillnetters participate only in the mixed human consumption fishery in the North Sea and Skagerrak[11]. The mixed human consumption fishery in the North Sea and Skagerrak can probably be divided into several different fisheries, but given the available data it seems not reasonable to divide this fishery further.

There is no information available about the length of the trips[12] and hence no information on the variable inputs per trip was available. It was decided to add the trip landings together to yearly data. Hence, for each vessel the total landings (output) and the number of trips (variable input) together with information on the KW and GRT (fixed factors) are provided.[13]

7. RESULTS AND DISCUSSIONS

The estimated capacity and variable input utilization of the Danish gillnet fleet are shown in Table 2. Of the 69 vessels, 37 (39) vessels have a CU based on technical efficient production (based on observed production) less than 1. The average CU is 0.91 (0.87), with a standard deviation of 0.11 (0.16). Nearly two thirds (43 vessels out of 69) of the fleet has a CU higher than 0.9, while 10 vessels have a CU less than 0.8. Using the CU measure based on observed output shows that 40 vessels have a CU higher than 0.9 and 20 vessels have a CU less than 0.8. This indicates that a minor, but significant part of the gillnet fleet has capacity problems. These results are in accordance with the result obtained in Vestergaard (1998), where the gillnet fleet was shown to be more efficient than other types of gear in the Danish human consumption fishery.

Forty eight vessels come from the port of Hvide Sande. Of these 48 vessels, 30 vessels have a CU less than 1. This indicates that the vessels belonging to the port of Hvide Sande have more excess capacity than the rest of the fleet. There does not seem to be any pattern with respect to vessel size and fishing area.

The variable input utilization (VIU) rates have the same distribution as the CU rates. About half of the vessels should increase the use of variable inputs, however this does only

[10] The data were provided by the Ministry of Fisheries.
[11] There are two exceptions where a gillnet vessel also operates in other areas.
[12] Since the fisheries in question are human consumption fisheries, where the trip length varies between 1-5 days, it is not assumed that the use of trips instead of number of days will give biased results when looking at similar vessels.
[13] Because of the lack of better data on the variable inputs the relatively homogenous vessel group of gillnetters was selected.

explain up the half of the excess capacity compared to capacity output (see Tables 2 and 3). The variable input utilization rate is 1.27 on average (with a standard deviation of 0.16), indicating that the vessels should increase the number of trips compared to the optimal number of trips.

Table 2. CU (observed and efficient), VIU and CU_{cod} for each vessel

DMU	CU-observed	CU-efficient	VIU	CU_{cod}	DMU	CU-observed	CU-efficient	VIU	CU_{cod}
1	0.903	0.903	1 604	1	39	1	1	1	1
2	1	1	1	1	40	0.576	0.815	1 659	0.787
3	1	1	1	1	41	1	1	1	1
4	0.387	1	0.742	0.259	42	0.901	0.97	1 216	0.980
5	1	1	1	0.893	43	0.874	0.88	1 374	0.714
6	1	1	1	0.971	44	0.947	0.947	1 593	1
7	1	1	1	1	45	0.778	0.962	1.09	0.787
8	1	1	1	1	46	0.880	0.912	1 377	1
9	1	1	1	0.935	47	1	1	1	1
10	1	1	1	1	48	1	1	1	1
11	1	1	1	0.877	49	0.841	0.859	1485	1
12	0.913	0.932	1 263	0.787	50	0.564	0.704	2.04	0.775
13	0.981	0.981	1 255	0.935	51	0.649	0.702	1.76	0.719
14	1	1	1	0.676	52	0.487	0.487	2 517	0.546
15	0.955	0.985	1 105	1	53	1	1	1	0.840
16	0.745	0.745	1 975	0.935	54	0.691	0.916	1 434	0.893
17	1	1	1	0.827	55	0.781	0.807	2 025	0.820
18	0.846	0.883	1 228	0.926	56	0.764	0.864	1 295	0.662
19	1	1	1	1	57	0.686	0.686	2 206	0.667
20	0.731	0.874	1 226	1	58	0.750	0.788	1 631	1
21	1	1	1	0.621	59	1	1	1	0.935
22	0.863	0.884	1 202	0.980	60	1	1	1	0.855
23	0.374	1.006	1 178	1	61	0.840	0.84	2 371	0.725
24	1	1	1	1	62	0.808	0.861	1 383	0.606
25	1	1	1	1	63	1	1	1	1
26	1	1	1	1	64	0.485	0.485	1	1
27	0.661	0.661	2.23	1	65	1	1	1	1
28	0.908	1	0.715	0.505	66	0.772	0.87	1 403	0.820
29	1	1	1	1	67	1	1	1	1
30	0.879	0.966	1 105	0.909	68	0.754	0.754	1 805	1
31	0.978	0.978	1 423	0.855	69	1	1	1	0.885
32	0.783	0.783	1 634	0.633	Average	0.87	0.92	1.27	0.88
33	0.790	0.869	1 204	1	St. dev.	0.16	0.12	0.16	0.15
34	1	1	1	0.800	CU=1	30	32		29
35	0.731	0.885	1 243	0.826	CU<1	39	37		40
36	1	1	1	0.885	VIU=1			31	
37	0.837	0.921	1 154	0.725	VIU<1			2	
38	0.933	0.933	1 214	1	VIU>1			36	

Capacity output and technically efficient output are calculated using the estimated value obtained from the DEA problems and for each species an aggregated CU is estimated (see Table 3). In total, the CU for each species shows basically the same results as those on the vessel basis with CUs around 0.85-0.95. The lowest CUs are associated with cod and sole, which is in accordance with how the regulation proceeded this year. Surprisingly, saithe has a higher CU than plaice. Haddock and saithe have the highest CU. Based on these results; the total excess capacity for cod is 15.9 percent, for sole 17.0 percent and for plaice 12.08 percent.

A partial CU measure (Segerson and Squires, 1990) is also estimated for cod. This approach varies only a single output. All other outputs are fixed at their actual levels. A partial CU measure can be defined as the observed output level divided by the capacity level of the output of concern given the actual output levels of all other products and fixed factor. The numerical value of this CU measure will vary across products so that it is not unique for a given firm, but they can give a consistent indication of the state of the firm's CU. The partial CU measures can also indicate that the degree of overcapitalization in the fishery can vary considerably across products (Segerson and Squires, 1990). There may be more slack in the fishery of one species than another. In the species with less slack or closer to full partial CU, the future demand for that species is likely to be of more importance in determining the future expansionary or contractionary forces in the fishery than is the demand for the species with greater slack.

Table 3. Fleet capacity and CU, Gillnetters (Tonnes)

	Cod	Haddock	Saithe	Plaice	Sole	Other
Catch	4 369	123	413	1 566	268	1 227
Technical efficient output	4 617	125	426	1 645	285	1 279
Capacity output	5 065	133	452	1766	314	1 377
Excess capacity	696	10	39	200	46	150
Excess capacity (%)	15.9	7.7	9.5	12.8	17.0	12.2
CU-observed	0.86	0.93	0.91	0.89	0.85	0.89
CU-efficient	0.91	0.95	0.94	0.93	0.91	0.93
$Capacity_{cod}$	5 030					
CU_{cod}	0.87					

The partial CU for cod only was examined, since it is the most important species in the fishery. The stocks in the North Sea are managed on a species-by-species basis and CU_{cod} can provide information on the degree of overcapacity related to cod. As indicated in Tables 2 and 3, the results are not very different on an aggregate basis. However, the results differ at the vessel level, where a vessel with CU=1 can now have CU_{cod} less than 1 and verse versa, 16 vessels operate at full capacity under both CU-observed and CU_{cod}.

8. REFERENCES

Berndt, E. & Morrison, C. 1981. Capacity Utilization Measures: Underlying Theory and an Alternative Approach. *American Economic Review*, 71: pp. 48-52.

FAO. 1998. Report of the Technical Working Group on the Management of Fishing Capacity. La Jolla, United States, 15-18 April 1998. *FAO Fisheries Report* No. 586. Rome, FAO.

Färe, R., Grosskopf, S. & Knox Lovell, C.A. 1994. *Production Frontiers*. Cambridge, United Kingdom: Cambridge University Press.

Farrell, M.J. 1957. The Measurement of Productive Efficiency, *Journal of the Royal Statistical Society, Series A*, CXX (3): pp. 253-290.

Johansen, L. 1968, Production Functions and the Concept of Capacity. Recherches Récentes sur la Fonction de Production, Collection *Economie Mathématiques et Econométrie 2*.

Kirkley, J.E. & Squires, D. 1999. Capacity and Capacity Utilization in Fishing Industries. *Discussion Paper* 99-16, University of California, San Diego.

Klein, L. 1960. Some Theoretical Issues in the Measurement of Capacity. *Econometrica*, 28: pp. 272-286.

Klein, L. & Long, V. 1973. Capacity Utilization: Concept, Measurement, and Recent Estimates*. Brookings Papers on Economic Activity*, 73: pp. 743-756.

Koopmans, T. 1951. An Analysis of Production as an Efficient Combination of Activities. In: Koopmans, T. (Ed.) *Activity Analysis of Production and Allocation.* Cowles Commission for Research in Economics, Monograph No. 13. New York: Wiley.

Morrison, C.J. 1985. Primal and Dual Capacity Utilization: An Application to Productivity Measurement in the United States Automobile Industry. *Journal of Business and Economics Studies*, 3: pp. 312-324.

Prochaska, F.J. 1978. Theoretical and Empirical Considerations for Estimating Capacity and Capacity Utilization in Commercial Fisheries. *American Journal of Agricultural Economics*, 60(5): pp. 1020-1025.

Segerson, K. & Squires, D. 1990. On the Measurement of Economic Capacity Utilization for Multiproduct Industries. *Journal of Econometrics*, 75: pp. 76-85.

Vestergaard, N. 1998. Property Rights Based Regulation in Fisheries: Applications and Theory. Ph.D. *Thesis* No. 77. Institute of Economics, University of Copenhagen.

TRADABLE PROPERTY RIGHTS AND OVERCAPACITY: THE CASE OF THE FISHERY

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Abstract: In fisheries, overcapacity is a critical problem that reduces rents and jeopardizes the sustainability of stocks. Using data from the British Columbia (BC) halibut fishery, before and after tradable property rights were adopted in the harvesting sector, the paper tests for the effects of private rights on capacity and capacity utilization. The results indicate that tradable property rights can be effective, even in the short-term, at reducing capacity per vessel per day and provide incentives to help overcome the "Tragedy of the Commons".

1. INTRODUCTION

Many of the world's most important natural resources are common-pool resources (CPRs) and are characterized by rivalry in use and by difficulties in exclusion. To avoid the 'Tragedy of Commons', many regulators have imposed overall limits on the total yield or harvest from CPRs and restrictions on the number of users. In many cases, input controls have also been used to economic overexploitation. Unfortunately, individuals and firms are often much better at substituting to non-regulated inputs than are the authorities at designing ways to prevent an undesirable level of harvesting effort (Squires, 1987a, 1987b; Devlin and Grafton, 1994). Consequently, and in the absence of well-specified and enforced property rights, the inputs used in many CPRs exceed that required to harvest the flow of benefits from the resource at least cost. For example, using existing capital measures, the Food and Agricultural Organization (FAO) argues that the gross registered tonnage of fishing vessels is double what is necessary to harvest the world's total catch of fish (Garcia and Newton, 1997).

Overcapacity in inputs poses a number of problems in terms of the optimal management of CPRs. First, it is wasteful and reduces economic rents and the economic viability of the industry. Second, overcapacity makes it difficult for resource owners to reduce the total yields from a resource without imposing bankruptcies and job losses. For example, socio-economic factors associated with overcapacity discouraged reductions in the total harvest in the late 1980s of one of the world's great fisheries, the Northern cod fishery off Newfoundland, and thereby contributed to the collapse of the resource in 1992 (Grafton, Sandal and Steinshamn, 1998). Third, overcapacity accentuates the risk associated with the use of limited harvesting seasons as a control on the total harvest, a regulation which is commonly employed in salmon fisheries and recreational hunting and fishing (Grafton and Nelson, 1998). For instance, in the presence of overcapacity, a small error in predicting the harvest given current capacity can lead to a very large discrepancy between the actual and desired total harvest. Fourth, overcapacity in one industry may spill into other CPRs as firms transfer their effort elsewhere in the face of low returns. Finally, high debt servicing costs that are often associated with overcapacity may encourage myopic behaviour that is detrimental to the long-run interest of the resource owner(s) and users.

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To help overcome the common-pool problem, in recent years regulators have begun to use tradable property rights to control air pollution, improve efficiency in commercial water use, and increase the returns from fisheries (OECD, 1997). In theory, if individuals have a durable and exclusive property right over the flow of benefits from a CPR, they also have a long-term interest in the resource and, under certain conditions, have an incentive to harvest their share of the yield from the resource at least cost. In fisheries, tradable property rights exist as a share of the total harvest and are called individual transferable quotas (ITQs). Private harvesting rights in fisheries have been introduced in a number of countries, including the Netherlands, United States, Iceland, New Zealand, Australia and Canada (Grafton, Squires and Kirkley, 1996; Squires, Kirkley and Tisdell, 1995; Grafton, 1996) and appear to be responsible for a reduction in the number of fishing vessels employed in many, but not all, of these industries.

A reduction in the number of fishing vessels due to the introduction of tradable property rights does not necessarily imply that ITQs reduce overcapacity that depends on the use of *all* inputs, both variable and fixed. Nevertheless, for a given level of fixed capital in a fishing fleet, over time the aggregation of quota and the exit of fishing vessels should, in theory, reduce overcapitalization. Moreover, changes in fisheries regulations associated with ITQs, such as an increase in the length of the fishing season, can allow fishers to adjust their variable inputs to minimize costs for a given quota level. The extent and speed at which these adjustments occur in terms of variable, quasi-fixed and fixed inputs may depend on the characteristics of both the fishers (such as their age and the opportunity cost of fishing) and their vessels (such as their size and age).

Despite the importance of overcapacity in CPRs, and in particular fisheries, to date no studies exist which test for changes in capacity and capacity utilization (CU) following the introduction of tradable property rights. Using data from a representative sample of vessels in the British Columbia halibut fishery from before and after the introduction of ITQs, we examine the effects of private harvesting rights (and the associated change in the fishing season) on fishing capacity and CU by vessel size class. The paper provides empirical evidence that tradable property rights have an important role in overcoming the ‘Tragedy of the Commons’.

2. OVERCAPACITY AND CAPACITY UTILIZATION

Capacity of a firm is commonly interpreted as “*...the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted*” (Johansen, 1968: p. 52). In fisheries, capacity is often equated with capital and is conceived of as the maximum available capital stock in a fishery that is fully utilized at the maximum technical efficiency (producing the maximum amount possible from all economic inputs) for a given time period under existing resource and market conditions.[5] Capital and capacity, however, only coincide where there exists one fixed input (a single, homogeneous stock of capital), all variable inputs are in fixed proportions to the fixed input, and production is characterized by constant returns to scale (Berndt and Fuss, 1989).

For renewable resources, such as fisheries, capacity measures are contingent on the

[5] See Kirkley and Squires (1999) for a review of the fisheries literature on capacity and capacity utilization.

level of the resource stock. Capacity is, therefore, the maximum yield in a given period of time that can be produced given the current technology and state of the resource. Thus, where resources are regulated by a total allowable catch (TAC), capacity measures must be referenced to the TAC and the level of the resource stock. Firms are at capacity output when their short and long-run costs function are equal and do not have any incentive to adjust their input levels. Capacity measured at the level of the individual firm, vessel, vessel size class, port, or region may also be aggregated over all categories to give a measure of overall capacity. Excess capacity exists when capacity output exceeds a desired or target level of output, such as the TAC (Kirkley and Squires, 1999; FAO, 1998). Capacity utilization is the proportion of capacity utilized by firms and is defined as observed output over capacity output. Thus, a CU value of less than unity implies that firms have the potential for greater production without having to incur major expenditures for new capital or equipment (Klein and Summers, 1966).

2.1 Measuring capacity using data envelopment analysis

Estimates of capacity can be derived directly from the primal problem, using output and input data, or derived from the dual using cost and price data.[6] An approach well suited to measuring capacity and CU in fisheries is a nonparametric approach developed by Färe, Grosskopf and Kokkelenberg (1989). Their methodology uses data envelopment analysis (DEA) and requires data on output and inputs to derive primal measures of capacity. The approach has two main advantages: first, it does not impose an arbitrary functional form to estimate capacity but constructs a piece-wise linear frontier; second, it does not require cost and price data which are difficult to obtain for CPRs.

The DEA approach calculates capacity output given that the variable factors are unbounded and the fixed factors, resource stock, and state of technology constrain output. Capacity output corresponds to the output which could be produced given full and efficient utilization of variable inputs and given the constraints imposed by the fixed factors, the state of technology, and resource stock.

Following Färe, Grosskopf and Kokkelenberg (1989), we define $j = 1,..., J$ observations or firms in an industry producing a scalar output $u^j \in R_+$ by using a vector of inputs $x^j \in R^N_+$. Further suppose that for each input n, $\Sigma_j x^j_n > 0, j = 1,..., J$ such that each input n is used by some firm j, for each j, $\Sigma_n x^j_n > 0, n = 1,..., N$ such that each firm uses some input, and that $u^j > 0 \ \forall \ j$ such that each firm produces some output. Capacity output is calculated by solving the following problem where Z defines the reference technology given the observed inputs x^j_n and outputs u^j.

$$Max_{(\theta, z, \lambda)} \ \theta$$

subject to:

[6] Duality-based econometric estimates of economic capacity and capacity utilization were initially developed by Berndt and Morrison (1981), Morrison (1985), and Nelson (1989), have been further developed and applied in fisheries by Squires (1987a) and Segerson and Squires (1990, 1992).

$$\theta u_j \le \sum_{j=1}^{J} z_j u_j \; ;$$
$$\sum_{j=1}^{J} z_j x_{jn} \le x_{jn} \, , \quad for \quad n \in \alpha \, ; \sum_{j=1}^{J} z_j x_{jn} \le \lambda_{jn} \, x_{jn} \, , \quad for \quad n \in \hat{\alpha} \, ; \tag{1}$$
$$z_j \ge 0 \, , \, j = 1,2,...,J; \quad \lambda_j \ge 0 \, , \quad for \quad n \in \hat{\alpha}$$

Problem (1) impose constant returns to scale and ensures full utilization of the variable inputs, defined by the set $\hat{\alpha}$, and constrains output with the fixed factors.[7] The λ vector is the ratio of the optimal use of the variable inputs to their current use, and is the CU of the n^{th} variable input for the j^{th} firm for $x_{jn} > 0$, $n \in \hat{\alpha}$.

An output-oriented measure of technical efficiency, relative to capacity, is defined by θ and which must be equal to or greater than unity. For this problem, θ is the output distance function and defines potential radial increase in output if firms are efficient, given their fixed factors, and if their production is not limited by the availability of the variable factors of production. For instance, if for a firm j θ=2.0, it implies that its capacity output is twice that of observed output.

3. CAPACITY AND THE BRITISH COLUMBIA HALIBUT FISHERY

Since 1979, the harvesting of Pacific halibut in Canadian waters has been restricted to Canadian registered fishing vessels and limited to a total of 435 halibut licences, with one licence per vessel. The licensing restriction on vessels is an attempt by the regulator, the Department of Fisheries and Oceans (DFO), to place a ceiling on the level of capital employed in the fishery. To ensure the sustainability of the fishery, DFO has also imposed gear restrictions, a TAC for the halibut fleet and a limited season length to prevent the TAC from being exceeded.

Despite these input controls, the number of vessels fishing for halibut rose by over 30 percent from 333 to 435 over the period 1980 to 1990. The increase in the number of vessels, as reported in Table 1, was also associated with an increase in the number of crew per vessel and more time spent fishing per vessel per day. The increased fishing effort forced DFO to reduce the fishing season from 65 days in length in 1980 to just six days per vessel by 1990 so as to prevent the TAC from being exceeded.

A declining fishing season and a drop of a third in the TAC from 1988 to 1990 led to a group of fishers to request DFO to introduce a system of individual output controls in the fishery. In 1991, ITQs were allocated *gratis* to holders of halibut fishing licences on the basis of past catches and vessel length. Private harvesting rights could not initially be traded, except when sold with the halibut fishing licence and vessel, but beginning in 1993 quota has been transferable although restrictions exist in terms of divisibility and the quantity of quota which can be used per vessel (Grafton, Squires and Fox, 1999).

The introduction of ITQs made the length of the fishing season a superfluous control in terms of regulating the total harvest. Consequently, the fishing season increased from six

[7] Variable returns to scale can easily be imposed and requires the convexity constraint $\Sigma_j z_j = 1$ (Färe, Grosskopf and Kokkelelnberg (1989).

days per vessel in 1990 to 214 days in 1991 and is currently 245 days long. ITQs have also made fishing safer (Grafton, Squires and Fox, 1999) and increased revenues because a longer fishing season has allowed fishers to sell most of their catch as a higher priced fresh product (Casey, Dewees, Turris and Wilen, 1996).

Table 1. Season length, number of active fishing vessels and total catch in the BC halibut fishery

Year	Season Length (days)	Number of Active Vessels	Total Catch (pounds)
1980	65	333	5 650 447
1981	58	337	5 654 856
1982	61	301	5 524 783
1983	24	305	5 416 757
1984	22	334	8 276 152
1985	22	363	9 587 902
1986	15	417	10 240 471
1987	16	424	12 251 086
1988	14	435	12 859 562
1989	11	435	10 738 715
1990	6	435	8 569 367
1991	214	433	7 189 273
1992	240	431	7 630 198
1993	245	351	10 560 141
1994	245	313	9 900 958
1995	245	294	9 499 717
1996	245	281	9 499 717

Source: Grafton, Squires and Fox (1999)

3.1 Testing for changes in capacity

Input and output data from a representative sample of 107 fishers (44 in 1988, 44 in 1991 and 19 in 1994) were used to solve the DEA problem (Table 2).[8] Specifically, the model uses the round weight of halibut landed (pounds) per vessel per day fished as the output and the vessel's capital stock, measured by its gross registered tonnes (GRT), as the fixed input. In a fishery, the inclusion of a measure of the resource stock is important so as to control for changes in the harvesting technology due to shifts in resource abundance.[9] Thus, halibut biomass (measured in tonnes) is also included as a fixed input and is divided by the number of days fished for each vessel to be consistent with the specification of output on a daily basis.[10]

From the model, capacity and CU were calculated per vessel per day fished for halibut. A daily measure of capacity allows for the full utilization of the variable inputs and accounts for the differences in season length before and after the introduction of ITQs. Daily measures may also be extrapolated to an annual basis for each vessel by multiplying the capacity per day by the number of days in the halibut season. Annual fleet capacity can be derived from the daily per vessel measures by multiplying the number of vessels in the fleet.

[8] See Grafton, Squires and Fox (1999) for further details about the data.

[9] Thus halibut biomass is specified as a technological constraint beyond the control of the individual firm or vessel rather than as an input or form of capital stock that is under the control of an individual firm. Changes in biomass then shift the harvesting technology rather than substitute with other inputs (as would be the case if biomass were an input).

[10] In the language of DEA, each vessel is a Data Management Unit (DMU), GRT and biomass per day fished are non-discretionary inputs, and halibut landed per day is a discretionary output.

Table 2. Summary statistics of the data

	All years		1998		1991		1994	
	Mean	St. dev	Mean	St. dev	Mean	St. dev	Mean	St. dev
Vessel length (m)	14.1	5.45	14.48	3.54	13.44	7.34	14.73	3.77
Crew-weeks	12.91	9.68	15.68	11.33	8.57	5.39	16.53	9.85
Fuel quantity (l)	6 995.15	9 505.11	8 303.38	13 201.26	4 153.69	2 767.51	10 545.78	7 758.94
Halibut revenue	88 747.81	70 140.23	107 329.5	74 208.75	51 378.07	34 241.58	132 257.1	82 213.02
Price of halibut	2.78	0.72	2.03	0.15	3.08	0.21	3.85	0.3
Halibut landings (lbs)	34 026.63	28 966.98	51 769.55	33 978.76	16 475.1	10 690.77	33 583.47	19 681.81
Crew	3.78	1.48	4.52	1.55	3.02	1.09	3.79	1.28
Weeks fished	3.36	1.92	3.39	1.97	2.91	1.79	4.37	1.74
Landings/crew	8 143.52	4 561.69	10 735.89	4 863.64	5 224.56	1 972.49	8 682.33	4 283.86
Landings/week	11 731.65	9 798.18	17 541.05	11 388.93	7 199.4	5 809.97	8 653.84	6 131.51
Fuel cost	2 420.62	3 634.45	3 257.05	5 137.61	1 122.86	710.79	3 488.95	2 548.3
Labour cost	2 081.87	740.22	2 346.55	767.18	1 745.87	590.17	2 247.05	715.96
No. observations	107		44		44		19	

Source: Grafton, Squires and Fox (1999). Notes: 1. All values are in C$1994 and are per vessel; 2. Crew size includes captain; 3. Weeks fished pertain to weeks actively fishing halibut; 4. Halibut landings are in pounds and the price is per pound; 5. Fuel quantity is in litres and vessel length in meters.

To evaluate the effects of ITQs on the fleet, capacity and CU measures were regressed upon dummy variables for year and vessel size classes in a second-stage analysis. The explanatory variables in these regressions were annual dummy variables for 1988 (D_{88}), 1991 (D_{91}) and 1994 (D_{94}), which were multiplied by dummy variables for two size classes of vessel length: small, or less than 1 400 cm (D_S), and large, equal to or greater than 1 400 cm (D_L). Tobit regressions account for the censoring of the CU measures at zero and one when CU was the dependent variable (CU ranges between 0 and 1 inclusive) but ordinary least squares was used when capacity output was the dependent variable.

The effects of transferable property rights are evaluated by tests of the null hypothesis of no changes in an efficiency measure between two time periods (1988-1991, 1991-1994, and 1988-1994) and for a given vessel size class (large and small). Thus, $D_{88}\ D_S - D_{91}\ D_S = 0$ tests the null hypothesis of equal efficiency for small vessels between 1988 and 1991. F-tests were used with the ordinary least squares regressions but Wald tests were used with the Tobit regressions. If the F or chi-square value is significant for an efficiency measure (given a single linear restriction and hence one degree of freedom) then the null hypothesis of equal efficiency is rejected.[11]

4. TRADABLE PROPERTY RIGHTS AND CAPACITY

Measures of the mean halibut capacity per vessel per day over the three years 1988, 1991, and 1994, and all years combined, are given in Table 3. The average capacity per vessel per day over the period 1988-1994 was 92 147 pounds and the CU was 0.38. The results suggest that, overall, vessels did not fully utilize their capacity and that capacity declined for both small and large vessels from 1988 to 1991 with the introduction of ITQs, and again from 1991 to 1994.

[11] This approach for testing changes in capacity and capacity utilization adopts the method used by Grafton, Squires and Fox (1999) where they also test for changes in efficiency following a change in the property rights.

Table 3. Summary statistics of capacity and capacity utilization per vessel per day

	All years		1998		1991		1994	
	CO	CU	CO	CU	CO	CU	CO	CU
Mean	92 147	0.38	111 408	0.47	84 703	0.23	64 782	0.55
Median	97 883	0.33	114 167	0.47	87 093	0.17	69 371	0.51
Maximum	162 100	1	162 100	1	136 984	1	90 654	1
Minimum	7 881	0.06	19 874	0.06	7 881	0.06	31 082	0.07
Std. Dev.	32 421	0.27	27 331	0.26	30 616	0.18	18 263	0.32

Notes: CO = capacity output. CU observed capacity utilization.

The total annual fleet capacity, calculated by multiplying annual mean capacity per vessel per day (Table 3), by the number of vessels and number of days in the halibut season (Table 1), was estimated for each year (Table 4). The very large increase in annual fleet capacity from 339 237 tonnes in 1988 to 3 924 375 tonnes in 1991 is due entirely to the dramatic rise in the season length from 14 days to 214 days. Correspondingly, the measure of excess capacity, and which also depends on the total harvest of the fleet, also rose over the period 1988-1991. Both the annual fleet capacity and excess capacity measures, however, are conditional on the length of the fishing season and thus any comparison requires a standardized metric, provided by the capacity measures per vessel per day. Over the period 1991 to 1994, annual fleet capacity fell 37 percent, despite an increase in the fishing season from 214 to 245 days. The fall in annual fleet capacity in the first three years after ITQs were introduced, and declines in capacity per vessel per day over the same period, provide evidence that tradable property rights can reduce capacity in CPRs.

Table 4. Fleet Capacity and Excess Capacity, Biomass and TAC by year

Year	Capacity	Biomass	TAC	Excess Capacity
1988	339 237 36	219 380	6 400	332 837 36
1991	3 924 347 70	212 880	3 572 50	3 920 775 20
1994	2 483 903 80	141 295	4 483 50	2 479 420 30

Notes: Capacity, TAC, and excess capacity are measured in tonnes.

The tests of the null hypotheses of no change in capacity and CU per vessel per day over the periods 1988-1991, 1991-1994 and 1988-1994 for small and large vessels requires parameter estimates for the dummy variables by year and vessel class. These parameter estimates are provided in Table 5. The estimates of the coefficients of the dummy variables are the mean values for the subgroups (vessels and periods).

Table 5. Second-stage regression results

	Tobit Regression for Capacity Utilization		OLS Regression for Capacity Output	
	Coefficient	t-stat	Coefficient	t-stat
1988 small	0.422	41 774	103 581.1	19 807 49
1991 small	0.077	1 606	79 534.04	17 736 63
1994 small	0.255	2 454	57 272.92	7 878 47
1988 large	0.557	21 335	121 706.4	20 289 39
1991 large	0.401	27 292	102 278.2	12 369 77
1994 large	0.736	7 001	77 654.19	7 857 648
Log likelihood	43 006		-1 237.09	

Notes: All variables are dummy variables. The estimates were obtained using the Berndt-Hall-Hall-Hausman maximization algorithm.

Thus, from Table 5, the average CU for small vessels in 1988 was 0.422 and the mean capacity was 103,581 pounds. With the exception of the coefficient D91 for small vessels, all coefficients are significant at the five percent level. Table 6 reports the results of the hypothesis tests of no change in the capacity CU measures between the three periods for both small and large vessels. The results of the hypothesis tests, whether CU increased or decreased, and whether the change was significant or not, are summarized in Table 7.

Table 6. Tests of significance for changes in capacity output and capacity utilization over time and by vessel size class

	Capacity Output per Vessel per Day			Capacity Utilization per Vessel Per Day		
	Test Stat.	Significance	Reject (Y/N)	Test Stat.	Significance	Reject (Y/N)
H_0 : 1988 (small) = 1991 (small)	12.18	0.00	Y	36.99	0.00	Y
H_0 : 1988 (large) = 1991 (large)	3.62	0.06	N	19.16	0.00	Y
H_0 : 1991 (small) = 1994 (small)	6.43	0.01	Y	3.73	0.06	N
H_0 : 1991 (large) = 1994 (large)	3.65	0.06	N	9.61	0.00	Y
H_0 : 1988 (small) = 1994 (small)	25.43	0.00	Y	2.33	0.13	N
H_0 : 1988 (large) = 1994 (large)	14.52	0.00	Y	2.92	0.09	N

Notes: Hypothesis tests for capacity output per vessel per day are F-tests with one degree of freedom; Hypothesis tests for capacity utilization are Wald tests with one degree of freedom; Test Stat. = test statistic.

Table 7. Percentage change and significance of capacity and capacity utilization changes over time and by vessel size class

	Small Vessels			Large Vessels		
	1988-91	1991-94	1988-94	1988-91	1991-94	1988-94
Capacity per Vessel per Day	-23.2*	-28.0*	-44.7*	-16.0	-24.1	-36.2*
Capacity Utilization per Vessel per Day with Biomass	-81.8*	+231.2	-39.6	-28.0*	+83.5*	+32.1

Notes: * = statistically significant at the 5 percent level.

The summary results in Table 7 indicate that capacity output per vessel per day for both small and large vessels significantly declined between 1988 and 1991 falling by 23 percent for small vessel and 16 percent for large vessels. The significant decline in capacity for small vessels continued over the period 1991 to 1994 and fell by a further 28 percent. Although capacity also fell for large vessels from 1991 to 1994, the decline was not significant at the five percent level. Over the entire period 1988 to 1991, capacity fell significantly by 45 percent and 36 percent for small and large vessels. CU per vessel per day significantly declined from 1988 to 1991 and did not change significantly over the periods 1991-1994 and 1988-1994 for small vessels. For large vessels, CU significantly declined from 1988 to 1991 but significantly increased from 1991 to 1994, and did not significantly change over the 1988-1994 period.

In summary, over the entire time period from 1988 to 1994, the introduction of tradable property rights is associated with a decline in capacity output for both vessel size classes. Moreover, ITQs contributed to a significant increase in CU for large vessels over in the first three years of the introduction of private harvesting rights.

4.1 Explaining changes in capacity and capacity utilization: 1988-1991

An important explanation for the decline in capacity and CU per vessel per day from 1988 to 1991 is the drop in the TAC for the halibut fleet from 6 400 to 3 572 tonnes, even though total biomass declined by only by slightly under three percent. This almost 50 percent decline in the total permitted harvest forced all fishers to catch much less than they wanted. A much longer fishing season, and an exclusive property right, provided the incentive for fishers to focus on improving quality and landing a fresher and higher priced product. Nevertheless, a lack of transferability of quota in the first two years of the programme (1991 and 1992) may have prevented fishers from fully adjusting capacity and CU. The net result was that CU per vessel per day declined, despite the fact that capacity fell over the period.

4.2 Explaining changes in capacity and capacity utilization: 1991-1994

Beginning in 1993 quota has been transferable on a temporary basis. As a result, the number of active vessels in the fishery fell from 433 in 1991 to 313 in 1994, a decline of about 28 percent. Quota trading has also enabled some fishers to exit and others to increase the scale of their operations. Consequently, the mean CU per vessel per day for both small and large vessels increased dramatically over the period 1991-1994 while mean capacity per vessel per day fell. The results suggest that harvesting rights need to be both exclusive and tradable to help ensure a reduction in capacity and an increase in CU of fishing vessels.[12]

5. CONCLUDING REMARKS

Economists have long been aware of how the lack of well-specified and enforced property rights over the flow of benefits from resources can lead to the Tragedy of the Commons. The classic example of the common-pool problem is the fishery where, despite a plethora of input regulations, many of the world's developed fisheries are characterized by low average returns and excessive levels of capacity. To help address these problems, increasingly regulators are beginning to use tradable property rights.

In recent years, private harvesting rights in the form of individual transferable quotas have been introduced into fisheries in Europe, North America and the Pacific. Despite the increasing importance of individual transferable quotas in fisheries, no empirical study currently exists that evaluates the changes in capacity and capacity utilization brought about by the tradable property rights. Using data from before and after the introduction of harvesting rights into fishery, the paper details how data envelopment analysis is used to estimate capacity and capacity utilization per vessel per day. The results indicate that, provided the property rights are exclusive and transferable, individual harvesting rights can significantly reduce capacity and increase capacity utilization. Given that overcapacity is an on-going and critical problem in many fisheries, the paper provides support to the view that the assignment of well specified and enforced property rights have an important role to play in addressing the challenges of the commons.

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[12] See Devlin and Grafton (1998) for a description of the characteristics of property rights and applications for natural resources.

7. REFERENCES

Berndt, E.R. & Fuss, M. 1989 Economic Capacity Utilization and Productivity Measurement for Multiproduct Firms with Multiple Quasi-Fixed Inputs. *Working Paper* No. 2932 Cambridge, MA: National Bureau of Economic Research.

Berndt, E.R. & Morrison, C.J. 1981. Capacity Utilization Measures: Underlying Economic Theory and an Alternative Approach. *American Economic Review*, 71: pp. 48-52.

Casey, K.E., Dewees, C.M., Turris, B.R. & Wilen, J.E. 1995. The Effects of Individual Vessel Quotas in the British Columbia Halibut Fishery. *Marine Resource Economics*, 10: 211-30.

Devlin, R.A. & Grafton, R.Q. 1994. Tradable permits, Missing Markets, and Technology. *Environmental and Resource Economics*, 4: pp. 171-186.

Färe, R., Grosskopf, S. & Kokkelenberg, E.C. 1989. Measuring Plant Capacity, Utilization and Technical Change: A Nonparametric Approach. *International Economic Review*, 30: pp. 655-666.

FAO. 1998. Report of the Technical Working Group on the Management of Fishing Capacity. La Jolla, United States, 15-18 April 1998. *FAO Fisheries Report* No. 586. Rome, FAO.

Garcia, S.M. & Newton, C. 1997. Current Situation, trends and prospects in world fisheries. In: Pickitch *et al*. (Eds) *Global Trends: Fisheries Management.* Bethesda, Maryland: American Fisheries Society.

Grafton, R.Q. 1996. Individual Transferable Quotas: Theory and Practice. *Reviews in Fish Biology and Fisheries*, 6: pp. 5-20.

Grafton, R.Q. &Nelson, H.W. 1997. Fishers' Individual Salmon Harvesting Rights: An Option for Canada's Pacific Fisheries. *Canadian Journal of Fisheries and Aquatic Sciences* 54: pp. 474-482.

Grafton, R.Q., Sandal, L. & Steinshamn, S.I. 1998. How to Improve the Management of Renewable Resources: The Case of Canada's Northern Cod Fishery. *Economics Discussion Paper* 9815, University of Otago.

Grafton, R.Q., Squires, D. & Fox, K.J. 1999. Private Rights and Economic Efficiency: A Study of a Common-Pool Resource. Economics *Discussion Paper* No. 9906, University of Otago.

Grafton, R.Q., Squires, D. & Kirkley, J. E. 1996. Turning the Tide? Private Property Rights and the Crisis in Fisheries Management. *Contemporary Economic Policy* 14: pp. 90-99.

Johansen, L. 1968. Production Functions and the Concept of Capacity Recherches Récentes sur la Fonction de Production. Collection *Economie Mathématique et Econométrie* 2.

Kirkley, J.E. & Squire, D. 1999. Measuring Capacity and Capacity Utilization in Fisheries. In: Gréboval, D (Ed). Managing Fishing Capacity: Selected Papers on Underlying Concepts and Issues. FAO *Fisheries Technical Paper* No 386. pp 75-200. Rome, FAO.

Klein, L.R. & Summers, R. 1966. The Wharton Index of Capacity Utilization. Philadelphia: University of Pennsylvania, Studies in Quantitative Economics, 94 pp.

Morrison, C.J. 1985. Primal and Dual Capacity Utilization: An Application to Productivity Measurement in the United States Automobile Industry. *Journal of Business and Economic Statistics*, 3: pp. 312-324.

Nelson, R. 1989. On the Measurement of Capacity Utilization. *Journal of Industrial Economics*, 37: pp. 273-286.

Organization for Economic Cooperation and Development (OECD). (1997) *Evaluating Economic Instruments for Environmental Policy.* Organization for Economic Cooperation and Development, Paris.

Segerson, K. & Squires, D. 1990. On the Measurement of Economic Capacity Utilization for Multi-Product Industries. *Journal of Econometrics*, 44: pp. 347-361.

Segerson, K. & Squires, D. 1992. Capacity Utilization under Regulatory Constraints. *Review of Economics and Statistics*, 75: pp. 76-85.

Squires, D. 1987a. Long-Run Profit Functions for Multiproduct Firms. *American Journal of Agricultural Economics,* 69: pp. *558-569.*

Squires, D. 1987b. Public Regulation and the Structure of Production in Multiproduct Industries: An Application to the New England Otter trawl Industry. *Rand Journal of Economics* 18: pp. 232-247.

Squires, D., Kirkley, J.E. & Tisdell, C. 1995. Individual Transferable Quotas as a Fishery Management Tool. *Reviews in Fisheries Science* 3: pp.141-169.

CAPACITY AND OFFSHORE FISHERIES DEVELOPMENT: THE MALAYSIAN PURSE SEINE FISHERY

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Abstract: Many developing countries pursue offshore fisheries development strategies to increase protein supply, expand employment, earn foreign exchange, and militate the conflict between large- and small-scale fisheries over the inshore resource stocks. This study evaluates the economic success of Peninsular Malaysia's offshore fisheries development policy for the west coast purse seine fleet, finding it has largely succeeded on economic grounds.

1. INTRODUCTION

One of the key issues facing sustainable development of fisheries in Southeast and South Asia, Africa, and many other developing countries is how best to expand fishing capacity in offshore waters to satisfy a combination of objectives. These objectives include generating employment, expanding production of high quality protein, earning foreign exchange or reducing imports, and more fully utilizing underexploited resource stocks.[5] The factor providing the most immediate impetus, however, is to tackle the excess capacity and overfishing in inshore fishing grounds and the accompanying conflicts between large- and small-scale fisheries.[6]

Both large-scale, industrial fisheries, using trawl or purse seine gear and with a clear commercial orientation, and small-scale (artisanal) fisheries, using traditional gear and with more of a subsistence orientation, built up a large portion of their fishing capacity to harvest the same resource stocks. In tropical waters, these resource stocks tend to be concentrated in the shallow, nutrient- rich, readily accessible inshore waters,[7] and include rich beds of commercially valuable prawns, which are harvested largely for export. The large numbers of

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[5] The spatial allocation of fishing capacity, with a more traditional inshore sector and a more capital-intensive large-scale sector, with links between them, raises parallel social and political issues to those discussed in agriculture. Platteau (1989a, 1989b), Kurien (1996) and Meyen (1989) provide further discussion of the social organization of the fishing sector in less developed countries. These types of issues, however, are beyond the scope of this paper.

[6] This issue has also been observed elsewhere in the world: e.g. North Yemen (Panayoyouu, 1982), Brazil and Sierra Leone (Lawson, 1984), and Morocco.

[7] Prawns are most common in waters of three to six fathoms, which occur mainly in the three-to- seven mile zone in Peninsular Malaysia (Vincent *et al.*, 1997). Moreover, in over-fished tropical waters, often only the younger age classes remain, which are located in inshore waters. Inshore waters are also the most nutrient rich. Kurien (1996) observes two salient features of tropical marine living resources: (a) over 70 percent of these resources are concentrated in the coastal zone and (b) the broad species diversity widely dispersed in this zone, with comparatively short life spans and with varied sizes at maturity, available in small quantities, and with a great degree of inter-species interaction.

small-scale fishers are generally confined to inshore operations by their small vessels, low engine power, and traditional fishing gear.[8] In contrast, the more limited number of large-scale fishers, with their larger vessels, are often free to fish both inshore and offshore waters.

The excess fishing capacity that has built up in the inshore waters exacerbates the poverty of the traditional, small-scale sector. Fish stocks become overexploited or even depleted, catch rates decline, small-scale fishers are crowded out and their gear overrun, and prawn beds depleted.[9] The open-access property right exacerbates this problem, because it allows virtually free access to the inshore resource stocks by all interested groups (Meyneu, 1989).[10] The large number of species in tropical waters, each occurring in small numbers and with complex interactions, also contributes to resource competition between different gear and vessel types, even if they do not target the same fish species (Panayotou 1982).

In Malaysia, a high level of poverty in the traditional sector, and differences in ethnic composition between the traditional small-scale and large-scale sectors, make fisheries the natural resource sector that most clearly exhibits the development issues that were a central concern of the New Economic Policy (Jahara, 1988; Vincent, Rozali, and Jahara, 1997), and subsequently in 1991, the New Development Plan. Similar concerns hold for Indonesia (Bailey, Dwiponggo and Marahudin, 1987), Thailand (Panayotou and Jetanavanich, 1987), and India and Sri Lanka (Kurien, 1996; Meyen, 1989).

One of the primary public policy responses to the excess capacity and overfishing in inshore fishing grounds, and subsequent conflicts between large- and small-scale fishers, has been to promote further development of the offshore fisheries by the large-scale sector (Ishak *et al.,* 1991; Vincent *et al.,* 1997; Bailey *et al.,* 1897; Majid, 1985). Malaysia promoted offshore fishing under the belief that offshore fish resources were underexploited (Ishak *et al.,* 1991; Ooi, 1990; Vincent *et al*., 1997). The objective was to develop the fishery through modernization and increased efficiency (Mohamed, 1991). Licences for deep-sea vessels were subject to fewer restrictions than licences for smaller vessels. The government promoted offshore joint ventures with foreign (primarily Thai) companies (Vincent *et al*., 1997). Indonesia similarly encouraged the expansion of the offshore purse seine fleet by providing loans for conversion of trawlers and the construction of new purse seine vessels (Bailey *et al.,* 1987), although the Java sea fishery may be overexploited (McElroy, 1991). In both Malaysia and Indonesia, purse seine vessels are most capable of catching the types of fish species found offshore. Thailand faced the opposite problem, that of contracting its offshore fleet when the establishment of Extended Economic Zones dramatically reduced its offshore fishing grounds (Panayotou and Jetanavanich, 1987).

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[8] Strictly speaking, some small-scale vessels have the size and engine power to harvest in the closer reaches of offshore waters. Nonetheless, ranges are limited for a variety of reasons: limited hold capacity, little or no ice, low engine power and small vessel size which give considerable vulnerability to the vicissitudes of weather and make for long transit times and vulnerability to break downs, and some traditional gear cannot operate in deep water.

[9] In many instances, artisanal and large-scale commercial fishers come from different ethnic groups, exacerbating the conflicts. In addition, larger vessels home port in larger urban areas rather than in the traditional fishing villages and hamlets strung along the coast. This poses another source of conflict, as almost all of the employment gains associated with large-scale fishing and from modernization of fishing fleets are concentrated in towns and cities and not in artisanal fishing communities (IPFC, 1994). Large-scale fishers concentrate on production for urban and export markets (especially prawns for export), while artisanal fishers tend to concentrate on own consumption and local markets, with only a limited export orientation.

[10] Customary use rights or even common property by small-scale indigenous Malay fisheries withstand outside encroachments only with great difficulty or not at all without vigorous support by the State.

A second primary public policy response to the excess capacity and conflicts in inshore waters has been to close off access to inshore grounds by large-scale vessels. Indonesia, by Presidential Decree 39 in 1980, outright banned all trawlers from waters off Java and Sumatra. In 1983, Indonesia extended the trawl ban throughout the country, except for some parts of eastern Indonesia and the Indian Ocean (Bailey, 1997). Malaysia similarly banned trawlers from the inshore waters fished by traditional, small-scale vessels. These bans not only substantively reduced conflicts with artisanal fishers, but also reserved the lion's share of the highly lucrative prawn resources for artisanal fishers.

In short, Malaysia and Indonesia both introduced an area licensing scheme to spatially allocate fishing capacity by gear type, vessel size, and type of ownership (Bailey *et al.,* 1987; Jahara, 1988; Ooi, 1990; Ishak, 1994).[11] Both Malaysia and Indonesia specified four zones, with the innermost belt reserved for artisanal fishing (Ooi, 1990; Saharuddin, 1995). Malaysia's programme distributes vessels by size class, with the larger vessels distributed in zones farther offshore.

This spatial allocation of fishing capacity was motivated in part to ensure sustainable resource exploitation, but even more so for social and political reasons. Use of inshore waters in both Indonesia and Malaysia was intended to achieve the social objective of employing traditional fishers, and use of offshore waters was intended to achieve the economic objective of producing fish (Bailey *et al.*, 1987; Ooi, 1990). In Malaysia, this policy was not based solely on resource stock conservation, but major consideration was given to economic, social and political aspects (Majid, 1985). Majid (1985: p. 321), states, "*The main criteria was to control excess capacity, taking into account socio-economic and political considerations*." Jahara (1988) further observed for Malaysia that the objective of allocating fishing grounds represented a strong emphasis on equity, and that the issue was as much politics as equitable allocation of fishery resources between highly efficient trawlers and less efficient small-scale fishers.

The purpose of this paper is to evaluate the strategy of focusing large-scale commercial fishing on offshore waters through a case study of Peninsular Malaysia's purse seine fleet. We focus on the purse seine fleet since it is well-suited to offshore fishing. The encouragement of fishing capacity to offshore waters might lead to either excess or under capacity, depending on the fleet's response. Shifting capacity offshore might also lead to technical inefficiency if vessels do not make efficient adaptations. Variable inputs might also not be optimally utilized. To address these questions, the paper evaluates the success of this strategy, asking whether or not the strategy has led to excess capacity and whether or not the offshore fleet is technically efficient. In particular, the paper asks how much of the current zonal fishing capacity, labour, and days-at-sea are utilized during monsoon and non-monsoon seasons, with an eye to suggesting improvements in technical efficiency and the utilization of capacity and variable inputs. The definition of fishing capacity and its approach to measurement draw upon the recent FAO Technical Working Group on the Management of Fishing Capacity, La Jolla, United States, 15-18 April 1998 (FAO 1998) and accompanying background paper of Kirkley and Squires (1999).

[11]See Wilen (1988) for a discussion of area licensing programs and Townsend (1990) for a review of licence limitation programs in general.

The analysis does not assess the optimal long-run, steady-state equilibrium level of fishing capacity and vessels by zone, which would require information on the resource stocks and their population dynamics which are simply unavailable.[12] The analysis also does not assess the achievement of social objectives.

The paper is organized as follows. Section 2 provides a background to the Peninsular Malaysian purse seine fishery. Section 3 discusses fishing capacity, technical efficiency, and variable input utilization; presents the empirical model used for measurement; and discusses the data. Section 4 reports the empirical results and discusses the implications for policy. Section 5 provides concluding remarks.

2. PENINSULAR MALAYSIAN PURSE SEINE FISHERY

The Peninsular Malaysian fishing industry provides a significant source of animal protein, employment, and to a lesser extent, foreign exchange (Ishak, 1994). Historically, it has been among the top ten or 15 in the world (Vincent *et al.*, 1997). Demersal fish (bottom dwelling) account for over 70 percent of the total fish harvested and some 80 percent are caught in inshore areas. Demersal fish comprise most landings on the west coast, whereas demersal and pelagic fish (surface or sometimes mid-water dwelling) are equally important on the east coast. Purse seine gear primarily harvest pelagic fish, such as mackerels, tunas, and sardines, whereas trawl gear primarily harvest prawns and demersal fish, such as pomfret, grouper, and snapper.

Inshore fishing grounds contain both demersal fish and pelagic fish, but the demersal stocks are the focus of most inshore fishing effort. Both pelagic and demersal fish inhabit offshore waters, and are generally thought to be underexploited. Offshore demersal resources are likely to remain beyond the reach of many trawlers in the foreseeable future due to technical and economic difficulties affecting trawl fishing in deep water, where the trawl net must be released and retrieved over a lengthy time and towed at considerable depth on or near the sea floor by vessels with powerful winches and engines. In contrast, offshore pelagic fish species are more readily accessible since they are usually surface dwelling and often form schools, which allows them to be readily harvested by purse seine gear, which can encircle the schools. For these reasons, the offshore fishery has historically targeted pelagic species using purse seine gear. Many pelagic species are migratory and scattered, which combined with the lengthy running time required to reach the farthest reaches of offshore grounds, requires vessels with refrigerated fish holds or the capacity to carry adequate stores of ice, fuel, and food to support more extended fishing trips.

The west coast fishing grounds lie largely in Malaysia's Extended Economic Zone in the Straights of Malacca (bounded by Sumatra) and the Southern Indian Ocean. The west coast's greater stocks of prawns and demersal fish provide the chief attraction for commercial vessels, and west coast issues have been the principal driving force for Peninsular Malaysian fishing policy during the last thirty years (Vincent *et al.*, 1997). Fishing operations on the west coast are more highly capitalized compared to the east coast. Landings and vessel numbers are much greater on the west coast than the east coast, largely due to the greater fish resource abundance on the west coast and the absence of large prawn resources on the east

[12] The science of population dynamics in the complex multispecies tropical waters is still in its rudimentary stage and in addition, scientific and data infrastructures tend to be underdeveloped.

coast, which sustain the trawl fishery of the west coast (Ooi, 1990). The west coast fishing grounds are generally shallow with muddy bottoms.

The concentration of fishing in inshore waters led to overfishing off the west coast, beginning in the late 1960s and early 1970s, fuelled by the introduction of trawling to harvest prawns for lucrative export markets.[13] Landings are increasingly comprised of lower-valued species, especially 'trash fish', which are often discarded at sea with high mortality.[14] Most of the untapped fishery resources are pelagic.

The deep-sea fishery is regarded as a new frontier, and the *Sixth Malaysia Plan* (Government of Malaysia, 1991) emphasized raising deep-sea production (Vincent *et al.*, 1997). The *Sixth Malaysia Plan* mentioned credit facilities for building offshore vessels and public investment in infrastructure for large vessels, such as harbour improvements, docks, and access roads. The *Sixth Malaysia Plan* (quoted in Vincent *et al.*, 1997: p.111) stated that, "*Due to the depletion of inshore resources, the future development of the fisheries sector will stress on [sic] deep-sea fishing and aquaculture in fresh and brackish water*."

The area licence limitation programme spatially distributes fishing capacity through four main zones (Majid, 1985): (1) Zone 1, within five miles from shore, is reserved for owner-operator traditional fishing gear; (2) Zone 2, 5-12 miles from shore, is reserved for owner-operator trawlers and purse seiners < 40 GRT; (3) Zone 3, 12-30 miles, is reserved for owner-operator trawlers and purse seiners > 40 GRT; (4) Zone 4, beyond 30 miles to the outer limit of the Exclusive Economic Zone, is reserved for foreign or partially-Malaysian owned vessels ≥ 70 GRT.

This area licensing system, in principle, spatially allocates vessels by size, with larger vessels farther offshore. The Department of Fisheries determines the number of licence granted for different gear although the actual allocation is determined at the state level (Vincent *et al.*, 1997). Because the zoning system restricts types of vessels and gear but not numbers, the Department of Fisheries imposed a moratorium on new licences for all west coast vessels except those of 40 GRT and above in the hope of a gradual reduction in fishing effort. Monitoring and enforcement are difficult, the zones – especially prawn-rich inshore zones – are intruded upon, and there are many illegal, unlicensed vessels.

Purse seine gear (*pukat jerut*, *pukat tarik*, *pukat kilat*, encircling nets)[15] is designed with fine mesh to catch anchovy, and with a larger, coarser mesh, one or more species of high- and/or low-valued pelagic fish such as Spanish and Indian mackerel, herring, and sprats (Firth, 1975; Bailey, 1983; Ishak, 1994). The net is made of nylon and furnished with floats at

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[13] Biological overfishing has occurred in inshore waters of the west coast of Peninsular Malaysia, particularly for the Straits of Malacca (Jahara, 1988). Jahara, footnote 2, provides a number of sources. Jahara further observes that symptoms of overfishing include: a persistent decline in total catch; a noticeable decrease in catch per unit effort; an increased proportion of "trash fish" in the demersal landings -- reducing the average size and age of species caught; the virtual disappearance of certain commercial species, such as *Lactarius lactarius* or *ikan shrumbu*; and declining trends in catch rates in inshore waters up to a depth of 50 meters in demersal resource surveys carried out by the Malaysian Fisheries Research Institute and in other cited surveys.

[14] Trash fish are primarily juveniles of commercially valuable species or species with little or no commercial value.

[15] Malay *pukat* - net, *jerut* - to tighten a slip-cord, *tarik* - *pull, kilat* - lightening (referring to the speed at which a power winch tightens the bottom rope of the net). In more detail, *pukat jerut* proper, sometimes known as *pukat jerut malam*, is used at might. *Pukat jerut tuas* (*tuas* - lure) refers to a day fishery using lures. *Pukat jerut bilis* is the purse seine gear for the capture of *ikan bilis* (anchovy).

the top and a row of heavy brass rings at the bottom through which a rope is reeved (Firth, 1975). The purse seine net, which provides employment to about 25 percent of all fishers, was introduced in the 1890s by Chinese fishers from South China who had settled in Thailand and latter migrated to Kedah and Pangkor Island. Purse seine vessels use inboard diesel-fuelled motors.

After locating a shoal (school) of pelagic fish, fishers encircle this shoal by a net. Traditionally, purse seine vessels operate on darker phases of the moon, although there is also an active day fishery.[16] A fish aggregating device, such as a buoy or bamboo raft with flag pole and trailing coconut leaves or palm fronds, is left in the water in a known fishing area (Firth, McElroy, Munro and Loy, 1978). Lamps are generally used at night to attract fish. The vessel stands by, with engine off, until a reasonably sized school accumulates below the aggregating device. The process may be repeated at several sites. Some vessels actively search for schools of fish, using sonar, but other vessels still rely on the manual hearing of fish experts. Once the fish are located, the net is anchored to one end to the main vessel while a smaller and swifter vessel carries it around the shoal of fish. Alternatively, a powered vessel may tow a second vessel, which may be an older vessel without an engine and which carries the net (Bailey 1983). The net is drawn back to the main vessel, either by hand or by a powered winch, while the net bottom is drawn together, much like a purse, to prevent fish from sounding and escaping through the bottom of the net. The net is then lifted onboard and its contents dumped onto the deck, where the fish are sorted by species and stored below deck in ice, an ice-saturated brine, or an ice-meltwater mix as frozen fish (McElroy ,1991).

Purse seining requires a good number of hands, with specialized crewmembers to perform technical assignments. There may be one to two captains (*Taikong*), fishing experts (*Juruselam*), one to two net men (*Jurupukat*), an engine person (*Juruenjin*), gasoline operator, and a set of ordinary deck workers, depending on the requirements of the vessel and net. The *Juruselam*, when employed, determines the existence of a shoal by manual hearing upon which shooting of the net occurs. The *Taikong* is in charge of the vessel, is responsible for the security and maintenance of all gear and equipment, gives commands as to when nets are dropped, and is the most knowledgeable and experienced person. In the absence of a *Juruselam*, the *Taikong* determines the existence of fish. Some vessels are more mechanized than others, equipped with fish detecting devices that can discriminate between targeted and non-targeted fish species, which is considerably more difficult for a *Juruselam*.

Fishing and fish abundance are affected by monsoons. Monsoons on the west coast, while not of the severity of the east coast, can still be accompanied by heavy seas and high winds. The more severe inclement weather makes fishing both more difficult and more dangerous. During the monsoon, stormy seas can combine with the increased run-off from rivers to produce a nutrient- rich environment in which plankton thrive, which in turn supports a wide variety of marine life (Bailey, 1983). At some point after the monsoon, catch rates can decline in step with the decline in organic content in the sea and hence marine life. During and immediately following monsoon periods, some species of fish may concentrate closer to the shoreline. During periods of calm, which coincides with reduced river discharge, nutrient levels drop and the fish may disperse over a wider area to forage for food.

[16] During bright phases of the moon, vessels frequently do not fish, since fish can see the shadow of the net and will avoid it (Bailey, 1983).

3. EMPIRICAL ANALYSIS[17]

3.1 Fishing capacity

Capacity can be defined and measured following either a technological-engineering approach or explicitly predicated on economic optimization from microeconomic theory (Morrison, 1985). Kirkley and Squires (1999) and the FAO Technical Working Group (TWG) on the Management of Fishing Capacity held in La Jolla, California in April, 1998 (FAO 1998) focused on the former because the general paucity of cost data in most fisheries world-wide militates against estimation of cost or profit functions to derive economic measures of capacity and capacity utilization (hereafter CU) (see Morrison (1995) for a survey of all approaches). The technological- economic approach is also the way that governments around the world define and measure capacity in all industries. In this paper, we focus on the technological-economic approach to measuring capacity and CU.

Capacity is a short-run concept, where firms and industry face short-run constraints, such as the stock of capital and existing regulations, and is conditional upon the existing state of technology (Morrison, 1995). Johansen (1968: p.52) defined capacity for the technological-economic approach as, "*...the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted.*" The concept of capacity generally conforms to that of a full-input point on a production function, with the qualification that capacity represents a realistically sustainable maximum level of output rather than some higher unsustainable short-term maximum (Klein and Long, 1973).

In fisheries and other natural resource industries, capacity can also be defined conditional upon the size and composition (e.g. age structure, species, and density) of the resource stock.[18] When capacity is defined conditional upon the size and composition of the resource stock, it is a measure of the maximum potential output that could be produced at given resource stock levels. In this case, it does not provide a measure of the potential output that could be produced in the absence of resource constraints.

Excess capacity can be defined as the situation when capacity output exceeds a desired or target level of output, such as the Total Allowable Catch (an aggregate annual quota for the industry or fishery typically set by population biologists) (FAO, 1998; Kirkley and Squires, 1999). The target level of output was defined by the TWG as (FAO, 1998) as, "*[t]arget fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized while satisfying fishery management objectives designed to ensure sustainable fisheries...*"[19] The TWG observed that current and target

[17] This section draws heavily from Kirkley and Squires (1998), who provide an extensive literature review of fishing capacity. Suffice it to note that the vast bulk of the fisheries literature equates capacity with the capital stock and CU with capital utilization. However, these concepts are equivalent only when there is a single measure of the capital stock, all variable inputs are in fixed proportions to the capital stock, and there are constant returns to scale. See Berndt (1990) for further discussion. This linear relationship between capacity and capital stock corresponds to a constant q or catchability coefficient in the basic population dynamics model.

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

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

capacity need to be evaluated and compared relative to the same resource stock size (FAO, 1998).

3.2 Technical efficiency

Technical efficiency reflects the ability of a firm to obtain the maximum possible output from a given set of inputs and production technology.[20] Technical efficiency is a relative concept, since each firm's production performance is compared to a best-practice input-output relationship or production frontier. The most efficient firms establish the production frontier. Technical inefficiency is then measured as the deviation of an individual firm from this best-practice frontier.

3.3 Capacity utilization

Capacity utilization represents the proportion of available capacity that is utilized. In the technological-economic approach that was adopted by FAO, full CU represents full capacity and CU cannot exceed one. A CU value less than one indicates that firms have the potential for greater production without having to incur major expenditures for new capital or equipment (Klein and Summers, 1960).

CU can be measured in two different ways in the technological-economic approach. CU can be measured as the ratio of observed output to capacity output, which is the standard approach (cf. Morrison, 1985). CU can also be measured as the ratio of technically efficient output to capacity output (Färe *et al.*, 1994). The latter definition corrects for any bias that could otherwise arise from technical inefficiency. That is, the technological-economic measure of capacity is predicated upon with full technical efficiency, so that the ratio of technically efficient output to capacity is consistent in that both numerator and denominator are technically efficient output levels. In contrast, the ratio of observed output to capacity output contains a numerator that may be technically inefficient and a denominator that is technically efficient. In turn, this may provide a CU measure that combines both deviations from full technical efficiency and full capacity.

3.4 Variable input utilization rate

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

[20] Two types of technical efficiency can be measured. The output-oriented measure addresses how much output quantities can be proportionally expanded without altering the input quantities used. The input-oriented measure addresses how much input quantities can be proportionally reduced without changing the output quantities produced. This paper uses the output-oriented measure of technical efficiency since that is consistent with the notion of capacity as the maximum quantity that can be produced given full utilization of variable inputs and fixed inputs. Note that technical efficiency does not require full utilization of variable inputs.

3.5 Measurement

Data envelopment analysis (DEA) can be used to estimate capacity, technical efficiency, and the variable input utilization rate (Färe *et al.*, 1989, 1994). DEA is a nonparametric or mathematical programming technique to determine optimal solutions given a set of constraints. The maximum possible output given full utilization of the variable inputs, prices, the resource stocks, regulations, and state of technology corresponds to the frontier output under these conditions, and the ratio of observed to capacity output gives a measure of CU, which is also the measure of output-oriented technical efficiency when variable inputs are fully utilized. Returns to scale are allowed to vary. Full utilization of the variable inputs means they are unconstrained, i.e. there are not any bounds on their use. All multiple outputs vary in fixed proportions (a radial expansion). The fixed inputs are bound by their observed values for each observation but do not have to be fully utilized.

The difference between observed and capacity output gives the excess capacity for that resource stock. In many fisheries, observed output is the Total Allowable Catch.

The heterogeneous capital stock forms quasi-fixed or fixed factors, and can be captured by different proxy variables, each of which measures one of the capital components. These proxy variables can include those that resource managers denote as most important at capturing production and which are most easily regulated, such as vessel length or gross registered tonnage and main engine horsepower. By specifying a heterogeneous capital stock, the specification does not necessarily *a priori* denote any individual piece of capital as binding or fully utilized, and in fact, not all fixed factors necessarily will bind. Instead, the data can determine the individual component of the heterogeneous capital stock that binds on a firm-by-firm basis. For instance, the vessel length might bind for one firm while engine horsepower might bind for another firm.

When there is a heterogeneous capital stock, so that there are multiple fixed or quasi-fixed factors, it may not be possible to determine the capacity output (Berndt and Fuss, 1989).[21] However, in two different ways, the DEA approach effectively converts the heterogeneous capital stock (multiple fixed factors) into a single measure of the capital stock (composite fixed factor) to solve this indeterminancy problem. First, because the DEA measure of capacity is output oriented, i.e. the maximum output given fixed inputs, the fixed inputs or heterogeneous capital stock are held constant at observed levels, and as discussed above, that individual component of the heterogeneous capital stock that is fully utilized (binding) is the individual capital stock that determines capacity. Second, and more importantly, the DEA measure of capacity entails a radial expansion of both outputs and inputs, that is, outputs are in fixed proportions for any output levels and inputs are in fixed proportions for any input levels. When fixed inputs are in fixed proportions, an aggregate

[21] With the technological-economic approach to capacity and a single output for example, CU may equal one, seemingly indicating full capacity, but when in fact one fixed factor may be fully utilized, while another has considerable excess capacity. Alternatively, in the economic approach to capacity, capacity corresponds to the tangency point of the short- and long-run average cost curves. With multiple fixed factors, there are multiple average cost curves, depending on the proportions of the fixed factors, or an average cost curve in which the proportions of fixed factors may vary with output levels. Alternatively, its interpretation becomes unclear with multiple fixed factors, since it is possible for CU to equal one even if the actual prices of the fixed factors do not equal their shadow values (e.g. if there are offsetting effects). The implications of this for investment incentives are unclear.

fixed input or capital stock can be formed (called Leontief separability). This effectively converts the multiple fixed factors into a composite measure.

When there are multiple outputs, a similar problem arises because a scalar measure of output does not generally exist (Segerson and Squires, 1990).[22] However, the DEA approach to capacity measurement effectively converts the multiple products into a single composite output because there is a radial expansion of outputs (outputs are in fixed proportions for different input levels), which gives a ray measure of capacity, and CU and implicitly imposes Leontief separability among the outputs.

We consider the output-oriented DEA model of capacity of Färe *et al.* (1989):

$$
\begin{aligned}
&\underset{\theta,z,\lambda}{Max} \quad \theta_1 \\
&\text{subject to} \\
&\theta_1 u_{jm} \le \sum_{j=1}^{J} z_j u_{jm}, \quad m = 1,2,\ldots,M, \\
&\sum_{j=1}^{J} z_j x_{jn} \le x_{jn}, \quad n \in \alpha \\
&\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, \quad n \in \hat{\alpha} \\
&z_j \ge 0, j = 1,2,\ldots,J, \\
&\lambda_{jn} \ge 0, n \in \hat{\alpha}.
\end{aligned} \tag{1}
$$

The variables are as follows: (1) u_{jm} is the m^{th} monthly output of the j^{th} observation, and there are nine outputs (J = 9); (2) x_{jn} is the n^{th} input used in a month, and there are four fixed factors and two variable factors. The four fixed factors are gross registered tonnage (GRT), length of hull in meters, engine horsepower, and length of net in meters. The two variable factors are days at sea per month and total number of crew per month.[23] We allow for variable returns to scale.

The problem for assessing only technical efficiency of production is solved by simply deleting the equality constraint on the variable inputs and including the variable inputs in the inequality constraint. The ratio of technical efficiency calculated from the output-oriented model, with the inequality constraints on the variable and fixed factors, to technical efficiency

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[22] A consistent scalar measure of output in multiproduct firms exists if all outputs are homothetically separable from inputs, and a direct analogue of the single-product primal measure of capacity and CU can be developed for the multiproduct firm (Segerson and Squires, 1994). When the technology is not homothetically separable, Segerson and Squires (1994) suggest two alternative ways of defining a primal CU measure: (1) outputs move along a ray, giving a ray measure of capacity and CU and (2) only output adjusts, giving a partial measure of capacity and CU.

[23] The inputs differ from the inputs typically considered in economic analysis (e.g. labour, energy, capital services and materials). Despite the fact the inputs are not well defined, they are the inputs most commonly considered in the economic analysis of fisheries and are consistent with the variable inputs typically considered by resource managers. Other than labour and materials and occasionally capital, there does not appear to have been any efforts by resource managers to regulate fisheries by controlling or limiting the conventional economic inputs. There is, however, a long history of regulation days at sea and crew size.

calculated from the output-oriented model with equality constraints on the variable inputs, gives an unbiased measure of CU (Färe *et al.*, 1989).

Our analysis excludes stock size because we do not have fishery-independent measures of stock abundance; our measures of stock abundance are the catch (CPUE) or landings (LPUE) per unit of fishing effort. The two measures, CPUE and LPUE, are well known to have numerous problems relative to being adequate indicators of resource abundance (Richards and Schnute, 1986).

3.6 Data

Data were obtained in a multistage sampling procedure. The first and second stages involved first the selection of States and then the fisheries districts within the States where most of the relevant gear operates. This was based on the *Annual Fisheries Statistics* of the Department of Fisheries, Malaysia, which provides statistics on landing of marine fish, number of licensed fishing vessels and gears, number of fishers, and other related information by fisheries districts, states, and fishing gears. Based on the criteria of gear concentration and their contribution to fisheries production and revenue the states selected were Johor, Perak, Kedah, and Perlis from the west coast of Peninsular Malaysia. The selected fishing districts were Mersing from Johor, Manjung from Perak, Kuala Kedah from Kedah, and Kuala Perlis from Perlis. Lists of licensed vessels with the owner's name and addresses were obtained from the Department of Fisheries. A second list was collected from the offices of the fisher cooperative association and the Department of Fisheries within the selected districts to determine the actual number of vessels operating in the fishery. The sample was randomly selected from this list.

The vessel owner was interviewed by administering a pre-tested questionnaire. The number of west coast purse seine vessels in the sample was 55. The number of fishers interviewed by State was: Perak (15), Kedah (14), and Perlis (26). The questionnaires were administered from August to October, 1988. Respondents were requested to provide information on one month's catch each of the non-monsoon season (April to October) and the immediate past monsoon season (November to March).[24]

The mean and proportion of the west coast Peninsular Malaysian purse seine catch, combining the monsoon and non-monsoon months are given in Table 1. Hardtail and round scad, Indian mackerel, and sardines are the most important catches by volume. Tuna and yellow tailed Trevally are also important.

[24] The absence of widespread and detailed formal record-keeping required data requests on a monthly rather than annual basis.

Table 1. Mean (kg) and proportion (%) of total purse seine catch by species group

West Coast	Vessel size classes (GRT)											
Species	<30		31-40		41-50		51-70		>70		All categories	
	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%
Hardtail scad	2 183	12%	2 345	13%	3 006	14%	2 621	12%	2 249	10%	2 556	12%
Selar scad	1 520	8%	1 408	8%	1 534	7%	1 041	5%	1 599	7%	1 292	6%
Tuna	892	5%	1 217	7%	2 767	13%	2 418	11%	1 127	5%	1 969	10%
Indian mackerel	3 829	21%	3 946	21%	4 525	21%	5 534	26%	5 508	24%	4 869	24%
Yellow striped trevally	1 862	10%	1 589	8%	1 703	8%	2 132	10%	3 090	13%	1 996	10%
Round scad	2 675	14%	2 820	15%	3 336	16%	2 685	13%	3 168	14%	2 869	14%
Ox-eye scad	1 350	7%	1 711	9%	1 077	5%	1 328	6%	1 440	6%	1 396	7%
Sardine	3 538	19%	3 107	17%	2 806	13%	2 795	13%	3 275	14%	2 963	14%
Mixed	738	4%	579	3%	360	2%	711	3%	1 482	6%	691	3%
All species	18 633	100%	18 720	100%	21 113	100%	21 265	100%	22 936	100%	20 600	100%

In Table 2, the mean vessel and fishing trip characteristics per month, by licence zone, combining monsoon and non-monsoon months are presented. Mean vessel size, indicated by the volumetric measure Gross Registered Tonnes (GRT), increases with distance from shore, although vessel length remains constant and some smaller vessels also fish in Zone 4. As vessels fish further offshore, their size tends to increase to hold larger catches and better handle rougher seas and adverse weather conditions. Engine horsepower remain roughly constant by zone. Mean expected life of the vessel hull increases with distance from shore.[25] The purse seine nets are long, averaging 356 meters, with the length consistently slightly increasing with distance from shore. Mean days at sea and number of trips per month increase with distance from shore, reflecting among other things, longer transit distances and times. Mean days per trip remains largely unchanged by zone. The mean number of hauls of the purse seine net per day per month increases with distance from shore. Interestingly, the mean number of crew (including captain) decreases with distance from shore, perhaps reflecting a greater eye to cost efficiency and stronger commercial orientation.

Fish abundance for the different species, measured by mean catch per day per month (catch per unit effort, CPUE), is also reported in Table 2.[26] We present CPUE only to provide information by which to relate technical efficiency, capacity, CU, and variable input utilization to resource levels. Abundance varies by species and zone. Zone 1 exhibits the greatest abundance for round scad, lolong, and sardines. Zone 2 exhibits the highest abundances for hardtail and selar scad and Indian mackerel. Zone 3 displays the highest abundances for only yellow striped Trevally and mixed species.

Days-at-sea utilization on an annual basis is very close to the optimum for Zones 3 and 4 (Table 2). However, optimum days at sea fall below the observed for Zone 2 vessels, suggesting these vessels should spend fewer days at sea.[27] Averaged over all zones, days-at-sea utilization drops slightly from the normal to monsoon seasons (Table 3). On a zonal basis, Zone 2 vessels' days-at-sea utilization increases slightly from the normal to monsoon season, while dropping slightly for Zone 3 and Zone 4 vessels (Table 4).

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[25] The questionnaire did not contain year built for the vessel hull, so the age of the vessel could not be determined. Instead, the closest information to capture vintage effects from vessel hull age is the respondent's estimate of expected life of the hull. Presumably, vessels with a longer expected life are newer.

[26] Catch is linearly aggregated, i.e. simply summed, for this measure.

[27] Since Zone 2 lies closest to the shore and hence ports, most of this time would be taken up by fishing rather than transit to and from fishing grounds.

Table 2. Mean vessel characteristics and empirical results by zone

	Total	Zone 2a	Zone 3	Zone 4
Gross registered tonnage	54.76	39.56 (30-57)	55.80 (30-195)	57.81 (43-70)
Length of hull (meters)	19.53	19.00 (18-20)	19.65 (15-23)	19.19 (14-23)
Engine horsepower	215.62	223.89 (195-250)	214.45 (160-350)	217.18 (195-250)
Length of net (meters)	356.33	352.33 (280-500)	355.75 (167-500)	361.63 (300-400)
Number of crew (incl. Cap.)	16.87	18.67 (11-22)	17.34 (10-30)	13.38 (10-20)
Number of trips per month	20.83	20.00 (18-22)	20.59 (14-26)	22.56 (20-25)
Total days at sea per month	22.40	20.67 (18-24)	22.46 (15-26)	23.06 (20-25)
Hauls per day per month	4.15	3.56 (2-4)	4.15 (2-7)	4.44 (3-6)
Days per trip per month	1.09	1.03 (1-1.2)	1.11(0.9-1.6)	1.02 (1-1.2)
Distance from shore (miles)	19.27	10.22 (10-11)	17.80 (12-27)	32.19 (30-40)
Expected life of hull (years)	16.44 (9-25)	15.89 (10-18)	16.20 (9-25)	18.00 (16-20)
Captain's experience (years)	16.25 (5-37)	14.44 (8-25)	15.52 (5-36)	21.19 (10-37)
No. of captain with training	23	2	17	4
No. of captain w/out training	32	1	26	5
No. of owner-non-operators	11	0	10	1
No. of owner-operators	19	0	14	5
No. of non-owner-operators	25	3	19	3
No. of Chinese captains	33	0	28	5
No. of Malay captains	22	3	15	4
Family size of captain	8.76 (3-15)	6.33 (4-8)	8.95 (3-15)	8.67 (6-12)
Species abundance (CPUE):				
Hardtail scad	108.98	76.29	114.99	95.45
Selar scad	54.92	53.33	58.35	37.63
Tuna	83.75	52.84	85.23	93.27
Indian mackerel	206.69	185.92	213.92	180.04
Y. S. Trevally	83.64	58.29	82.86	102.01
Round scad	123.50	157.53	121.43	115.32
Lolong	58.71	66.43	59.50	50.17
Sardine	126.03	165.88	124.35	112.53
Mixed species	28.91	17.04	28.17	39.48
Output technical efficiency	1.09 (1.00-1.89)	1.08 (1-1.17)	1.11(1-1.89)	1.04 (1-1.17)
Capacity technical efficiency	1.14 (1.00-1.90)	1.19 (1-1.55)	1.14 (1-1.9)	1.10 (1-1.41)
CU: observed (%)	89.46 (52.63-100.00)	85.42 (64.52-100)	89.47 (52.63-100)	91.68 (70.92-100)
CU: Färe et al. (%)	96.55 (61.35-100.00)	91.67 (64.52-100)	97.38 (61.35-100)	94.88 (70.92-100)
Crew utilization (%)	104.99 (79.09-203.09)	95.72 (79.09-139.06)	102.74 (81.95-203.09)	122.19 (99.62-197.98)
Optimal crew size	17.24 (11.00-30.00)	17.33 (15.29-20.00)	17.52 (11.00-30.00)	15.71 (11.00-20.00)
No. of trips: crew shortage	29	2	19	8
No. of trips: crew surplus	31	5	25	1
No.of trips: optimum crew	50	2	41	7
Days-at-sea utilization (%)	101.87 (95.25-136.00)	111.45 (99.54-131.67)	101.24 (95.25-136.00)	99.82 (95.48-106.54)
Optimal days-at-sea	22.74 (20.00-26.00)	22.85 (20.00-24.00)	22.68 (20.00-26.00)	23.00 (20.00-25.00)
No. of trips: shortage days	31	6	22	3
No. of trips: surplus days	29	1	22	6
No. of trips: optimum days	50	2	41	7
No. trips: optimum crew & days	49	2	40	7
No. of observations	110	9	85	16

[a]Zones are based on nautical distances from shore: (1) Zone 2 > 5 miles but < 12 miles; (2) Zone 3 > 12 miles but< 30 nautical miles; and (3) Zone 4 > 30 nautical miles. Ranges given in parentheses. Year is 1988. Results averaged over both monsoon and non-monsoon.

Table 3. Mean vessel characteristics and empirical results by monsoon and non-monsoon

	Total	Non-monsoon	Monsoon
Gross registered tonnage	54.76	54.76	54.76
Length of hull (meters)	19.53	19.53	19.53
Engine horsepower	215.62	215.62	215.62
Length of net (meters)	356.33	356.33	356.33
Number of crew (incl. Cap)	16.87	16.87	16.87
Number of trips per month	20.83	20.89	20.76
Total days at sea per month	22.40	22.47	22.33
Hauls per day per month	4.15	4.18	4.11
Days per trip per month	1.09	1.09	1.09
Distance from shore (miles)	19.27	19.58	18.96
Expected life of hull (years)	16.44 (9-25)	16.44 (9-25)	16.44 (9-25)
Captain's fishing experience (years)	16.25 (5-37)	16.25 (5-37)	16.25 (5-37)
No. of captain with training	23	23	23
No. of captain without training	32	32	32
No. of owner-non-operators	11	11	11
No. of owner-operators	19	19	19
No. of non-owner-operators	25	25	25
No. of Chinese captains	33	33	33
No. of Malay captains	22	22	22
Family size of captain	8.76 (3-15)	8.76 (3-15)	8.76 (3-15)
Species abundance (CPUE)			
Hardtail scad	108.98	121.76	96.19
Selar scad	54.92	61.58	48.26
Tuna	83.75	94.59	72.92
Indian mackerel	206.69	231.36	182.03
Y. S. Trevally	83.64	93.89	73.38
Round scad	123.50	134.01	112.98
Lolong	58.71	65.70	51.72
Sardine	126.03	138.52	113.54
Mixed species	28.91	32.60	25.21
Output technical efficiency	1.09	1.02 (1.00-1.48)	1.17 (1.00-1.89)
Capacity technical efficiency	1.14	1.04 (1.00-1.51)	1.24 (1.00-1.90)
Capacity utilization: observed (%)	89.46	96.94 (66.23-100.00)	81.98 (52.63-100.00)
Capacity utilization: Färe et al. (%)	96.55	98.32 (70.92-100.00)	94.78 (61.35-100.00)
Crew utilization (%)	105.99 (79.09-203.09)	104.33 (79.09-197.98)	105.65 (80.23-203.09)
Optimal crew size	17.24 (11.00-30.00)	17.19 (11.00-30.00)	17.28 (12.00-30.00)
Number of trips: crew shortage	29	10	19
Number of trips: crew surplus	31	8	23
Number of trips: optimum crew	50	37	13
Days-at-sea utilization (%)	101.87 (95.25-136.00)	101.25 (95.5-131.67)	102.48 (95.25-136.00)
Optimal days-at-sea	22.74 (20.00-26.00)	22.71 (20.00-26.00)	22.77 (20.00-26.00)
Number of trips: shortage days	31	9	22
Number of trips: surplus days	29	9	20
Number of trips: optimum days	50	37	13
No. trips: optimum crew & days	49	37	12
Number of observations	110	55	55

Ranges are given in parentheses. Year is 1988.

Table 4. Mean vessel characteristics and empirical results by zone and monsoon and non-monsoon

Characteristic	Zone 2		Zone 3		Zone 4	
	Non-monsoon	Monsoon	Non-monsoon	Monsoon	Non-monsoon	Monsoon
Gross registered tonnage	39.00	39.83	55.02	56.60	58.78	56.57
Length of hull (meters)	19.33	18.83	19.63	19.67	19.11	19.29
Engine horsepower	230.00	220.83	214.27	214.62	217.22	217.14
Length of net (meters)	330.00	363.50	356.74	354.74	363.11	359.71
Number of crew (incl. Cap.)	20.67	17.67	17.30	17.38	13.56	13.14
Number of trips per month	20.00	20.00	20.63	20.55	22.44	22.71
Total days at sea per month	20.00	21.00	22.51	22.40	23.11	23.00
Hauls per day per month	3.67	3.50	4.19	4.12	4.33	4.57
Days per trip per month	1	1.05	1.11	1.11	1.03	1.01
Distance from shore (miles)	10	10.33	17.60	18.00	32.22	32.14
Expected life of hull (years)	16.67 (16-18)	15.50 (10-18)	16.09 (9-25)	16.31 (9-25)	18.0 (16-20)	18.0 (16-20)
Captain's experience (years)	14.67 (9-20)	14.33 (8-25)	15.30 (5-36)	15.74 (5-36)	21.33 (10-37)	21.00 (10-37)
No. of captain with training	2	2	17	18	4	3
No. of captain w/out training	1	4	26	24	5	4
No. of owner-non-operators	0	0	10	10	1	1
No. of owner-operators	0	1	14	14	5	4
No. of non-owner-operators	3	5	19	18	3	2
No. of Chinese captains	0	3	28	26	5	4
No. of Malay captains	3	3	15	16	4	3
Family size of captain	6.33 (4-8)	7.67 (4-12)	8.95 (3-15)	8.83 (3-15)	8.67 (6-12)	9.28 (7-12)
Species abundance (CPUE):						
Hardtail scad	97.16	65.85	125.71	104.01	111.14	75.27
Selar scad	68.61	45.69	65.20	51.32	41.94	32.09
Tuna	51.56	54.48	96.33	73.87	100.59	86.87
Indian mackerel	221.25	168.25	240.98	186.20	188.77	168.81
Y. S. Trevally	50.11	62.37	92.02	73.49	117.44	82.17
Round scad	203.47	134.55	132.24	110.37	119.34	110.14
Lolong	77.78	60.75	67.89	50.91	51.18	48.87
Sardine	193.90	151.87	138.03	110.34	122.36	99.89
Mixed species	22.53	14.30	31.51	24.75	41.16	37.33
Output technical efficiency	1.00 (1.00-1.00)	1.11(1.00-1.17)	1.02 (1.00-1.48)	1.19 (1.00-1.89)	1.01 (1.00-1.07)	1.08 (1.00-1.17)
Capacity technical efficiency	1.04 (1.00-1.19)	1.27 (1.12-1.55)	1.03 (1.00-1.51)	1.25 (1.00-1.90)	1.07 (1.00-1.41)	1.15 (1.00-1.29)
CU: observed (%)	96.6 (90.9-100.0)	79.8 (64.5-89.2)	97.4 (66.2- 100.0)	81.3 (52.6-100.0)	94.6 (70.9-100.0)	87.9 (77.5-100.0)
CU: Färe et al. (%)	96.6 (90.9-100)	89.1 (61.5-100.0)	99.0 (87.7- 100.0)	95.6 (61.3-100.0)	95.3 (70.9-100.0)	94.3 (83.3-100.0)
Crew utilization (%)	88.1 (79.0-100.0)	99.0 (80.2-139.0)	101.1 (83.2- 149.5)	103.8 (81.9-203.0)	122.7 (100.0-197.9)	121.4 (99.6-160.0)
Optimal crew size	18.1 (17.0-20.0)	16.91 (15.2-18.2)	17.3 (11.0-30.0)	17.6 (12.0-30.0)	15.9 (11.0-20.0)	15.4 (12.9-20.0)
No. of trips: crew shortage	0	2	6	13	4	4
No.of trips: crew surplus	2	3	6	19	0	1
No.of trips: optimum crew	1	1	31	10	5	2
Days-at-sea utilization (%)	112.5 (100-131.6)	110.9 (99.5-130.9)	100.8 (96.7- 119.1)	101.6 (95.2-136.00)	99.5 (95.5-105.3)	100.1 (95.4-106.5)
Optimal days-at-sea	22.3 (20.0-23.7)	23.1 (21.7-24.0)	22.6 (20.0-26.0)	22.6 (20.0-26.0)	23.0 (20.0-25.0)	23.0 (20.0-25.0)
No.of trips: shortage days	2	4	6	16	1	2
No.of trips: surplus days	0	1	6	16	3	3
No.of trips: optimum days	1	1	31	10	5	2
No. trips: optimum crew & days	1	1	31	9	5	2
No. of observations	3	6	43	42	9	7

[a]Zones are based on nautical miles from shore: (1) Zone 2 > 5 but < 12 miles (2) Zone 3 > to 12 but < 30 miles (3) Zone 4 > 30 miles. Ranges in parentheses. Year is 1988.

In summary, the DEA empirical results, reported in Tables 2-4, indicate: (1) close to full technical efficiency for all three offshore licence zones, measured at both observed output and at full capacity, during the non-monsoon season, and declining during the monsoon; (2) for all three offshore licence zones, close to full CU during the non-monsoon season but somewhat reduced CU during the monsoon season; (3) vessels in Zones 3 and 4 with about the right days at sea during both seasons for full technical efficiency evaluated at full capacity output; (4) vessels in Zone 3 with the right crew size but vessels in Zone 4 somewhat overmanned during both seasons for full technical efficiency evaluated at full capacity output;

and (5), vessels in Zone 2 that should fish fewer days at sea and add crew for both seasons to enhance technical efficiency evaluated at full capacity output.

The high degrees of technical efficiency, CU, and variable input utilization do not appreciably vary by forms of owner-operatorship (Tables 2-4). This constancy across arrangements suggests that moral hazard or principal-agent problems arising from the divorce of ownership and operatorship do not arise.

4. CONCLUDING REMARKS

Malaysia's fisheries policy promoting fishing capacity offshore, including movement from inshore waters has, for the west coast purse seine fleet of Peninsular Malaysia, largely resulted in, and/or coincided with, the desired matching of catch with capacity and with a very high level of technical efficiency. In light of the generally perceived belief (although not universally agreed upon) that offshore resource stocks are not overfished, and in the absence of formal biological resource stock assessments, Malaysia's policy for the west coast purse seine fishery can be viewed as biologically and economically sustainable. Whether the policy was the main motivating impetus behind the high level of technical efficiency and close to full CU cannot be directly ascertained, but at a minimum, the policy did not hinder. The truth probably lies somewhere in between, as a combination of governmental policy and industry responses to biological, governmental, and market conditions. There is also the added bonus that production is technically efficient.

The empirical results of this paper are short-run, conditional upon the existing capital and resource stocks. While at the vessel-level the government policy is largely successful on the west coast given the capital and resource stocks, the fishery as a whole might have excess capacity. The long-run steady-state level capacity can only be assessed with biological estimates of optimum fish stock sizes for the different species and the corresponding annual catch levels (total allowable catches or TACs). If optimal TACs were available by licence zone, the sum of the vessel capacities could be summed and matched with the TACs to provide a measure of excess capacity (Kirkley and Squires, 1999).

Although the broad capacity and overall technical efficiency pictures are about right, the Malaysian government and purse seine industry could, nonetheless, enhance efficiency by some fine-tuning. Government and industry could promote larger crew sizes and fewer days at sea for those purse seine vessels fishing in the licence zone just outside of that reserved for artisanal fishers and could encourage slightly smaller crews for those purse seine vessels fishing farther offshore.

In sum, the policy promoting harvests of offshore waters to efficiently produce fish, provide employment, and more fully utilize natural resource stocks appears to have been satisfied for purse seine vessels and pelagic fish species on the west coast of Peninsular Malaysia. In the absence of evidence to the contrary, the fishery and policy are biologically and economically sustainable.

5. REFERENCES

Bailey, C. 1983. *The Sociology of Production in Rural Malay Society*. Kuala Lumpur: Oxford University Press.

Bailey, C., Dwiponggo, A. & Marahudin, F. 1987. *Indonesian Marine Capture Fisheries*. ICLARM Studies and Reviews 10. Manila: International Centre for Living Aquatic Resources Management, Jakarta, Indonesia: Directorate General of Fisheries, and Marine Fisheries Research Institute, Ministry of Agriculture, 196 pp.

Bailey, C. 1997. Lessons from Indonesia's 1980 Trawler Ban. *Marine Policy*, 21(3): pp. 225-235.

Berndt, E.R. 1990. Comment to 'The Measurement of Capital' by Charles R. Hulten. In Ernst R. Berndt and Jack E. Triplett, eds., Fifty Years of Economic Measurement. *Studies in Income and Wealth Volume 54*, National Bureau of Economic Research. University of Chicago Press.

Berndt, E.R. & Fuss, M. 1989. Economic Capacity Utilization and Productivity Measurement for Multiproduct Firms with Multiple Quasi-Fixed Inputs. National Bureau of Economic Research Working Paper No. 2932. Cambridge, Mass.

Charnes, A., Cooper, W.W., Lewin, A.Y. & Seiford, L.M. 1994. *Data Envelopment Analysis: the Theory, the Method and the Process*. Boston: Dordrecht, London: Kluwer Academic press.

Department of Statistics, Government of Malaysia. Various years. *Annual Fisheries Statistics*.

Färe, R., Grosskopf, S. & Kokkelenberg, E.C. 1989. Measuring Plant Capacity, Utilization and Technical Change: A Nonparametric Approach, *International Economic Review*, 30(3): pp. 655-666.

Färe, R., Grosskopf, S. & Lovell, C.A.K. 1994. *Production Frontiers*. Cambridge, United Kingdom: Cambridge University Press.

FAO. 1998. Report of the Technical Working Group on the Management of Fishing Capacity. La Jolla, United States, 15-18 April 1998. *FAO Fisheries Report* No. 586. Rome, FAO.

Firth, R. 1975. *Malay Fishermen: Their Peasant Economy*, second edition, New York: Norton.

Indo-Pacific Fishery Commission (IPFC) 1994. *Socio-Economic Issues in Coastal Fisheries Management*, Bangkok.

Ishak, H.O., Noh, K.M., Abdullah, N.M.R. & Kuperan, K. 1991. Malaysian Fisheries Policy: Search for New Grounds. *Marine Policy*, 16(6): pp. 438-450.

Ishak, H.O. 1994. Market Power, Vertical Linkages and Government Policy*: The Malaysian Fish Industry*, Singapore: South-East Asian Social Science Monographs, Oxford University Press.

Jahara, Y. 1988. Fishery Management and Regulation in Peninsular Malaysia: Issues and Constraints, *Marine Resource Economics*, 5: pp. 83-98.

Johansen, L. 1968. Production Functions and the Concept of Capacity, In *Recherches récentes sur la fonction de production*. Namur: Centre d'Etudes et de la Recherche Universitaire de Namur.

Kirkley, J.E. & Squire, D. 1999. Measuring Capacity and Capacity Utilization in Fisheries. In: Gréboval, D (Ed). Managing Fishing Capacity: Selected Papers on Underlying Concepts and Issues. *FAO Fisheries Technical Paper* No 386. pp. 75-200. Rome, FAO.

Klein, L.R. & Long, V. 1973. Capacity Utilization: Concept, Measurement, and Recent Estimates, *Brookings Papers on Economic Activity*, 3: pp. 743-756.

Klein, L.R. & Summers, R. 1966. *The Wharton Index of Capacity Utilization*. Philadelphia: University of Pennsylvania, Studies in Quantitative Economics, 94 pp.

Kurien, J. 1996. *Towards a New Agenda for Sustainable Small-Scale Fisheries Development*. Kerala, India: South Indian Federation of Fishermen Societies.

Lawson, R. 1984. *Economics of Fisheries Development*. New York: Praeger Publishers.

Majid, S.A. 1985. Controlling Fishing Effort: Malaysia's Experience and Problems. FAO *Fisheries Technical Report* 289, Supplement 3. Rome, FAO.

Malaysia, Government of. 1991. *Sixth Malaysia Plan*. Kuala Lumpur.

McElroy, J. 1991. The Java Sea Purse Seine Fishery: A Modern-Day 'Tragedy of the Commons'? *Marine Policy*, 15(4): pp. 255-271.

Meyen, W. 1989. Fisheries Development Resources Depletion and Political Mobilization in Kerala: The Problem of Alternatives, *Development and Change*, 20(4): pp. 735-770.

Mohammed I.H.M.. 1991. National Management of Malaysian Fisheries. *Marine Policy*, 15(1): pp. 2-14.

Morrison, C.J. 1985. Primal and Dual Capacity Utilization: An Application to Productivity Measurement in the United States Automobile Industry. *Journal of Business and Economic Statistics*, 3: pp. 312-324.

Ooi, J.B. 1990. Development Problems of an Open-Access Resource*: The Fisheries of Peninsular Malaysia. Occasional Paper No. 86*. Singapore: Institute of Southeast Asian Studies.

Panayotou, T. 1982. Management Concepts for Small-Scale Fisheries: Economic and Social Aspects, *FAO Fisheries Technical Paper*, No. 228. Rome, FAO.

Panayotou, T. & Jetanavanich, S. 1987. The Economics and Management of Thai Marine Fisheries. *ICLARM Studies and Reviews 14*. Manila: International Centre for Living Aquatic Resources Management, 82 pp.

Pauly, D. 1997. Small-Scale Fisheries in the Tropics: Marginality, Marginalization, and Some Implications for Fisheries Management, in E.K. Pikitch, D.D. Huppert, and M.P. Sissenwine (eds.)*, Global Trends: Fisheries Management. American Fisheries Society Symposium 20*, Bethesda, Maryland.

Platteau, J.P. 1989a. The Dynamics of Fisheries Development in Developing Countries: A General Overview, *Development and Change*, 20: pp. 565-597.

Platteau, J.P. 1989b. Penetration of Capitalism and Persistence of Small-Scale Organizational Forms in Third World Fisheries. *Development and Change*, 20: pp. 621-652.

Richards, L.J. & Schnute, J.T. 1986. An Experimental and Statistical Approach to the Question: Is CPUE An Index of Abundance? *Canadian Journal of Fisheries and Aquatic Sciences*, 43: pp. 1214-1227.

Robinson, M.A. 1976. Reconciling Conflicts Among Economic Interest Groups in Southeast Asian Fisheries. In Klau Tiews, ed., *Fisheries Resources and Their Management in Southeast Asia*. Bonn: Druckerei Heinz Lammerich.

Saharuddin, A.H. 1995. Development and Management of Malaysian Marine Fisheries. *Marine Policy*, 19(2): pp. 115-126.

Segerson, K. & Squires, D. 1994. On the Measurement of Economic Capacity Utilization for Multi-Product Industries. *Journal of Econometrics*, 44: pp. 347-361.

Townsend, R.E. 1990. Entry Restrictions in the Fishery: A Survey of the Evidence. *Land Economics*, 66(4): pp. 359-378.

Vincent, J.R., Rozali, A. & Jahara, Y. 1997. *Marine Fisheries*. Chapter 8 In J.R. Vincent and Rozali Ali, eds., Environment and Development in a Resource-Rich Economy: Malaysia under the New Economic Policy. Cambridge, MA: Harvard University Press for Harvard Institute for International Development.

Wilen, J. 1988. Limited Entry Licensing: A Retrospective Assessment. *Marine Resource Economics*, 5: pp. 313-324.

ASSESSING CAPACITY AND CAPACITY UTILIZATION IN FISHERIES WHEN DATA ARE LIMITED

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Abstract: Excess capacity is globally recognized by resource managers as a major problem for fisheries. Yet, the concept of capacity remains vague, ill-defined, and often ambiguous. Presently, measuring capacity and capacity utilization in fisheries has become more important or of greater public concern than ever because of various national and international agreements or policies to reduce capacity in fisheries throughout the world. In this study, we propose data envelopment analysis (DEA) as one method that may be used to calculate a production-oriented measure of capacity. We conclude that although the DEA approach is limited and does not provide measures of capacity and CU consistent with the long-run optimum scale of operation, it can provide information useful to resource managers concerned with downsizing fleets or matching capacity to resource levels. We illustrate the approach by examining the capacity of ten sea scallop vessels operating between 1987 and 1990. We conclude that the ten vessels had the capability to harvest considerably more than they actually did, and the fleet should be reduced by 68 percent or more if managers desire to match capacity to a recommended sustainable yield of 20 million pounds.

1. INTRODUCTION

The potential for excess capacity has been a long-standing argument to support access controls in fisheries. Simply, in the absence of access controls, firms enter a fishery until it is no longer profitable for other entities to enter. Although this outcome is no different than the long-run competitive equilibrium at which profit is also zero, it is troublesome because of the possibility of technological externalities, excessive harvesting capability, and the potential for economic waste. That is, the resource at any time is finite, and entry can lead to a fleet that is capable of harvesting well in excess of any reasonable sustainable level. Alternatively, production is neither technically efficient nor at minimum cost (i.e. there is economic waste because more resources are used to harvest a given level of output than is actually necessary).

Most recently, Mace (1997), before a World Congress meeting on sustainable fisheries, stated that excess harvesting capacity was the most important problem confronting fishery managers. Representatives from approximately 40 nations, in fact, recognized that excess capacity was such a serious problem that an international study should be undertaken to define and develop measures of capacity and capacity utilization (CU). This international study was sponsored and managed under the auspices of the Food and Agriculture Organization (FAO) and was to be conducted in two phases: (1) development and

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international acceptance of the definitions of capacity and capacity utilization, and (2) the development and acceptance of methods to assess or calculate capacity and CU.

A major reason for the concern is that many nations need to reduce capacity in order to comply with various national and international fishery agreements (e.g. Code of Conduct for Responsible Fisheries). The need to understand and measure capacity is equally important to the United States. The Sustainable Fishing Act of 1996 requires that resources be rebuilt to at least maximum sustainable yield (MSY) levels within a ten-year period (United States Congress, 1996). Under the present United States regulatory regime, the only permissible option for rebuilding many fish stocks is a drastic reduction in fishing activity.

There are three broad options available to United States regulators to reduce fishing activity. One, regulators may impose extremely stringent regulations on fishermen which could even include a moratorium on harvesting activities; the necessary levels of reduction in fishing activity for most fisheries, however, will impose extreme financial hardship and possibly bankruptcy for many vessel owners. Second, regulators may implement either a public or private funded buyback programme to purchase active vessels and reduce capacity. Third, regulators could subsidize the present vessel owners until stocks did rebuild; this last option is not one that has even been considered by regulators or the United States Congress. A fourth option is rights-based strategies such as individual transferable quotas (ITQs); ITQs or similar rights-based strategies (e.g. individual transferable effort programmes), however, are prohibited under the present regulatory regime. It appears that the only viable short-term option is some type of capacity reduction programme such as a vessel buyback. If a buyback programme is to be implemented with the intent of matching harvesting capacity to resource levels, managers must have information about capacity and capacity utilization.

Although there is widespread recognition that capacity in fisheries must be reduced, the term, capacity, remains vague and generally ill-defined when considered for the case of fisheries. The vagueness exists despite a long and rich history of research on capacity in conventional industries and fisheries by economists (e.g. Klein and Summers, 1966; Morrison, 1985a, 1985b and 1986; Berndt and Fuss, 1989; Nelson, 1989; Apostle *et al.*, 1993; Christy, 1996; Augstyn, 1996; Banks, 1997; Valatin [no date]).[7] Between 1996 and 1998, the Food and Agriculture Organization and various nations attempted to define and develop measures of capacity and capacity utilization for fisheries.

In nearly all the FAO-sponsored studies, however, researchers actually attempted to define and develop measures of capital and capital utilization. In a limited number of cases, though, researchers did attempt to develop standardized measures of capacity based on various vessel characteristics and potential catch. The purpose of developing these standardized measures was to facilitate downsizing various fleets in accordance with removing or reducing harvesting capacity (e.g. a 50 gross registered ton vessel constructed of steel and having 400 horsepower equated to a potential harvest of 75 metric tonnes a year).

There are many definitions of capacity. Johansen (1968: p. 52), though, provides a widely accepted and useful definition "*...the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted.*" The Johansen definition is a short-run concept of capacity in

[7] Kirkley and Squires (1999) provide an extensive discussion and listing of various approaches and previous research on capacity and capacity utilization in fisheries.

that there are fixed and variable inputs. Johansen's definition is, nevertheless, equivalent to the FAO general definition of capacity agreed upon by researchers representing forty nations at a Technical Working Group meeting held at La Jolla, California in April 1998. Alternatively, the FAO definition states that capacity output is the maximum output that could be produced given full and efficient utilization of the variable and fixed factors of production. The Johansen and FAO definitions are also equivalent to the definition offered by Christy (1996): The capacity of an individual fishing unit is a measure of the quantity of fish that it can take, assuming there are no limits on the yield from the stock, or stocks. Fleet capacity is the sum of the capacities of all fishing units in the fishery. Presently, a United States Congressional Task Force on capacity and subsidies in fisheries is using a nearly identical definition to that provided by Johansen, FAO, and Christy.

The Christy (1996), FAO (1998), United States Congressional Task Force, and Johansen (1968) definitions are all primal based in that they do not directly assess capacity from a cost or economic framework. The definitions may be viewed as technological-engineering definitions (Kirkley and Squires, 1999). In contrast to the primal-based definition, Morrison (1985a, 1985b, 1986), Nelson (1989), and Berndt and Fuss (1989) offer an economic based definition of capacity. The economic concept of capacity is defined as the output level coinciding with an equilibrium between the minimum long-run and short-run average cost curves. Berndt and Fuss (1989), however, have shown that there may be an indeterminancy problem when there are multiple products and more than one fixed or quasi-fixed factor of production. Thus, empirical implementation of the economic definition often requires aggregation over outputs and multiple fixed factors. More recently, Färe and Grosskopf (1998) offered an approach that may avoid the indeterminancy problem by using a dual data envelopment approach to measure or assess capacity.

While the approaches of Färe and Grosskopf (1998), Morrison (1986), Berndt and Fuss (1989), and Nelson (1989) are all useful and capable of providing important information, they are not likely to be very useful for assessing capacity in fisheries. Simply, the data necessary for such measures are typically unavailable for fisheries. Moreover, resource managers appear to be more interested in a primal based approach; an approach which is more consistent with the types of data typically available on fisheries and the requirements of various national and international policies (e.g. the Sustainable Fishing Act of the United States). If any type of guidance for capacity reduction programmes is to be provided to resource managers, it is a likely that such guidance will have to be based on a primal approach.

Given the widespread recognition that excess capacity is a major problem for fisheries, it is quite alarming that there has been little work to develop or adopt existing empirical methods to determine capacity, capacity utilization, and input utilization in fisheries. Two approaches which may be used are the peak-to-peak approach of Klein and Summers (1966) and the DEA approach of Färe (1984), Färe *et al.* (1989), and Färe *et al.* (1994). Both approaches, however, restrict capacity measures to the short to intermediate time period (i.e. only variable inputs may be changed). The peak-to-peak approach was used by Ballard and Roberts (1977) to examine capacity utilization rates of fishing vessels in ten major Pacific coast fisheries. The peak-to-peak approach, although having widespread applicability in the examination of capacity in United States industries, fails to offer guidance on technical efficiency and optimum input usage. In contrast, the DEA approach of Färe *et al.* (1989) explicitly eliminates any bias caused by failing to adjust the capacity and capacity utilization rates for inefficiency (i.e. CU with respect to the frontier).

The Färe *et al.* (1989) approach is based on solving an output-oriented linear programming (LP) problem. The solution to the LP problem of Färe *et al.* (1989) provides measures of technical efficiency corresponding to capacity output. The Färe *et al.* approach also can be used to obtain information about optimum input usage or input utilization rates. In addition, the Färe *et al.* (1989) or DEA approach easily accommodates multiple products and multiple fixed factors; this is not the case for the conventional economic-based assessment methods.

A third possible approach is the one-stage stochastic frontier approach of Battese and Coelli (1995). With appropriate modification of Battese and Coelli's (1995) approach, it may be possible to determine the maximum output corresponding to technically efficient production and conditional on the most binding fixed factor of production. We do not further consider the stochastic frontier approach of Battese and Coelli (1995), however, because the necessary procedures have not been formally developed and the approach cannot accommodate multiple outputs, which are common in fisheries.

In this paper, we provide a review of the DEA approach of Färe *et al.* (1989) and Färe *et al.* (1994). Using a panel data set on ten scallop vessels operating between 1987 and 1990, we examine capacity, capacity utilization, and input utilization. We determine that the sample fleet had considerable excess capacity relative to what they harvested. Alternatively, the fleet had the capability to harvest considerably more scallops than it actually did. We also suggest that the fleet operated at levels that were sub-optimal relative to full capacity. That is, the number of days at sea and crew size per trip was sub-optimal. Last, we show that for trips with high resource abundance, the fixed factors rather than the resource abundance actually limited production.

2. THE DEA FRAMEWORK

Following Färe *et al.* (1989), let there be $j = 1,...,J$ observations or firms in an industry producing a scalar output $u^j \in R_+$ by using a vector of inputs $x^j \in R_+^N$. We also assume that for each n, $\sum_{j=1}^{J} x_n^j > 0$, and for each j, $\sum_{n=1}^{N} x_n^j > 0$. The first assumption states that each input is used by some firm. The second assumption indicates that each firms uses some input. A remaining assumption is that each firm produces some output, $u^j > 0$ for all j.

In order to calculate Johansen's notion of capacity, Färe *et al.* (1989, 1994) propose the following data envelopment analysis (DEA) problem:

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

The variable factors are denoted by $\hat{\alpha}$ and the fixed factors are denoted by α. Problem (1) enables full utilization of the variable inputs and constrains output with the fixed factors. Moreover, λ is a measure of the ratio of the optimal use of the variable inputs (Färe *et al.*, 1989, 1994). Problem (1) imposes constant returns to scale, but it is a simple matter to impose variable returns to scale (i.e. variable returns to scale requires the constraint $\sum_{j=1}^{J} z_j = 1$.

The parameter θ is the reciprocal of an output distance function and is a measure of technical efficiency relative to capacity production, $\theta \geq 1.0$. It provides a measure of the possible increase in output if firms operate efficiently, and their production is not limited by the availability of the variable factors of production (e.g. a value of 1.50 indicates that the capacity output equals 1.5 times the current observed output).

If we also desire to calculate capacity utilization (CU), we need to consider the possibility that the commonly used measure, observed output divided by capacity output, may be downward biased (Färe *et al.*, 1989). The possibility for the conventional measure of CU to be downward biased is because the numerator in the traditional CU measure, observed output, may be inefficiently produced. Färe *et al.* (1989) demonstrate that an unbiased measure of CU may be obtained by dividing an output-oriented measure of technical efficiency corresponding to observed variable and fixed factor input usage by the technical efficiency measure corresponding to capacity output (i.e. the solution to problem (1)).

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

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

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

Problems (1) and (2) are typical DEA problems which provide measures of technical efficiency from an output orientation (i.e. inputs are held constant and outputs are allowed to vary). Problem (1) provides a measure of TE, θ_1, which corresponds to full capacity production. Problem (2) provides a measure of TE, θ_2, which corresponds to technically efficient production given the usage of the variable inputs. The ratio of the two θs, θ_2/θ_1, is an unbiased measure of capacity utilization (Färe *et al.* 1989).

Solutions to problems (1) and (2) provide estimates of technical efficiency, capacity, capacity utilization, and optimal input utilization relative to a best practice frontier. The solutions are not indicative of absolute efficiency and capacity. Based on the solutions, we may only conclude that an observation depicts more or less efficient production or capacity relative to another observation (e.g. we find that using an identical level of fixed and variable inputs, one fishing vessel has a higher production than that of another fishing vessel; we may conclude that the vessel with the higher production was more technically efficiency than was the vessel with the lower production).

The Färe *et al.* (1989) approach is also limited because it provides only a short-run measure of capacity (i.e. capacity is calculated conditional on fixed factors). It is possible, however, to impose constant returns to scale and determine the optimal levels of the fixed factors that would approximately correspond to the long-run level of capacity. Alternatively, it is possible to assess the optimum levels of the fixed and variable factors that correspond to scale efficiency and use those levels as benchmarks for assessing capacity in the long-run. We defer these other possible approaches to future research because there is no comparative basis upon which to evaluate the corresponding results. More important, though, is that even if the approach cannot provide measures of capacity and capacity utilization for the long-run, it can still provide measures useful for determining the potential capacity removed with vessel reduction programmes. Also, it is highly probable that any capacity reduction programme implemented by resource managers would have additional constraints on the existing vessels such that capacity would not be allowed to increase in a short to intermediate time period.

In the case of fisheries, there is a question about whether or not resource levels should be included. By including resources, it is possible to calculate capacity conditional on resource levels. A conditional capacity is not, however, the notion of capacity which primarily interests resource managers. Managers typically want to know what is the potential maximum catch if resource conditions were not limiting; this measure provides a benchmark for evaluating excess harvesting capacity. There also remains an issue about whether or not resource levels, if they are to be included, should be included as nondiscretionary inputs rather than discretionary inputs; captains have little control of resource levels other than by area selection.

Other issues that could be considered with the DEA framework of Färe *et al*. (1989) include calculation of capacity output under various by-catch mitigation programs or habitat restoration policies. Adding by-catch to the problem simply requires reformulating the problem such that by-catch is treated as an undesirable output; this requires weak sub-vector disposability constraints. Alternatively, the problem may be specified in terms of directional distance functions.

3. THE UNITED STATES NORTHWEST ATLANTIC SEA SCALLOP FISHERY

The United States northwest Atlantic sea scallop, *Placopecten magellanicus*, fishery was traditionally one of the most important United States fisheries in terms of ex-vessel revenues. Prior to the imposition of extremely restrictive regulations in 1994 and 1995, only five to six species generated ex-vessel revenues higher than those associated with sea scallops. In 1995, the ex-vessel value of sea scallops ranked ninth relative to other species.

The northwest Atlantic sea scallop is harvested primarily from Georges Bank and various Mid-Atlantic resource areas. The primary gear type is the dredge. Small quantities of sea scallops, however, are harvested with a trawl net. The primary landed product form is meats. Only small quantities of sea scallops are landed in the shell. The fleet is mostly comprised of vessels which are 51 or more gross registered tonnes in size. Crew sizes per trip, prior to the more restrictive regulations of 1994 and 1995, were typically between nine and 12 individuals. The number of days at sea per trip, also prior to the more restrictive regulations of 1994 and 1995, varied by homeport. Vessels from New England and New Jersey ports typically made 11 to 14 day trips. Vessels from the more southern areas of the Mid-Atlantic (Virginia and North Carolina) typically had trips between 15 and 20 days.

The sea scallop fishery has been managed by the New England Fishery Management Council (NEFMC) since 1983. Prior to 1994, scallops were managed mostly by age-at-entry restrictions. Shucked meats were restricted to a maximum count of 33 meats per pound (MPP) plus a ten percent tolerance; trips in which the average meat count exceeded 36.3 were cited as being in violation of the meat count regulations. Trips for which 40 or more scallops out of a sample of 400 scallops landed in the shell were less than three and a half inches were cited as being in violation of the shell-height regulation.

The meat count regulations were considered to be inadequate to control overfishing (Kirkley and Du Paul, 1993). Moreover, the regulations did not adequately control access or the potential excess capacity. Crew could and did mix scallop meats of different sizes to comply with the meat count regulation; it only required a few large scallop meats to be mixed with a lot of small meats to comply with the regulations. Crew also soaked meats in water to increase their size, and thereby, also contributed to a quality problem. In 1994, the NEFMC imposed new regulations that restricted the number of days at sea per vessel per year. In addition, crew size was restricted to seven individuals; prior to these new regulations, there were no constraints on crew size and vessels routinely had nine to 12 individuals. Other regulations were implemented to affect the catchability of small scallops (e.g. the rings of dredges were increased from three to three and a half inches; rings could not be linked by more than one link; and chafing gear was prohibited).

It appeared that the new regulations would be adequate to rebuild the stock and allow most of the existing vessels to remain in the fleet. The Sustainable Fishing Act (SFA), however, was implemented, and it appeared that the new regulations would not be adequate to achieve the objectives of the SFA. In fact, preliminary analysis indicated that the number of days per vessel per year would have to be reduced to between 35 and 75 days. Analysis by Kirkley and DuPaul (1993) and Edwards (1997), however, revealed that the number of days required for a vessel to break even ranged from 140 to 175 days. The only apparent viable option was to reduce the number of vessels or capacity and reallocate the days at sea among the remaining vessels. There is thus a strong urgency to develop measure of capacity for the northwest Atlantic sea scallop fleet.

4. DATA AND EMPIRICAL STRUCTURE FOR ASSESSING CAPACITY IN THE SCALLOP FISHERY

In this section, we discuss the data and potential problems of the data. We also outline the structure of analysis and reasons for selecting the structure.

4.1 Data

Using a panel data set on ten scallop vessels, we calculate capacity, capacity utilization, and input utilization with and without resource levels. Our primary purpose of calculating capacity is to demonstrate one approach that may be easily used to assess capacity in fisheries, particularly when economic data are not available which is quite typical of fisheries. Our calculations are derived under variable returns to scale. We treat resource abundance as a discretionary input. The assumption that resource abundance is discretionary is questionable because captains do not have control of the resource levels. Captains do, however, have control over the selection of fishing areas and scallops are relatively immobile or stationary relative to geographic areas.

The panel data set contains observations on output and input levels, resource abundance, and characteristics indicative of the fixed factors. The data set is for the years 1987 through 1990 and corresponds to trip level activity. Data were directly obtained from settlement sheets provided by vessel owners. Output is measured in terms of pounds of sea scallop meats landed per trip. We have two variable inputs days at sea and crew size per trip. The fixed factors are vessel gross registered tonnage (GRT), engine horsepower, and dredge width in feet. Stock abundance is treated as an input even though it is more indicative of the state of technology. Stock abundance measures are fishery dependent, but were obtained from previous monitoring programmes in which vessels made one tow at the end of a trip in order to provide information about resource abundance, state of reproduction, and age-class distribution (Kirkley and DuPaul, 1989; Kirkley *et al.*, 1995, 1998). Stock abundance is measured in terms of the number of baskets per standard tow.

The inputs are not typical of those considered in analyses of other industries (e.g. fuel and capital services). The inputs are, however, consistent with the way managers and fishery researchers typically consider the inputs for fisheries. Moreover, the inputs are those that have often been subject to fisheries regulation (e.g. allowable days at sea or maximum number of crew). Days at sea reflects capital, energy, materials, and labour. It may be considered as an intermediate output of the first stage of a nonseparable two-stage technology (Pollak and Wales, 1987). Crew size is a stock and not a flow variable, but the services may be assumed to be proportional to total crew size.

4.2 Empirical structure of analysis

We initially calculate technical efficiency corresponding to full capacity. We solve problem (1) with and without resource abundance included. The solution to problem (1) without resource abundance provides a measure of the potential output that could be possible if only the fixed factors were constraining production. The fixed-factor conditional capacity measure provides a reference for assessing whether or not the vessel had excess harvesting capacity relative to what was actually harvested or could have been efficiently harvested. Next, we again solve problem (1), but subject to constraints on resource abundance. The solution to problem (1), with resource abundance included, provides a measure of capacity conditional on the fixed factors and resource abundance.

We next compare the two calculated capacity outputs to determine whether or not resource abundance or the fixed factors constrained output. Because of the nature of linear programming, adding additional constraints should reduce the value of the solution if the additional constraints are binding. If the two measures are equal, we can determine that the fixed factors and not the resource level constrained output.

The approach of Färe *et al.* (1989, 1994) provides useful information about capacity output per trip, but it does not provide a framework for assessing the actual capacity over a year for a fishing fleet. This limitation, however, is not because of the method, but rather because of fishing practices. In previous studies by Färe *et al.* (1989), capacity and CU were assessed using annual production information for industries that would be expected to operate a relatively fixed number of days per year (e.g. electric utilities). Unlike many conventional industries that operate between 260 and 365 days a year, vessels do not always make the same number of trips or fish the same number of days a year. In fact, even the length of trips may be quite variable because of economic conditions or unforeseen events such as weather and medical and mechanical emergencies at sea.

Table 1. Annual production, days at sea, and average days and crew size per trip of ten mid-Atlantic sea scallop vessels

		1987	1988	1989	1990
Vessel 1:	Production	200 775	178 034	146 944	163 323
	Days at sea	249	262	247	263
	Days per trip	16.60	14.55	14.53	20.23
	Crew per trip	10.47	9.67	9.47	9.15
Vessel 2:[a]	Production	101 656			
	Days at sea	148			
	Days per trip	9.87			
	Crew per trip	11.60			
Vessel 3:	Production	150 832	124 401	117 993	117 707
	Days at sea	242	245	253	254
	Days per trip	10.52	16.33	15.81	15.88
	Crew per trip	10.91	9.93	9.25	8.68
Vessel 4:	Production	81 794	156 419	153 199	171 494
	Days at sea	112	242	267	285
	Days per trip	14.00	15.13	16.69	20.35
	Crew per trip	9.75	10.19	10.44	9.43
Vessel 5:	Production	143 150	141192	129 642	129 389
	Days at sea	228	262	265	268
	Days per trip	14.25	14.56	13.95	19.14
	Crew per trip	10.25	9.61	9.47	9.14
Vessel 6:	Production	140 533	165 499	129 453	137541
	Days at sea	190	267	254	246
	Days per trip	11.88	16.69	14.11	17.57
	Crew per trip	9.75	9.13	9.22	9.64
Vessel 7:	Production	211 532	164 037	143 554	160 576
	Days at sea	260	263	253	259
	Days per trip	17.33	17.53	16.87	18.50
	Crew per trip	9.67	9.07	8.73	8.71
Vessel 8:	Production	164 566	140 333	127 165	136 992
	Days at sea	228	254	251	243
	Days per trip	14.25	16.93	15.69	16.20
	Crew per trip	10.13	9.33	9.56	8.13
Vessel 9:	Production	152 841	142 949	114 039	138 701
	Days at sea	198	264	270	238
	Days per trip	16.50	16.50	14.21	14.88
	Crew per trip	10.33	9.50	9.89	9.13
Vessel 10:	Production	128 031	139 334	98 500	152 797
	Days at sea	186	271	216	267
	Days per trip	12.40	15.06	14.40	16.69
	Crew per trip	10.20	10.11	9.47	8.40

[a] Vessel Number 2 left the fishery in October, 1987.

In 1987, the average total number of days per vessel per year equalled 223 (Table 1). In 1988, the average total number of days per vessel increased to 259; the average total number of days declined to 153 in 1989. In 1990, the average total number again increased 258 days per vessel per year. Between 1987 and 1990, the actual number of days per year per vessel varied from a low of 112 for vessel #4 in 1987 to a high of 285 days for the same vessel in 1990. The number of days at sea per trip ranged from a low of three to a high of 26.

Crew size per trip ranged from a low of seven to a high of 13. Most of the vessels took between 12 and 18 trips per year.

The actual number of days varies in accordance with a wide variety of factors (e.g. weather, regulations, family ties, economic factors such as prices and costs, availability of labour, and numerous other possible factors). The ten vessels are relatively homogeneous in terms of characteristics, and they all faced identical economic conditions such as output prices and factor costs. They all fished the same areas and thus encountered similar weather conditions. What are some possible reasons for the differences in the number of days per year per vessel?

In some cases, differences may be attributed to unscheduled maintenance (e.g. blown engine, broken winches, faulty electronics, etc.). In other cases, differences may reflect the preferences of captains; some captains are willing to work only so many days a year (Gautam *et al.*, 1995). In other cases, economic and social factors may explain reasons for the differences. The only way to accurately determine the maximum potential number of days is to conduct very extensive economic and social surveys and analysis.

While detailed economic and social surveys and analyses may provide the information necessary for adequately determining the potential maximum number of days per year, such surveys and studies are costly and would likely lead to decision rules for determining the number of days rather than upper limits on the potential number of days (e.g. in years when abundance and output prices are high and fuel prices are low, vessel operators may decide to fish 260 to 280 days a year). Moreover, management agencies are unlikely to wait until such surveys and analyses have been completed before implementing capacity reduction programmes. In the interim, and based strictly on empirical observation, it is suggested that capacity output be determined based on two limits: (1) the observed maximum number of days per year per vessel; and (2) the average number of days per vessel per year.

In our panel data set, the observed maximum number of days was 285 which occurred in 1990 for vessel #4. Given the relatively homogeneity of vessel characteristics, we assume that all vessels could operate at least 285 days a year in each year. Based on the optimum days at sea per trip per vessel, we calculate the capacity output for each year by multiplying the capacity output per trip per vessel times the number of trips which could be taken using 285 days at sea per year and the optimum number of days per trip subject to resource and no resource constraints.

Our calculation of capacity output subject to resource conditions is somewhat complicated. In addition to incorporating an upper limit on the total number of days a year a vessel may be at sea, it is also necessary to incorporate limits on the number of days a vessel may fish within a shorter interval of time (e.g. if a vessel is already working 28 to 30 days a month, we cannot assess capacity by allowing another trip in that month). Alternatively, it becomes necessary to consider the possible reorganization of fishing practices (e.g. taking trips in different months or by determining whether or not it would have been possible for a vessel operator to take another trip within a given month).

Initially, the assessment of capacity output is restricted to those observations having the highest capacity output (i.e. data are sorted by boat capacity output in descending order). The optimal number of days are summed over that time period and compared to the maximum number of days. If the total number of optimal days exceeds 285, trips of optimal length and minimum capacity output are removed from the analysis until the total number of days equals 285. If the total number of optimal days is less than 285, trips of optimal length are added to the analysis until the total days at sea equals 285; the additional trips are added only to those periods for which it actually would have been possible for the vessel to have made a trip. The total number of optimal days at sea per trip per vessel per year may not exactly equal 285 for all vessels because of the use of empirically determined optimal days per trip (e.g. a vessel operator could take one more trip of 18 days and realize the capacity output, but that 18 day trip might cause the total number of optimal days to equal 287).

The average number of days per year per vessel between 1987 and 1990 equalled 248.25 days. We thus use 248.25 days and the optimum number of days for each vessel to calculate capacity output with and without resource constraints. The calculation of capacity output with resource constraints subject to an upper limit on days equal to the average number of days is done using the same procedures as stated in the previous paragraph.

We also calculate technical efficiency based on the solutions to problem (2) with resources included. This provides a measure of technical efficiency and the potential output that could be produced if production was efficient given different levels of resource abundance (i.e. the potential maximum output conditional on variable and fixed factor levels and resource abundance). It also provides the required numerator, θ_2, for calculating capacity utilization (i.e. $CU = \theta_2/\theta_1$).

5. CAPACITY, CAPACITY UTILIZATION, AND INPUT UTILIZATION IN THE SEA SCALLOP FISHERY

In the following section, the empirical results and analysis are presented. We initially present and discuss the empirical measures of capacity. We next discuss input utilization levels relative to the full capacity output level. We also provide a discussion of the need to consider resource abundance when calculating capacity. Last, we conclude with a discussion of capacity utilization.

5.1 Capacity

Examination of the solutions to the various DEA problems reveals that the fleet did have the capability to harvest considerably more than what was actually harvested between 1987 and 1990. In 1987, the fleet landed 1.48 million pounds (Table 2). Had the vessels efficiently used their variable inputs (problem 2), the catch could have been approximately 2.08 million pounds. If the fleet had operated at full capacity in 1987 over 285 days, but subject to resource limitations, it could have harvested 3.08 million pounds. Alternatively, if the fleet had operated at full capacity subject to resource limitations, but at the mean number of days of 248.25, the fleet had the potential to harvest 2.73 million pounds. If the fleet had operated at full capacity without resource limitations, but spent 285 days at sea, it had the capacity to harvest 3.48 million pounds. Operating at the mean number of total days per year per vessel of 248.25 and without resource limitations, the fleet had the potential to harvest 3.01 million pounds.

Overall, if vessels had operated efficiently they could have increased their total production of scallop meats by approximately 50.8 percent between 1987 and 1990. Improvements in just technical efficiency, given resource levels, could have increased production to 37.5 percent of capacity output in 1987, 62.6 percent in 1988, 38.0 percent in 1989, and 46.7 percent in 1990. Operating at the optimum level of days at sea and crew size and over 285 days, subject to resource conditions, would have allowed production to increase by another 39.9 percent between 1987 and 1990.

Presently, there are approximately 175 full-time vessels operating in the northwest Atlantic sea scallop fishery. In 1996, there were 82 vessels of the same size class (Tonnage class III which is 51 to 150 gross registered tonnes (GRT)) as those of the panel data set operating in the fishery. There were 132 vessels of the next size class (> 150 GRT) operating in the fishery. There were 120 vessels of the smallest documented size class (5 to 50 GRT). The long-term potential catch has been estimated to equal approximately 29.3 million pounds of meats (Northeast Fisheries Science Center, 1998). Recent information by a group of stock assessment scientists charged with defining allowable harvests and the levels of nominal catch corresponding to overfishing, however, suggests a sustainable harvest of approximately 20 million pounds per year (NEFSC, 1997). If only the 82 vessels are considered, they have a potential capacity output of approximately 29 million pounds if allowed to operate 285 days a year. If all tonnage class III and IV vessels are considered, they have a potential capacity output well in excess of 76.7 million pounds.[8] There should be little doubt that the sea scallop fishery does, in fact, have substantial excess harvesting capacity relative to proposed long-term or sustainable yields.

Table 2. Average performance and input usage, technical efficiency, and potential capacity output

Variable	1987	1988	1989	1990
Average catch per trip	9 773	9 199	7 685	9 913
Average stock abundance per trip	3.31	2.81	2.43	2.70
Average technical efficiency per trip	1.74	1.96	2.55	1.81
Average capacity efficiency with stock abundance	3.94	3.39	6.50	4.43
Average capacity efficiency without stock abundance	5.29	3.94	7.98	5.30
Average output per trip-technically efficient production	13 770	15 098	13 744	14 675
Average output per trip ⅛apacity with resource levels	20 135	20 332	19 414	19 722
Average output per trip-capacity without resource levels	23 061	23 260	23 260	23 260
Average days per trip	13.52	15.85	15.07	17.60
Optimal days per trip (with stock)	18.76	19.14	18.97	19.15
Optimal days per trip (without stock)	19.02	19.02	19.02	19.02
Average crew per trip	10.36	9.63	9.51	8.92
Optimal crew per trip (with stock)	11.46	11.22	11.00	11.11
Optimal crew per trip (without stock)	12.99	12.99	13.04	13.07
Total actual catch (million pounds)	1.48	1.35	1.16	1.30
Potential catch (million pounds) ffechnically efficient[a]	2.08	2.22	1.73	1.94
Potential catch (million pounds) —apacity with stock[b]	3.08	2.74	2.66	2.67
Potential catch (million pounds) Capacity without stock[c]	3.46	3.13	3.13	3.13
Potential catch (million pounds) Capacity with stock[d]	2.73	2.41	2.34	2.36
Potential catch (million pounds) Capacity without stock[e]	3.01	2.72	2.72	2.72

[a] The fleet output if vessels operated efficiently using the same level of inputs. [b] The fleet output if the vessels operated efficiently and at full capacity (285 days) given resource levels. [c] The fleet output if the vessels operated efficiently and at full capacity (285 days) without resource limits. [d] The fleet output if the vessels operated efficiently and at full capacity (248.25 days) given resource levels. [e] The fleet output if the vessels operated efficiently and at full capacity (248.25 days) without resource limits.

[8] The estimate of fleet capacity is based on the assumption that capacity output for tonnage class III vessels equals the capacity output for tonnage class IV and all vessels fish 285 days a year. Our estimate is likely to be substantially downward biased given that tonnage class IV vessels likely have considerably more capacity.

5.2 Full capacity utilization of inputs

The average actual catch, number of days, and crew size per trip in 1987 were 9773 pounds, 13.52 days, and 10.36 crew in 1987. Results suggest that the average optimum number of days and crew per trip should have been 19.02 and 18.76 days and 13.02 and 11.46 crew without and with stock abundance included in the analysis.[9] In 1987, 51 out of 151 trips had more than 18 days at sea, while 72 trips had crew sizes larger than or equal to 11 individuals. If the number of trips with days less than ten are eliminated from the average, the average number of days per trip increases to 17.36; 92 percent of the vessels had trips longer than ten days in 1987. The corresponding average capacity output, constrained only by the fixed factors, per trip in 1987 is estimated to equal 23 061 pounds of scallop meats. If we consider the potential output with respect to only improvements in technical efficiency, but using the same level of inputs as observed, the potential output per trip is estimated to equal 13 770 pounds. The potential capacity output per trip, subject to resource constraints, is estimated to equal 20 135 pounds.

A more detailed examination of the full capacity utilization of days at sea and crew size per trip reveals that very few trips operated at the full capacity utilization levels between 1987 and 1990 (Table 3). In 1987, only seven trips, conditional on resource levels, had the full capacity utilization number of days and optimum crew size. With respect to the full capacity

Table 3. Number of trips with full utilization levels of days at sea and crew size

	1987	1988	1989	1990
With Resource:[a]				
Observed Days = Optimum Days	17	22	15	15
Observed Crew = Optimum Crew	12	2	5	3
Both Optimum	7	0	2	3
Without Resource:[b]				
Observed Days = Optimum Days	18	30	19	19
Observed Crew = Optimum Crew	0	1	0	0
Both Optimum	9	2	0	2
Number of Trips for which[c]				
18 ≤ Observed Days ≤ 20	50	68	49	60
11 ≤ Crew Size ≤ 13	55	22	29	9
Total Number of Trips	151	147	151	132

[a] With resource abundance included in the analysis of capacity, 552 observations had a calculated optimum number of days between 18 and 20, and 444 observations had a calculation optimum crew size between 11 and 13. [b] Without resource abundance, 581 observations had a calculated optimum number of days between 18 and 20, but only 286 observations had a calculated optimum crew size between 11 and 13. [c] Eighteen to twenty days represents the approximate range of the full capacity number of days, and 11 to 13 crew represents the range of the full capacity crew size.

level of days at sea and crew, without resource limitations, zero trips had the optimum levels. With respect to only the optimum days at sea, 39.1 percent of all trips between 1987 and 1990 had days at sea within plus or minus one day of the optimum given resource levels. The number of trips within plus or minus one individual of the optimum crew size, given resource

[9] The term optimal level of inputs used in the text actually refers to the input usage at maximum potential capacity (Fare *et al.*, 1989).

conditions, was only 22 percent between 1987 and 1990. With respect to the full capacity output without resource constraints, only 14.8 and 2.2 percent of all trips between 1987 and 1990 had, respectively, the optimum days and crew size.

We also found differences in the various potential output and optimum input levels over time. This was because of how potential output was calculated, the exit of one vessel in October 1987, and varying resource conditions between 1987 and 1990. Since the analysis was conducted on a per trip basis, the potential output was calculated by multiplying the number of trips times the respective potential output. In 1987, the ten vessels made 151 trips. In 1988, there were only nine vessels and they made a total of 147 trips. The number of trips in 1989 and 1990 were, respectively, 151 and 132. In the calculation of the two capacity outputs, the calculations were always based on the maximum 285 observed days at sea or the average 248.25 days at sea.

5.3 Abundance and capacity

There was a relative consistency between resource abundance and the levels of the potential output under technically efficient production and capacity production conditional on resources levels. Average abundance per trip declined between 1987 and 1989, and the actual and capacity output, conditional on resource abundance, also declined. Between 1987 and 1990, there also was some apparent substitution between days at sea and crew size. The number of days per trip increased while the crew size decreased (e.g. the average number of days and crew size per trip in 1987, respectively, equalled 13.52 and 10.36; in 1990, the average number of days and crew size per trip, respectively, equalled 17.60 and 8.92). Reasons for the changes may be related to numerous factors which are not considered in the analysis (e.g. an increase in the abundance of larger scallops might motivate captains to increase their days at sea per trip, but also to decrease the crew size since less crew would be needed to shuck large scallops).

What about the possibility that the controllable fixed factors rather than resource abundance constrained capacity output? Out of a total of 581 trips made by the ten vessels between 1987 and 1990, only 25 trips were not constrained by resource conditions. Alternatively, the potential capacity output was constrained by resource levels for 556 trips. Those trips for which the potential capacity output conditional on resource abundance equalled the potential capacity output without resource abundance were associated with very high stock levels. The mean stock abundance index for trips in which the capacity output conditional on resource levels equalled the capacity output without resource abundance was 5.37 baskets per tow; the corresponding range was 4.26 to 6.85 baskets per tow. For those trips for which the capacity outputs were not equal, the mean stock abundance index was 2.70 baskets per tow, and the corresponding range was 0.28 to 4.25 baskets. The largest number of trips for which resource abundance would not constrain output occurred in 1987. In 1987, the capacity output for 23 trips would not have been constrained by resource abundance. The potential capacity output for all trips in 1988 would have been constrained by resource levels. The potential capacity output for only one trip in 1988 and one trip in 1989 would not have been constrained by resource abundance.

5.4 Capacity utilization

A remaining issue is that of capacity utilization. Färe *et al.* (1989) calculated CU by taking the ratio of the output-oriented technical efficiency measure to the output oriented capacity technical efficiency measure. Given the various possibilities because of the possible number of days at sea and the various possible groupings, we report CU measures on a per vessel basis and for each year between 1987 and 1990 (Table 4). Unfortunately, our CU measures may pose some problems. The calculation of CU was over all observations. If vessel operators actually operated at full capacity utilization, they would require more days than are available in a year. We thus calculate CU conditional our days at sea limits of 285 (maximum observed).[10] We provide measures of CU with and without resource abundance included in the analysis and with respect to the observed and technically efficient output.

Table 4. Average capacity utilization per vessel conditional on vessel operating 285 days per year

Vessel	1987		1988		1989		1990	
	Observed[a]	Efficient[b]	Observed	Efficient	Observed	Efficient	Observed	Efficient
With Resource:[c]								
1	60.7	85.6	55.2	82.3	47.1	80.1	51.5	76.7
2	40.4	45.9						
3	49.7	71.6	45.4	77.3	46.6	78.1	47.0	69.3
4	26.9	39.6	48.9	82.1	48.5	87.6	54.7	80.2
5	49.0	71.2	53.4	85.6	49.3	74.5	51.0	77.1
6	44.0	64.6	51.9	80.4	41.8	75.5	44.7	73.4
7	64.6	81.4	51.9	76.7	45.7	70.5	51.7	69.1
8	52.3	77.5	45.2	76.5	41.8	79.6	46.1	64.4
9	48.0	67.3	46.5	80.9	38.3	86.8	44.6	73.2
10	40.8	64.9	45.3	87.3	33.4	67.8	49.0	71.8
Fleet	48.0	67.6	49.3	81.0	43.6	77.9	49.0	72.5
Without Resource:[d]								
1	56.0	79.1	46.7	74.0	41.0	69.7	45.6	65.2
2	30.5	34.6						
3	45.2	65.1	37.3	63.5	35.4	59.4	35.3	52.0
4	22.8	33.6	43.7	73.2	42.8	77.3	47.9	70.2
5	42.9	62.4	42.3	67.8	38.9	58.7	38.8	58.7
6	40.1	58.9	47.2	73.1	37.0	66.7	39.3	64.4
7	59.0	74.4	45.8	67.7	40.0	61.7	44.8	59.9
8	47.9	71.0	40.8	69.1	37.0	70.4	39.9	55.6
9	42.6	59.7	39.9	69.5	31.8	72.0	38.9	63.5
10	36.4	57.8	39.6	76.3	28.0	56.7	43.4	63.5
Fleet	42.4	59.7	43.0	70.5	36.9	66.0	41.6	61.6

[a] Capacity utilization calculated as the ratio of observed output to the capacity output conditional on 285 days a year. [b] Capacity utilization calculated as the ratio of technically efficient output to the capacity output conditional on 285 days a year. [c] Capacity output determined conditional on resource abundance and other fixed factors. [d] Capacity output determined without resource abundance.

Overall, we find that average capacity utilization per trip, when based on observed output and resource constraints, is quite low. When CU is assessed using the technically efficient output in the numerator, CU is relatively high. Technical inefficiency appears to be a major reason why vessels have not operated near optimal capacity. Alternatively, if we restricted our analysis of CU to the ratio of observed output divided by capacity output, we would have a substantial downwards bias in our assessment relative to the frontier output (Färe *et al.*, 1989). In general, vessel operators have tended to take shorter trips than they should have if they were to operate at the optimal capacity. CU conditional on resource abundance and observed output ranged from 26.9 for vessel 4 in 1987 to 54.7 in 1990; when

[10] Measures of capacity utilization conditional on mean and observed number of days per year may be obtained from the authors.

considered relative to the technically efficient output level, CU ranged from 39.6 for vessel 4 in 1987 to 80.2 for vessel 4 in 1990. When CU is assessed without resource abundance, CU is alarmingly lower. In 1987, CU for vessel 4, when calculated using observed output, was 22.8; CU for vessel 4 in 1990 was only 47.9. Similarly, CU for vessel 4, when calculated using the technically efficient output level was only 33.6 in 1987 and only 70.2 in 1990.

If we consider CU relative to the observed number of days per year, CU is considerably higher. CU conditional on resource abundance and calculated using the technically efficient output and observed number of days ranged from a low of 72.2 for vessel 2 in 1987 to a high of 96.6 for vessel 1 in 1987; in 1990, CU ranged from 72.5 for vessel 8 to a high of 85.3 for vessel 9.

6. CONCLUSIONS

The approach of Färe *et al.* offers one viable way to assess capacity, capacity utilization, and input utilization in a fishery. Although it is production or primal oriented, it does provide information that may be extremely useful to resource managers. In addition, it provides information consistent with the way many resource managers view capacity (i.e. what could an existing fleet harvest in the absence of regulatory or resource constraints?). Last, it offers a more complete basis for calculating capacity than the commonly-used measure of number of vessels in a fishery (NEFSC, 1998).

The approach, however, also has some limitations. First, because it is production oriented, it does not adequately reflect the underlying economics. That is, economic conditions may be the reason why a firm does not operate at capacity; alternatively, the approach does not readily allow the determination of the economic conditions under which a firm would operate at capacity. As shown by Berndt and Fuss, though, the economic measure may be indeterminate in the presence of multiple fixed or quasi-fixed factors. Recently, Färe and Grosskopf (1998) developed a possible DEA approach that does allow for calculating the economic concept of capacity. Their approach has not, however, been empirically applied, and would not likely have widespread applicability in fisheries because of the absence of data on production costs. Moreover, it is not known if the recent Färe and Grosskopf approach adequately solves the indeterminancy problem associated with multiple fixed factors. Second, in the case of multiple outputs, which are quite common to many fisheries, capacity output is calculated based on a radial expansion of all outputs. It is possible that this limitation could be corrected by considering a non-radial expansion of outputs (Färe *et al.*, 1994).

Regarding the sea scallop fishery, our limited empirical analysis revealed that there was substantial excess harvesting capacity by the ten vessels which comprised the panel data set and relative to the entire fleet. We also found that technical inefficiency and sub-optimal levels of variable inputs were two major reasons why many of the vessels did not operate near full capacity utilization. For most of the vessel trips, we determined that resource levels and not the fixed factors constrained capacity output between 1987 and 1990.

Our analysis also provided results somewhat consistent with the current recommendations of a national team of scientists charged with determining the optimal level of catch and the corresponding reduction in fishing vessel effort. The national team has recommended that the annual harvest of sea scallops should be limited to approximately 20 million pounds. In order to accomplish this objective, the national team has suggested that the annual number of days which vessels fish should be reduced by approximately 60 percent. If converted into simple average catches conditional on number of days, the number of vessels that could produce the equivalent recommended harvest is approximately 65. Our results would suggest a fleet of 56 or fewer vessels could harvest the recommended 20 million pounds. Differences are associated with the explicit calculation of capacity, recognition of different vessel size classes, and the fact that the national team used average catches and the assumption that the relationship between fishing mortality and days at sea is constant, regardless of different size vessels. Finally, we offer that although the approach of Färe *et al.* has limitations, it does offer information that could be particularly useful to resource managers concerned with developing buyback or fleet downsizing programmes.

7. REFERENCES

Apostle, R., McCay, B. & Mikalsen, K. 1993. Overcapacity and Privatization: The Case of ITQs in the Scotia-Fundy Groundfish Fisheries. Paper presented to the Twelfth Anniversary Conference of the International Society for the Study of Marginal Regions. University College, Swansea and Gregynog, Powys.

Augstyn, J. 1996. Government Policies to Match Fleet Capacity to Available Marine Resources. Memo to Fisheries Department, Food and Agriculture Organization of the United Nations, from Sea Fisheries, Department of Environmental Affairs, Government of South Africa, Capetown.

Ballard, K. & Roberts, J. 1977. *Empirical Estimation of the Capacity Utilization Rates of Fishing Vessels in 10 Major Pacific Coast Fisheries.* Washington, D.C.: National Marine Fisheries Service.

Banks, R. 1977. Adjustments to Capacity in the European Union. Paper prepared for F.A.O. Fisheries Department.

Battese, G.E. & Coeli, T.J. 1995 A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data. *Empirical Economics* 20:325-332.

Berndt, E.R. & Fuss, M.A. 1989. Economic Capacity Utilization and Productivity Measurement for Multiproduct Firms with Multiple Quasi-Fixed Inputs. National Bureau of Economic Research Working Paper No. 2932. Cambridge, Mass.: National Bureau of Economic Research.

Christy, F.T. 1996. Over Capacity in Fisheries: Problems and Approaches. Washington, D.C.: IMARIBA.

Edwards, S. 1997. Preliminary Analysis of Economic Returns from Different Allocations of Days at Sea in the Northwest Atlantic Sea Scallop Fishery. Northeast Fisheries Science Centre, National Marine Fisheries Service).

Färe, R. 1984. The Existence of Plant Capacity. *International Economic Review* 23: pp. 209-213.

Färe, R., Grosskopf, S. & Kokkenlenberg. E. 1989. Measuring Plant Capacity Utilization and Technical Change: A Nonparametric Approach. *International Economic Review* 30: pp. 655-666.

Färe, R. Grosskopf, S. & Lovell, C.A.K. 1994. *Production Frontiers*. New York: Cambridge University Press.

Färe, R., & Grosskopf, S. 1998. Primal and Dual DEA Measures of Capacity Utilization. Dept. of Econ. And Dept. of Agri. And Res. Economics Discussion Paper, Oregon State University.

FAO. 1998. Report of the Technical Working Group on the Management of Fishing Capacity. La Jolla, United States, 15-18 April 1998. *FAO Fisheries Report* No. 586. Rome, FAO.

Gautam, A., Strand, I. & Kirkley. J.E. 1996. The Backward Bending Supply of Labour. *J. Env. Econ. And Man*. 31: pp. 352-367.

Johansen, L. 1968. Production Functions and the Concept of Capacity. Recherches Récentes sur la Fonction de Production, Collection, *Economie Mathématique et Econométrie* 2.

Kirkley, J.E. & Du Paul, W.D. 1989. Science, Commercial Practices, and the Determination of Fishery Regulations. *Journal of Shellfish Research* 8: pp. 139-149.

Kirkley, J.E. & Du Paul. W.D. 1993. Elimination of the Meat Count Standard: A Preliminary Assessment of Impacts. Prepared as contract report for Mid-Atlantic Fisheries Management Council.

Kirkley, J.E., Squires, D.E. & Strand, I.E. 1995. Technical Efficiency in Commercial Fisheries. *Amer. J. Agr. Econ*. 77: pp. 686-697.

Kirkley, J.E., Squires, D.E. & Strand, I.E. 1998. Characterizing Managerial Skill and Technical Efficiency in a Fishery. *J. Productivity Analysis* 9: pp.145-160.

Kirkley, J.E. & Squire, D. 1999. Measuring Capacity and Capacity Utilization in Fisheries. In: Gréboval, D (Ed). Managing Fishing Capacity: Selected Papers on Underlying Concepts and Issues. *FAO Fisheries Technical Paper* No 386. pp. 75-200. Rome, FAO.

Klein, L.R. & Summers, R. 1966. *The Wharton Index of Capacity Utilization*. Philadelphia: University of Pennsylvania, Studies in Economics.

Mace, P. 1996. Developing and Sustaining World Fishery Resources: The State of Science and Management. Paper delivered to the World Fisheries Congress, Brisbane.

Morrison, C. 1985a. Primal and Dual Capacity Utilization: An Application to Productivity Measurement in the United States Automobile Industry. *Journal of Business and Economic Statistics* 3: pp. 312-324.

Morrison, C. 1985b. On the Economic Interpretation and Measurement of Optimal Capacity Utilization with Anticipatory Expectations. *Review of Economic Studies* 52: pp. 295-310.

Morrison, C. 1986. Productivity Measurement with Non-Static Expectations and Varying Capacity Utilization. *Journal of Econometrics* 33: pp. 51-74.

Nelson, R. 1989. On the Measurement of Capacity Utilization. *Journal of Industrial Economics* XXXVII (3): pp. 273-286.

North East Fisheries Science Centre 1997. Report of the 25th Northeast Regional Stock Assessment Workshop (25th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. [By Northeast Regional Stock Assessment Workshop No. 25.] December 1997. CRD 97-14. NOAA: United States.

North East Fisheries Science Centre 1998. Report of the 27th Northeast Regional Stock Assessment Workshop (27th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. [By Northeast Regional Stock Assessment Workshop No. 27.] December 1998. CRD 98-15. NOAA: United States.

Pollak, R.A. & Wales, T.J. 1987. Specification and Estimation of Nonseparable Two-Stage Technologies: The Leontief and the Cobb Douglas CES. J. Polit. Econ. 95: pp. 311-333.

United States Congress. 1996. *The Sustainable Fishing Act*. Washington, D.C.

Valatin, G. [no date] The Impact of a Decommissioning Scheme on Aggregate Fishing Effort: The Variability in Effort of Similar Boats. Economics Unit, Sea Fish Industry Authority: Edinburgh.

SIMPLE CAPACITY INDICATORS FOR PEAK-TO-PEAK AND DATA ENVELOPMENT ANALYSES OF FISHING CAPACITY – A PRELIMINARY ASSESSMENT

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Abstract: It is generally recognized that there is an imbalance between the resources and fishing capacity in major world fisheries. Improved management and monitoring of fishing capacity will contribute to sustainable, conservation-based fisheries. To facilitate the consistent measurement and assessment of fishing capacity worldwide, some simple and practical methods must be devised so that they can be readily applied by most countries without undue investment of human and financial resources. The FAO Technical Working Group on the Management of Fishing Capacity recommended the use of peak-to-peak analysis and Data Envelopment Analysis (DEA) as the most practical alternatives for measuring capacity. This paper presents some preliminary work on the application of both peak-to-peak and DEA methodologies using simple capacity indicators to a number of important fisheries in Canada. The indicators selected are: the number of species licences, the number of registered fishers, the number of registered fishing vessels, gross registered tonnage, and annual landings by species. All of these are readily available across fisheries and fleet sectors. Based on the preliminary results, it appears that, while more complex physical or economic data are required for better understanding of fishing capacity, with careful interpretation a coordinated use of simple indicators could serve as a minimum requirement for estimating actual and desired capacity level and trends in capacity utilization over time.

1. INTRODUCTION

Fishery resources provide a major source of protein and incomes in many regions of the world. Over the past decades, the world fishery resources have been subject to intense stress due to the rapid growth of global population and economic activities. Aside from natural or human-induced adverse environmental changes, the steady build-up of the world fishing fleets and continuous increase in fishing intensity has contributed to the depletion of some high-value resources. It is generally recognized that there is an imbalance between the resources and fishing capacity in major world fisheries. The 1995 FAO *Code of Conduct for Responsible Fisheries* calls for improved management and monitoring of fishing capacity that will contribute to sustainable, conservation-based fisheries. To facilitate the consistent measurement and assessment of fishing capacity worldwide, some simple and practical methods must be devised so that they can be readily applied by most countries without undue investment of human and financial resources. The FAO Technical Working Group on the Management of Fishing Capacity recommended the use of peak-to-peak analysis and Data Envelopment Analysis (DEA) as the most practical alternatives for measuring capacity. The Working Group also called for worked examples and case studies to evaluate the peak-to-peak and DEA methodologies for measurement.

This paper presents some preliminary work on the application of both peak-to-peak analysis and DEA using simple capacity indicators. First, a brief discussion is given to some commonly used simple capacity indicators. This is followed by an assessment of the availability of basic technical/biological data in the existing data systems that can be used as capacity indicators. The indicators selected are: the number of species licences, the number of registered fishers, the number of registered fishing vessels, gross registered tonnage (GRT),

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and annual landings by species, all of which are readily available across fisheries and fleet sectors. Next, preliminary results are presented and discussed on the application of both methodologies using the above mentioned simple capacity indicators to a number of important fisheries in Canada. The paper concludes with a brief discussion of some data and methodological issues with respect to the measurement of fishing capacity as a result of this preliminary investigation. Tables and charts are included in a statistical annex.

It should be noted that the intent of this paper is of an exploratory nature with a view to contributing to an international effort to develop a practical and effective monitoring system for fishing capacity worldwide. As such, the preliminary findings and conclusions presented in this paper do not represent the official endorsement of any set of methods or capacity indicators without further research and validation. It is also important to recognize that such a monitoring system once tested and implemented would provide a useful indication of fishing capacity relative to the level of fishery resources regardless of the capacity/fisheries management regimes in place. On the other hand, what the monitoring system provides would be a set of indicators that can not replace the more comprehensive information and more rigorous analysis required for appropriate actions by the government or industry according to the conservation, economic and social objectives on hand.

2. SIMPLE CAPACITY INDICATORS

In economic terms, a conventional definition of capacity is the output level at which the short-run average total cost of production is minimum. Other economic capacity measures can be defined in terms of break-even point or profit maximization. Economic capacity is usually less than physical capacity which is the maximum output that can be physically produced under a given set of resource and technology constraints. For application in fisheries, both capacity measures require complex economic, biological and technical data that are not always available and can be quite computation intensive. To achieve the purpose of consistent measurement and assessment of fishing capacity worldwide, it is desirable that some simple and practical measures be developed so that they can be readily applied by most countries without undue investment of human and financial resources.

The Technical Working Group recommended that the definition of fishing capacity be formulated in units of catch as it is consistent with economic production theory and makes more sense to the fishing industry (FAO, 1998). For fisheries management purposes, this output measure sometimes needs to be translated into input terms, e.g. the number of vessels and number of participants. Therefore, capacity indicators can be either output or input oriented. In output terms, the most commonly used simple indicators are annual landings and landed values by species. In input terms, simple indicators can be defined in volumetric measures such as gross or net registered tonnes, cubic numbers and hold capacity, or in number of operating units/participants such as the number of vessels, licences and fishers.

Under normal resource conditions, annual vessel landings present a good capacity indicator as it usually reflects a rational business decision under a given set of economic, biological and technological realities at the time. In an overexploited fishery beyond a certain long-term production limit such as maximum sustainable yield, the usefulness of annual vessel landings as a capacity indicator is very limited as it reflects rather an act of economic survival under a stressed resource than normal economic activities. The same can be said of annual vessel landed value, but it also gives an additional dimension of income earned by fishers. In a highly volatile market, however, annual vessel landed values usually exhibit a great fluctuation over time even under normal resource conditions and thus can hardly bear any indication of capacity utilization.

Gross or net registered tonnes are volumetric measures in units of 100 cubic feet of total space or cargo space respectively onboard a vessel. Cubic number is the product of three outer dimensions of a vessel, i.e. length, width and depth. As such, these measures are more an indicator for carrying capacity than fishing capacity. Nonetheless, larger vessels usually catch more fish and thus possess greater fishing capacity. There is also hold capacity which actually measures the fish holding/carrying capacity. Again, one can expect larger vessels with greater fishing capacity. But it is well known that hold capacity is rarely fully utilized during fishing trips and thus cannot be taken as the maximum amount of fish that can be caught per trip (Smith and Hanna, 1990).

The number of licences, vessels and fishers measure the number of operating units/participants in fisheries. These are probably the most commonly available data that can be used as proxies to fishing capacity. However, careful interpretation is required in their applications. Fishing capacity implications would be quite different between removal of a licence attached to a large vessel and removal of a licence attached to a small vessel. For example, the 1993 Northern Cod Adjustment and Recovery Programme (NCARP) retired 876 groundfish licences that accounted for five percent of groundfish licences but less than 1 percent of the groundfish value because over 90 percent of the licences retired were associated with vessels under 35 feet (Gardner Pinfold, 1994). The same can be said of using the number of vessels as capacity indicator. The number of fishers, on the other hand, is more an indicator for labour capacity/social dependence on fisheries than fishing capacity.

Despite the shortcomings cited of the above simple indicators, it is thought that, through coordinated use of both input and output indicators, some reasonable estimates of fishing capacity may be achievable. In other words, capacity can be defined as either the potential output given certain inputs or the optimal input given certain outputs.

3. ASSESSMENT OF EXISTING DATABASES

The Canada Department of Fisheries and Oceans (DFO) maintains harvesting and licensing data for both Atlantic and Pacific fisheries. In the early 1990s, the harvesting sector employed about 35 000 vessels, over 90 percent of which are under 65 feet. The harvesting data comprises fish catches/landings and fishing efforts by species. Because of the sheer number of landings made by small vessels, individual vessel landings data are often incomplete for these small vessels and only aggregates are available on a geographic basis. This is especially true for the Atlantic fisheries prior to 1993. For the same reason, it is difficult to link species licences with individual vessel landings for the small vessel sector. It is also impossible to link fish landings with individual fishers.

In terms of vessel characteristics, overall length is required universally for registration of fishing vessels in Canada. Cubic numbers are used for some fisheries. Information on GRT and hold capacity is not mandatory. GRT usually accompanies length information as both are commonly used vessel characteristics, but often incomplete for small vessels. However, there is generally a high correlation between GRT and overall length and, with adequate data, it is possible to estimate missing GRT based on available length information.

Given the above data constraints, only aggregate data from the existing databases are used for the preliminary analysis: annual total landings and landed values by species, total GRT, the number of species licences issued, the number of registered vessels and the number of registered fishers. The study period is chosen to begin with 1984, as more compatible and comprehensive Quebec harvesting and licensing data only became available in 1984 when DFO resumed management responsibilities for marine fisheries from the Province of Quebec.

Eight fisheries are selected for the preliminary analysis: Atlantic coast – inshore (vessels under 100 feet) groundfish, herring, scallop, lobster, shrimp, queen crab, total inshore fishery; Pacific coast – total salmon fishery. The Atlantic inshore groundfishery provided a major source of incomes to many fishers and their communities prior to the extensive fisheries closures since 1992 and has been the target for licence retirement programmes under NCARP, TAGS (The Atlantic Groundfish Strategy) and CFAR (Canadian Fisheries Adjustment and Restructuring). Atlantic herring supports the most important pelagic fishery off Canada's east coast while scallop, lobster, shrimp and queen crab have always supported the lucrative shellfish industry and maintained the viability of the Atlantic fisheries after the collapse of the groundfishery. Pacific salmon has long been the staple fishery on Canada's west coast, and has been the subject of major restructuring and adjustment programmes such as PSRS (Pacific Salmon Revitalization Strategy) and CFAR since it hit the lowest harvest level in 1995-1996. Finally, the total Atlantic inshore fishery (groundfish, pelagic and shellfish) is selected not only because of its social and economic importance to the region but also with a view to providing some initial indication of multiple-species effect on the level of desired capacity.

4. PEAK-TO-PEAK ANALYSIS

Peak-to-peak analysis is a univariate time series model to assess the capacity utilization over time. Given a time series of output-to-input ratios, the outstanding peaks during the period represent relatively full capacity utilization (or capacity production) under normal operating and economic conditions. These peaks also reflect changes in technology over time. The capacity output-to-input ratios in the intervening years between the peak years can be estimated by mathematical interpolation/extrapolation. The capacity utilization is then defined as the actual output-to-input ratio divided by the capacity output-to-input ratio. Detailed description of the peak-to -peak analysis can be found in Ballard and Roberts (1977), and Kirkley and Squires (1999).

Let U_t represent the output that can be produced in the current period t and V_t the input or a composite index of inputs in time t, the following relationship can be established:

$$\frac{U_t}{V_t} = AT_t \tag{1}$$

where A is a constant and T_t is an adjusting technology trend. The above equation measures the short-run capacity or potential productivity under constant returns to scale (i.e. a proportionate increase in inputs results in the same proportionate increase in output).

The potential productivity is then estimated by identifying the peak years as having relatively full-capacity production and, for the intervening years, through linear interpolation between the peak years.

$$T_t = T_{t-m} + \left[\frac{\left(\frac{U_{t+n}}{V_{t+n}}\right) - \left(\frac{U_{t-m}}{V_{t-m}}\right)}{\left(\frac{n+m}{m}\right)} \right] \tag{2}$$

where m and n correspond to the length of time from the previous and following peak years.

Over the longer run, however, the above productivity measure given by equation (1) also reflects the changing economic conditions and the corresponding business decision made on the optimal production level. Thus it is desirable to separate the effects of technological and economic factors, if possible, so that a better indication of the economic capacity can be obtained. If the technology trend can be reasonably estimated, a normalized potential activity measure is given by rewriting equation (1) as

$$\frac{U_t}{X_t} = A_t \tag{3}$$

where X_t ($=T_tV_t$) is the technology-adjusted input index. It can be seen that A_t is no longer a constant and may encompass the effects of long-term economic trend and cycles. In its estimation of capacity utilization in non-manufacturing industries, Statistics Canada (1993) uses the Hodrick-Prescott filter (1980) to estimate the effect of long-term economic trend and cycles by minimizing

$$\sum_t \gamma_t (Y_t - G_t)^2 + \beta \left\{ \sum_t \left[(G_{t+1} - G_t) - (G_t - G_{t-1}) \right]^2 - \mu N \overline{Y}^2 \right\},\ t=1,2,\ldots,N \tag{4}$$

where N is the total number of periods, Y_t ($=U_t/X_t$) is the original series and G_t is the smoothed trend/cyclic series, γ_t and β are adjustable weighting factors, and μ is the tolerance limit for the smoothing process. As β approaches infinity, a linear trend line is produced. The trend/cyclic series generated can be further adjusted to take into account additional information available from actual capacity surveys or other economic indicators. Prior to 1992, capacity utilization rates were calculated using the simple straight-line peak-period approach.

Ballard and Roberts (1977) and Ballard and Blomo (1978) applied the peak-to-peak analysis to a number of Pacific fisheries in the United States In Canada, a DFO working group on capacity measurement estimated capacity utilization in the Atlantic processing sector between 1971 and 1989 (DFO 1990). The capacity utilization rates were calculated using Statistics Canada’s simple base-year approach calibrated by some benchmark DFO capacity surveys. In this paper, the peak-to-peak analysis incorporating the Hodrick-Prescott filter is used. The productivity index is measured by the annual catch divided by technology-adjusted number of licences for the selected fisheries under study. A set of technology coefficients weighted by distributions of fixed and mobile-gear licences over time are calculated for each of the selected fisheries based on the trend of relative technology coefficients reported by Fitzpatrick (1996).

5. DATA ENVELOPMENT ANALYSIS (DEA)

There is a wealth of literatures on DEA as a powerful tool for non-parametric frontier modelling and efficiency measurement (e.g. Afriat, 1972; Färe, Grosskopf and Kokkelenberg, 1989; Coelli, 1995; Coelli and Perelman, 1996a, 1996b). In essence, DEA is a mathematical programming technique that can be used to find frontier production, minimum cost or maximum profit involving multiple inputs and outputs. As in all the mathematical programming problems, an objective function is defined for maximization or minimization subject to a set of constraint functions. The unique feature of DEA, however, lies in its underlying assumption about the shape of the frontier function. The frontier function is assumed to be a non-decreasing and concave function. In other words, DEA models the rising limb of a production function where the marginal product is constant or the effect of diminishing marginal product prevails. Other than the property of non-decreasing and concavity, the production frontier assumes no specific functional form and is derived completely in terms of the given data sets of inputs and outputs.

In this paper, three types of DEA applications are studied: output maximization, input minimization and profit maximization. Output maximization involves, for each given pair of inputs and outputs, finding an optimal set of inputs that maximize the outputs. The resultant inputs and outputs are expressed as a linear combination of all inputs and outputs respectively in the data space. The present study comprises a single output and up to two inputs. The following maximization scheme can be formulated:

$$\begin{aligned} &\text{Maximize} && \phi^i (= u^{*i} / u^i) \\ &\text{subject to} && \sum_i z^i u^i \geq u^i,\ \sum_i z^i x_n^i \leq x_n^i \text{ and } z^i \geq 0 \end{aligned} \tag{5}$$

where the z's are weighting factors; u's are outputs and $u^{*i} = \sum_i z^i u^i$; x's are inputs and $x^{*i}_n = \sum_i z^i x_n^i$; $i=1,2,...,K$ number of data points and $n=1,2,...,N$ number of inputs.

The above scheme estimates the production function under constant returns to scale (CRS). For variable returns to scale (VRS), an additional constraint is imposed, i.e. $\sum_i z^i = 1$.

Input minimization provides another perspective of the frontier function by determining the most efficient set of inputs for the fixed outputs. The resultant production function comprises the fixed outputs and the corresponding most efficient set of inputs again as a linear combination of all inputs in the data space. The minimization scheme is formulated as follows:

$$\begin{aligned} &\text{Minimize} && \theta^i (= x^{*i} / x^i) \\ &\text{subject to} && \sum_i z^i u^i = u^i,\ \sum_i z^i x_n^i \leq x_n^i,\ (\sum_i z^i = 1 \text{ for VRS) and } z^i \geq 0 \\ & && (\sum_i z^i = 1 \text{ for variable returns to scale)} \end{aligned} \tag{6}$$

where again *z's* are weighting factors; *u's* are outputs and $u^{*i} = \sum_i z^i u^i$; *x's* are inputs, $x^{*i}_n = \sum_i z^i x^i_n$, $x^{*i} = \left| \sqrt{\sum_n (x^{*i}_n)^2} \right|$ and $x^i = \left| \sqrt{\sum_n (x^i_n)^2} \right|$; *i=1,2,…,K* number of data points and *n=1,2,…,N* number of inputs.

As both output maximization and input minimization model the same frontier function, the resulting function from one approach would simply be the extension of the resulting function from the other approach. In the case of single-output and single-input, the frontier function under CRS is expected to be a straight line with a positive slope which equals to the productivity of the most efficient period. For the frontier function under VRS, a non-decreasing curve with diminishing slope is expected which should also contain the point corresponding to the most efficient period.

The above optimization schemes estimate frontier production functions in terms of technical efficiency. Profit maximization adds an economic dimension to DEA. It not only estimates the frontier production based on minimum cost along the frontier but also provides information on economic capacity in terms of break-even point and maximum profit given the price-cost structure. Profit maximization follows the following optimization scheme:

$$\text{Maximize} \qquad \pi^i = pu^i - \sum_n c_n x^i_n \tag{7}$$

$$\text{subject to} \qquad \sum_i z^i u^i = u^i,\ \sum_i z^i x^i_n \le x^i_n,\ (\sum_i z^i = 1 \text{ for VRS}) \text{and } z^i \ge 0$$

where again *z's* are weighting factors; *u's* are outputs and $u^{*i} = \sum_i z^i u^i$; *x's* are inputs, $x^{*i}_n = \sum_i z^i x^i_n$, $x^{*i} = \left| \sqrt{\sum_n (x^{*i}_n)^2} \right|$ and $x^i = \left| \sqrt{\sum_n (x^i_n)^2} \right|$; is the output price and *c's* are unit input costs; *i=1,2,…,K* number of data points and *n=1,2,…,N* number of inputs.

Both output maximization and input minimization are used to estimate frontier functions for the selected Canadian fisheries. Annual harvest by species is the single output while the number of species licences is the main input studied. Multiple inputs including the number of registered fishers and fishing vessels are used for the total Atlantic inshore fishery. GRT is also tested for the Atlantic inshore ground fishery. Profit maximization requires costs and earnings information, which is not universally available for the Canadian fisheries under study. As such, the example of world fisheries used in a global bio-economic model by Garcia and Newton (1994) is adopted for profit maximization as well as output maximization and input minimization. Again, all the inputs are adjusted with their respective technology coefficients to reflect advances in fishing technology over time.

6. PRELIMINARY MODEL APPLICATIONS TO SELECTED FISHERIES

The following sections present the preliminary results of application of both peak-to-peak analysis and DEA to Atlantic inshore (vessels under 100 feet) ground fishery, Atlantic inshore fishery (DEA only); Pacific salmon fishery; and world capture fisheries (DEA only). Although preliminary analyses were also carried out for herring, scallop, lobster, shrimp and queen crab fisheries on the Atlantic coast, the results are not presented due to space constraint of the paper. Annual landings and landed value by species are taken as the output variable. The number of species licences is the main input variable used in most Canadian fisheries except the total Atlantic inshore fishery where the number of registered fishers and fishing vessels are used as multiple inputs. GRT is also tested for the Atlantic inshore ground fishery while both GRT and the number of decked vessels are assessed separately for world capture fisheries. All input variables other than fishers are adjusted for technological advances over time using the technology coefficients given in Table 1. Landed values are expressed in constant 1986 dollars and the technology coefficients used are also 1986 based. It should be noted that all the Canadian fisheries investigated are managed through various types of input or output control. As such, the model results would likely be conservative.

Table 1. Technology Coefficients for Selected Fisheries

Year	Atlantic Inshore Groundfish*	Total Atlantic Inshore Fisheries*	Pacific Salmon*	World Capture Fisheries**
1970				0.69
1975				0.84
1978				0.93
1980				1.00
1981				1.07
1982				1.13
1983				1.20
1984	0.94	0.94	0.94	1.26
1985	0.97	0.97	0.97	1.33
1986	1.00	1.00	1.00	1.39
1987	1.03	1.03	1.03	1.46
1988	1.06	1.06	1.06	1.53
1989	1.09	1.09	1.09	1.59
1990	1.12	1.12	1.12	
1991	1.15	1.15	1.15	
1992			1.18	
1993			1.21	
1994			1.24	
1995			1.27	

* Based on the trend of relative technology coefficients reported by Fitzpatrick (1996), it was assumed that the technical efficiency of mobile gear doubled between 1980 and 1995 while that of fixed gear increased by 50 percent for the same period. These coefficients are then weighed by distributions of fixed and mobile-gear licences over time for each of the selected Canadian fisheries. ** Based on Garcia and Newton (1994). Technology coefficients are simple arithmetic averages of Fitzpatrick's relative technology coefficients over time.

7. ATLANTIC INSHORE GROUNDFISH

The Atlantic inshore groundfish landings registered 427 000 tonnes in 1984 and had declined ever since. Before the closure of the most important northern cod fishery in 1992 and subsequent closures of other major groundfish stocks Atlantic wide, the inshore groundfish landings plunged to 321 000 tonnes in 1991. Because of the extensive fisheries closures since 1992, the study period is therefore confined to 1984-1991. During this period, however, the number of groundfish licences had not decreased due to a number of factors including relatively good prices for groundfish since 1986, industry's expectation of early recovery of the declining resources and lack of alternative economic opportunities in many coastal communities. Consequently, there existed an imbalance between the resource and fishing capacity. This gap has been further widened over time because of the continuous improvement in fishing technology (FRCC, 1997). As described earlier, the number of licences is thus adjusted with the technology coefficient over time to reflect increased fishing capacity due to technological advances. The landings and landed values versus actual and technology-adjusted number of licences between 1984 and 1991 are shown in Figures 1a and 1b respectively. The total number of groundfish licences is used as a proxy to inshore licences. The inclusion of offshore licences is not expected to cause significant bias to the analysis as offshore licences only accounts for approximately one percent of total groundfish licences.

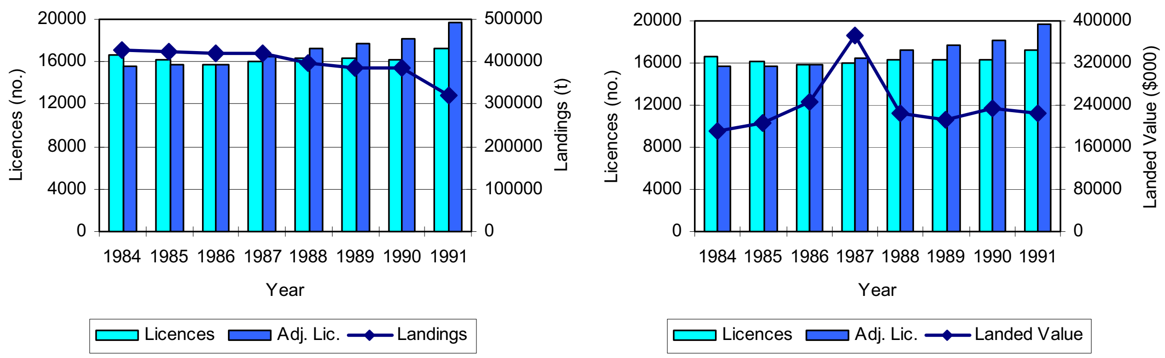


Figure 1. Inshore Atlantic Groundfishery, 1984-1991 a) landings and licences; b) landed values (1986 US$) and licences

7.1 Peak-to-Peak Analysis

The peak-to-peak analysis incorporating the Hodrick-Prescott filter (Equations 3 and 4) is performed on both annual landings per adjusted unit of licence and annual landed value per adjusted unit of licence and the results are shown in Figures 2a and 2b. In terms of landings, the capacity utilization rate throughout 1984-1991 was quite high (averaging over 95 percent during 1984-1990 and 72 percent in 1991) despite declining landings (Figure 2a). This implies that fishers consciously lower their catches to achieve minimum average total cost. However, it is well known that the Atlantic fishing industry in general and the groundfish industry in particular are price takers who would catch all the fish available to them if a constant TAC could be maintained. In the presence of declining resources/TAC and non-decreasing fishing capacity, one would expect corresponding decrease in capacity utilization. As such, it is thought that a constant capacity productivity based on the maximum productivity observed in 1984, i.e. 27.3 t/licence, as shown in Figure 3a would be more appropriate. The revised capacity utilization rates now follow a downward from the relatively full-capacity production in 1984 to only 60 percent in 1991. As for capacity utilization in terms of landed values, a smoothed curve (Figure 2b) or a straight line (Figure 3b) all result in a similar pattern of capacity utilization. The utilization rate reached its maximum in 1987 when the record landed value of US$370.9 million was registered and tapered towards both ends of the time span around 50-60 percent. It is quite clear that such a utilization pattern merely reflects the fluctuation in market prices and bears no indication of actual capacity utilization. It also confirms that landed value is not a very useful capacity indicator unless a steady price prevails over time.

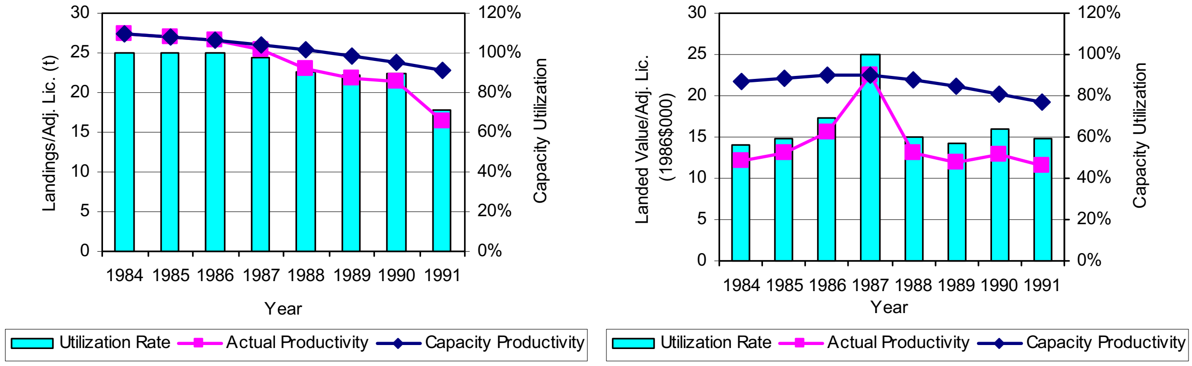


Figure 2. Potential Capacities and Capacity Utilization (based on Hodrick-Prescott filter) – Inshore Atlantic Groundfish a) landings/licence; b) landed value/licence

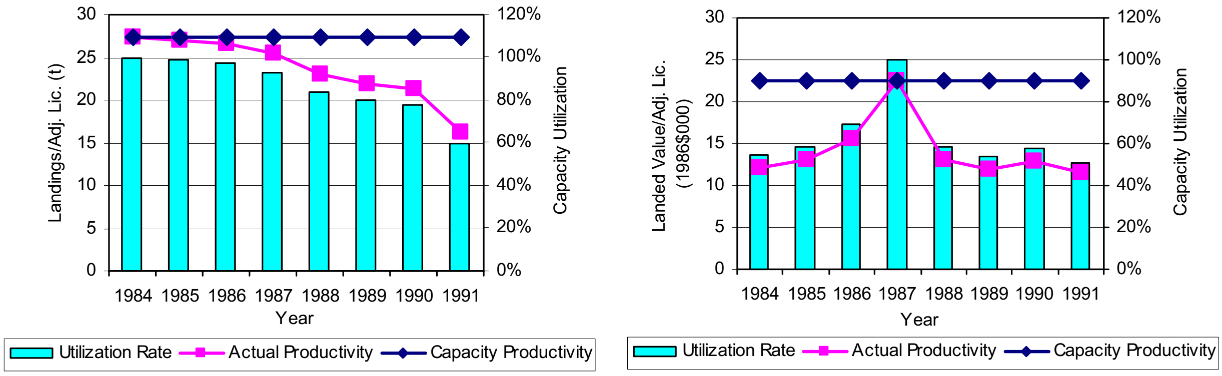
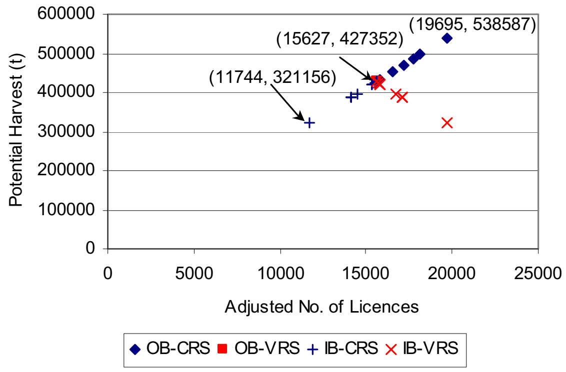


Figure 3. Potential Capacities and Capacity Utilization (based on Constant Capacity Productivity) – Inshore Atlantic Groundfish a) landings/licence; b) landed value/licence

7.2 DEA

The DEA results are presented in Figures 4a and 4b for annual landings and annual landed values as the output respectively. Output-based (OB) maximization (Equation 5) and input-based (IB) minimization (Equation 6) are both performed under the scenarios of constant returns to scale (CRS) and variable returns to scale (VRS). The results are combined and displayed in one graph. From Figure 4a, it can be seen that the CRS estimates form a straight line as expected with a positive slope of 27.3 t/licence which in effect is the 1984 productivity, the maximum productivity observed during the 1984-1991 period. The VRS estimates, on the other hand, exhibit a rather peculiar pattern. Instead of a non-decreasing function, it follows a downward trend with increasing licences. This can be explained by the fact of declining catches in the presence of increasing fishing capacity as approximated by the adjusted number of licences (Figure 1a). Keeping in mind that DEA only models the rising limb of a production function, in the present case only the maximum point should be kept and the remaining points on the falling limb can be disregarded. As expected, the maximum point in terms of the 1984 catches and adjusted number of licences, i.e. 427 352 tonnes and 15 627 licences, is contained in both CRS and VRS functions. The CRS function suggests that with the 1991 catch level at 321 156 tonnes it can only support 11 744 licences while the 1991 level of 19 695 licences have the capacity to harvest 538 587 tonnes of groundfish if the resource is not a constraint. Both estimates imply a 1991 capacity utilization around 60 percent (=11 744/19 695=321 156/538 587). The VRS seems to indicate that with the capacity of 15 627 licences the potential harvest limit is reached at 427 352 tonnes, any increase in capacity beyond this point would result in decreasing catches. It appears that the CRS estimates give an indication of instant catchability at maximum efficiency while the VRS estimates provide information on long-term potential yields. In this context, the 1991 level of 19 695 licences certainly is not desirable as it would result in catches way beyond the apparent long-term potential harvest limit of 427 352 tonnes.



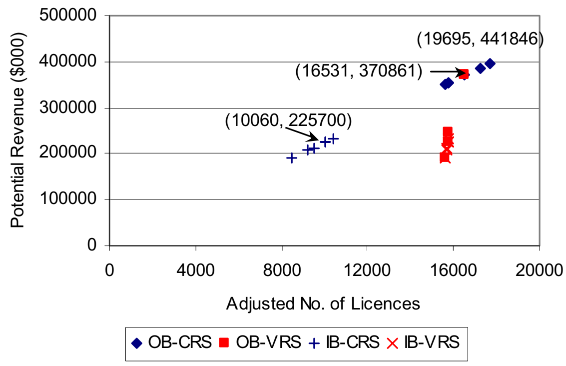


Figure 4. a) Potential Harvest vs licences; b) Potential Revenue (1986US$) vs licences – Inshore Atlantic Groundfish

The CRS and VRS functions presented in Figure 4b based on landed values can be examined in the same vein. In summary, the estimated level of capacity for the 1991 revenue of US$225.7 million would be 10 060 licences, the instant earning potential for the 1991 capacity at maximum efficiency would be US$441.8 million and the long-term maximum sustainable revenue would be US$370.9 million with a fishing capacity of 16 531 licences. Again, DEA results based on landed values do not seem to provide meaningful information on a realistic relation between potential production and capacity due to the influence of fluctuating prices, and annual landed values thus cannot be considered as a good capacity indicator. As such, all the subsequent discussions will focus on the use of annual landings as the primary output indicator.

Two additional observations can be drawn from the above model results. First, when comparing the results between the peak-to-peak analysis with a constant capacity productivity and the DEA CRS approach, it can be seen that both methods yield exactly the same results. Second, by multiplying the estimated 1991 capacity utilization rate of 58.8 percent to the 1991 actual number of licences, i.e. 17 200, results in a lower level of capacity at 10,136 which compares favourably to the estimated level of 10 435 core groundfish licences for TAGS (Auditor General, 1997). This gives some assurance that both peak-to-peak analysis and DEA can indeed provide some reasonable first-cut estimates of actual and desired level of capacity.

7.3 GRT

GRT has been widely used in international communities as a capacity indicator. Even though overall length (LOA) or cubic meters are more commonly used management tool in Canada, it is nevertheless desirable to test the use of GRT as an alternative capacity indicator. Using more detailed Atlantic licensing data available for 1986-1991 at the DFO headquarters, a functional relationship is established between GRT and LOA. The missing GRT values are then estimated from the existing LOA information which is universally required on licences and vessel registration. Annual landings versus actual and technology-adjusted GRT from 1986 to 1991 are shown in Figure 5. It can be seen that, after adjustment for technological advances, GRT is on a rising trend between 1986 and 1991.

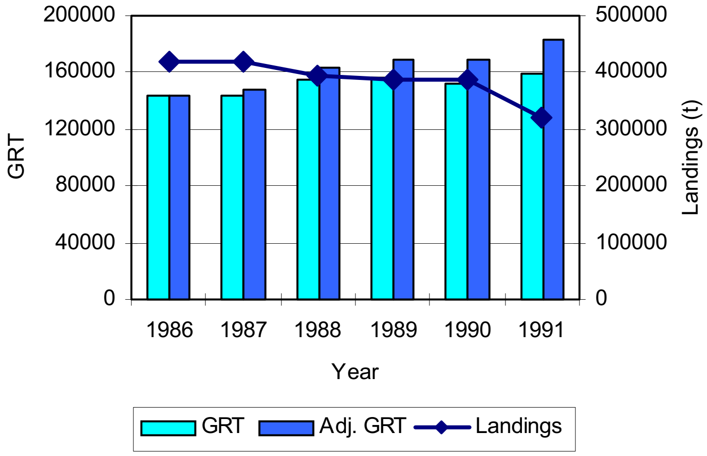


Figure 5. Inshore Atlantic Groundfishery, 1986-1991 – landings and total GRT

Both peak-to-peak analysis and DEA are performed and the results are given in Figures 6 and 7 respectively. Because of the shorter time series, the most efficient period falls in 1986 with the maximum productivity of 2.9 t/GRT. Both the peak-to-peak analysis with a constant capacity productivity and the DEA CRS approach yield the same 1991 capacity utilization rate of 60 percent. The CRS estimates suggest that, given the best fishing efficiency, the 1991 catch level of 321 156 tonnes can only support an effort level of 109 602 GRT. On the other hand, the 1991 level of 182 554 GRT possesses a potential harvest capacity of 534 921 tonnes. The VRS estimates appear to indicate that with an effort level of 149 971 GRT the long-term sustainable catch limit is reached at 420 308 tonnes.

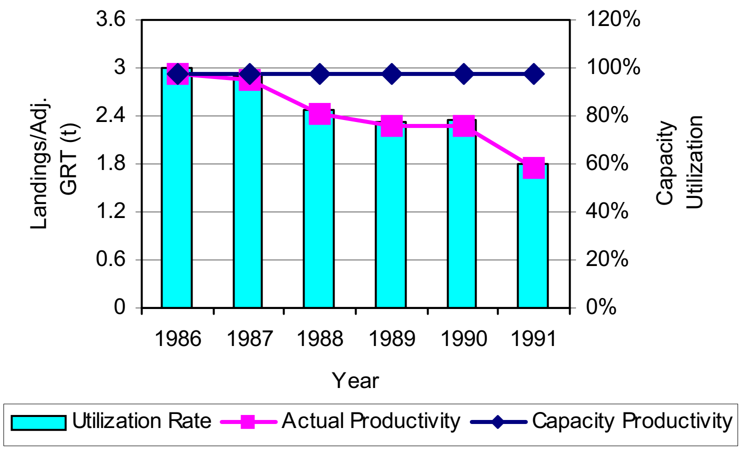


Figure 6. Potential Capacities and Capacity Utilization (based on Constant Capacity Productivity) – Inshore Atlantic Groundfish landings/GRT

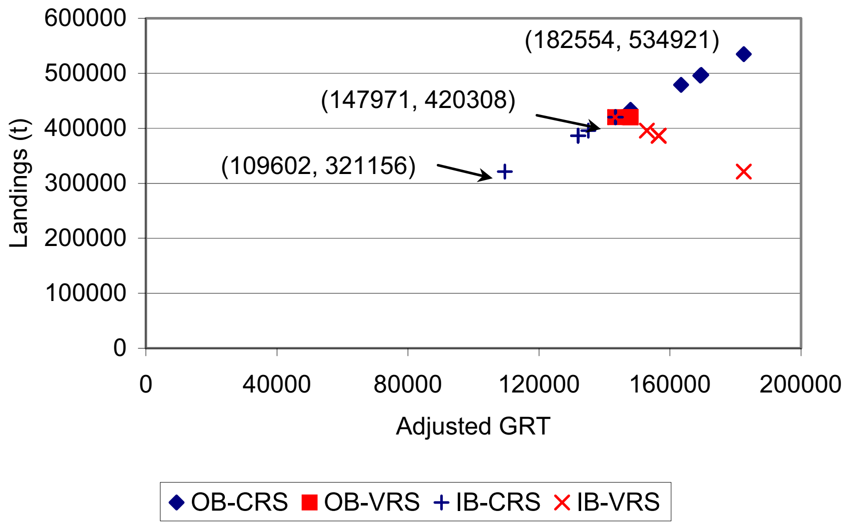


Figure 7. Potential Harvest vs GRT – Inshore Atlantic Groundfish

Since there exists a high correlation between GRT and LOA, it is expected that LOA could also serve as a potential capacity indicator. Annual landings versus actual and technology-adjusted GRT from 1986 to 1991 are presented in Figure 8. It can be seen that adjusted LOA follows the same rising trend as GRT during 1986-1991. The peak-to-peak analysis and DEA all yield similar results as GRT (Figures 9 and 10). The 1991 capacity utilization rate at maximum efficiency is estimated to be around 63 percent. It is interesting to note that both GRT-based and LOA-based CRS estimates give comparable 1991 capacity utilization rates around 60 percent, which is also indicated by the licence-based analysis.

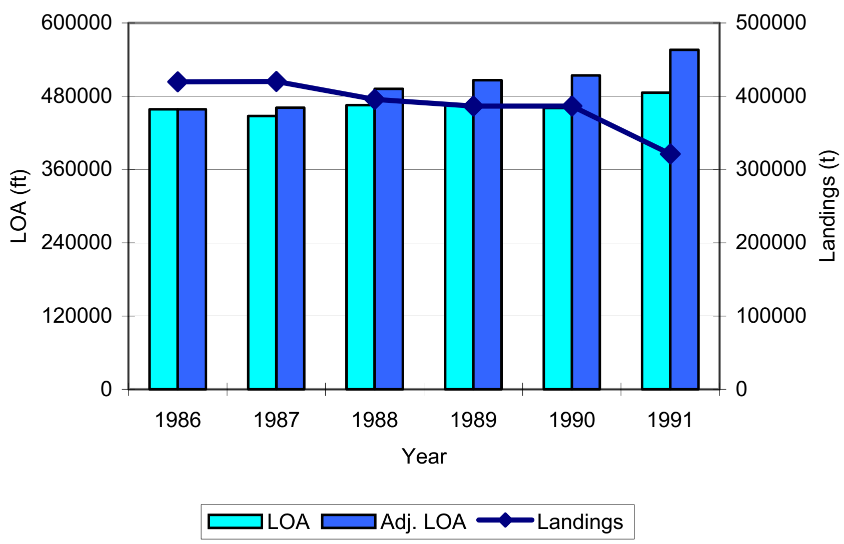


Figure 8. Inshore Atlantic Groundfishery, 1986-1991 – landings and total LOA

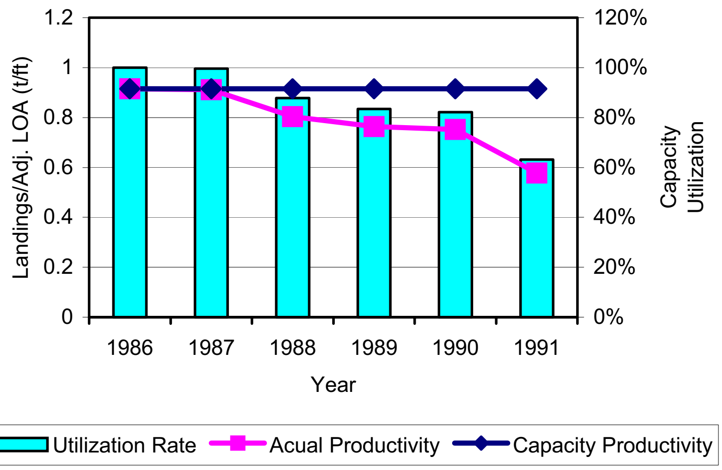


Figure 9. Potential Capacities and Capacity Utilization (based on Constant Capacity Productivity) – Inshore Atlantic Groundfish landings/LOA

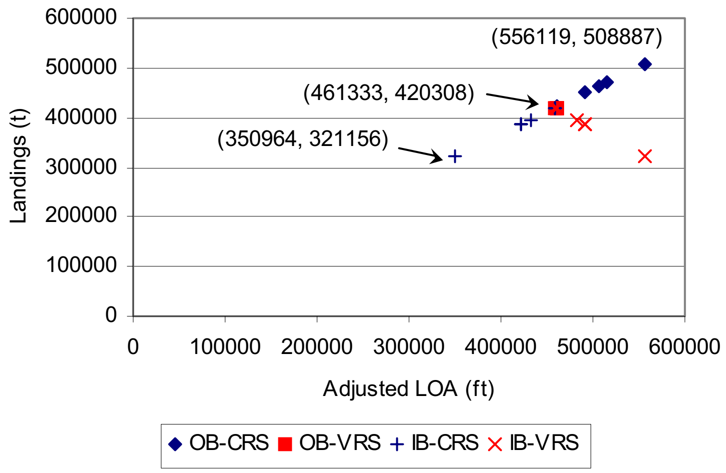


Figure 10. Potential Harvest vs LOA – Inshore Atlantic Groundfish

7.4 Pacific salmon

Pacific salmon consists of five major pacific salmon species off Canada's west coast, i.e. chinook, sockeye, coho, pink and chum, and to a minor extent the steelhead salmon. It is known that Pacific salmon runs exhibit noticeable cyclic patterns. A preliminary analysis of long-term total salmon landings revealed a pronounced four-year cycle with possible three and six-year cycles. To accommodate these possible cycles, a 12-year landing series from 1984 to 1995 is selected for the study. Total Pacific salmon landings versus actual and technology-adjusted number of licences between 1984 and 1995 are presented in Figure 11. The Pacific salmon landings fluctuate over this period reaching a record high of 107 564 tonnes in 1985 and plunging to a historical low of 48 550 tonnes in 1995 after which major conservation measures including area closures were introduced. The number of salmon licences remained relatively stable around 4 400 to 4 500. Taking into account technological advances, however, the 1986-based adjusted number of licences reveals a steady upward trend from 4 198 in 1984 to 5 551 in 1995.

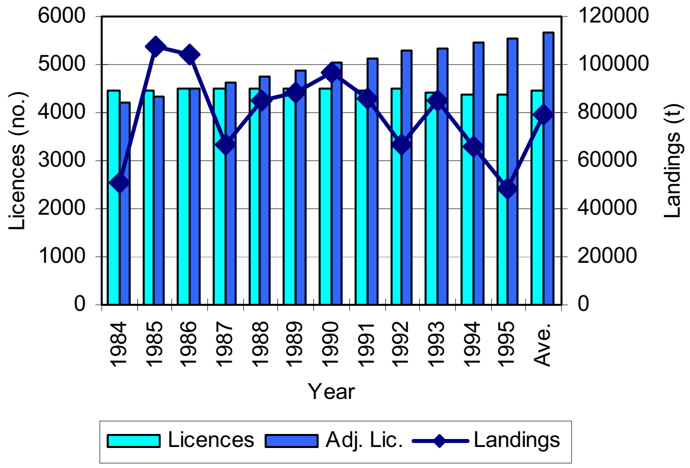


Figure 11. Pacific Salmon Fishery, 1984-1995 – landings and licences

7.5 Peak-to-peak analysis

The results from the application of peak-to-peak analysis are shown in Figure 12. Given the fact that the Pacific salmon industry is also a price taker, a constant capacity productivity based on the maximum productivity in 1985, i.e. 24.8 t/licence is used. The resulting capacity utilization pattern follows the same trend as landings with 1995 experiencing the lowest utilization rate at 35 percent.

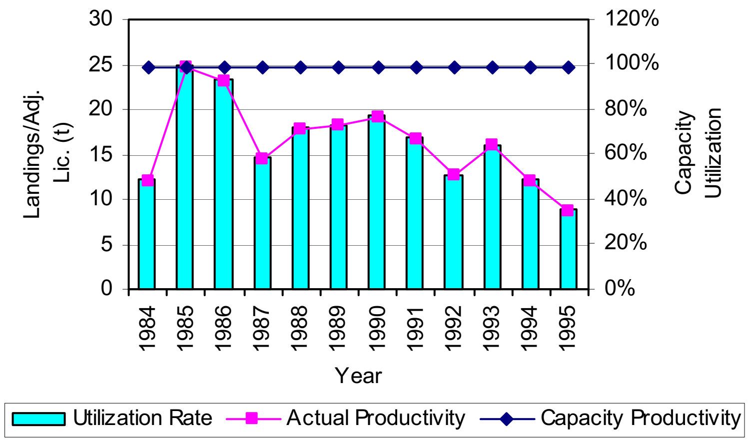


Figure 12. Potential Capacities and Capacity Utilization (based on Constant Capacity Productivity) – Pacific Salmon landings/licences

7.6 DEA

The DEA results as shown in Figure 13 are quite different from those related to the inshore Atlantic ground fishery with respect to the VRS estimates. The VRS estimates reveal a rather steep rising limb of the production function. Given the cyclic nature in the natural production of the Pacific salmon fishery, however, it is clear that this steep slope just reflects the catch levels other than the cyclic peaks in the presence of a steady number of licences. Further, from Figure 6, it can be seen that the peak catches appear to follow a declining trend over the study period. Therefore the only valid point on the VRS function is the maximum productivity point observed in 1985, i.e. a catch level of 107 564 tonnes with 4 342 licences technology-adjusted. This then can lead to the conclusion that the Pacific salmon fishery, like the Atlantic ground fishery, may have fished beyond its long-term potential harvest limit with the capacity level in the early 1990s. The CRS estimates, on the other hand, suggest that with the 1995 catch level at 48 550 tonnes it can only support 1 960 licences while the 1995 level of 5 551 licences have the harvest capacity of 137 514 tonnes without resource constraint. This translates into a 1995 capacity utilization rate of 35 percent. One can probably argue that, in view of the cyclic nature of the Pacific salmon fishery, it may be more appropriate to estimate the desired capacity level in terms of the long-term average harvest instead of the low point of the catch cycle. This is done by including the 1984-1995 average of salmon catches and technology-adjusted average number of licences in the DEA model run. The results suggest that with the average catch level of 79 177 tonnes it can only support 3 196 licences while the average level of 5 670 licences can potentially catch 140 481 tonnes of salmon. In fact, these figures can be obtained by simple arithmetic interpolation/extrapolation from the CRS line. The resulting utilization rate for the average salmon fleet is estimated to be 56 percent.

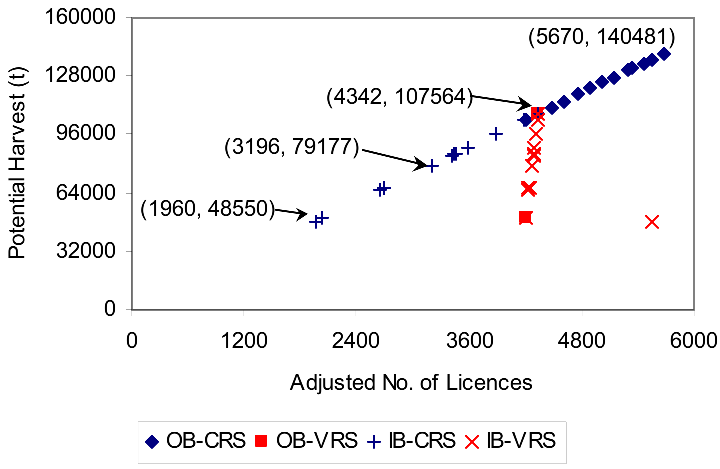


Figure 13. Potential Harvest vs licences – Pacific Salmon

As in the case of Atlantic inshore ground fishery, the peak-to-peak analysis with a constant capacity productivity and the DEA CRS approach yield exactly the same results in capacity utilization. In terms of the actual number of licences, the estimated 1995 utilization rate of 35 percent suggest a capacity level of 1 541 licences which is approximately 150 less than that recommended under a low catch projection scenario by the B.C. Job Protection Commission (1998). If one assumes a more optimistic average harvest level of 79 177 tonnes, a less drastic capacity reduction would be needed and the estimated desired capacity in terms of actual licences would be 2 513.

7.7 Total atlantic inshore fishery

The total Atlantic inshore fishery (including groundfish, pelagic and shellfish) is selected to study the effect of multiple-species fishery on level of estimated capacity. Total Atlantic inshore landings versus registered fishers and actual and technology-adjusted number of registered fishing vessels between 1984 and 1991 are presented in Figure 14. Despite the continuous decline in groundfish landings, total inshore landings did not discern drastic changes during the 1984-1991 period. Total inshore landings peaked over 850 000 tonnes in the late 1980s and the 1991 landings fell to the 1984 level around 710 000 tonnes. The number of registered fishers and fishing vessels were also quite steady around 60 000 and 30 000 (technology-adjusted) respectively and also peaked in the late 1980s.

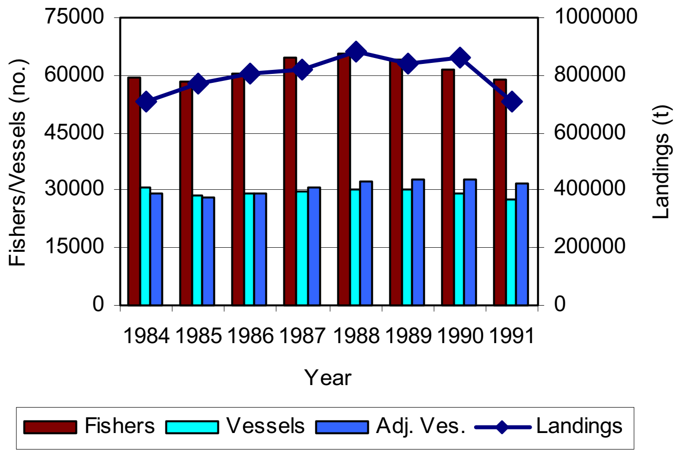


Figure 14. Atlantic Inshore Fisheries, 1984-1991 – landings, fishers and vessels

The DEA is performed on total Atlantic inshore landings with two inputs -- registered fishers and fishing vessels. For the two-input case, a composite input index is used in the optimization scheme (Equations 5 and 6). It is a input distance function defined as the square root of the sum of squares of the input variables (Coelli and Perelman, 1996a). For presentation purposes, the resultant frontier estimates are transformed into two-dimensional functions as shown in Figure 15. The CRS estimates reveal that there are two most efficient periods in 1986 and 1990 respectively. The results also suggest that, given the best fishing efficiency, the 1991 catch level of 711 102 tonnes can only support 50 829 fishers and 27 066 vessels. On the other hand, the 1991 level of 58 872 fishers and 31 883 vessels possess a potential harvest capacity of 823 631 tonnes. The VRS estimates appear to indicate that with the capacity of 65 791 fishers and 32 197 vessels the long-term potential catch limit is reached at 880 572 tonnes.

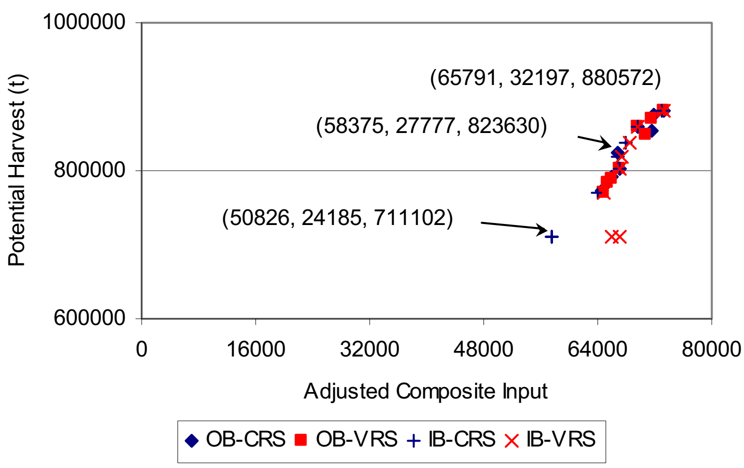


Figure 15. Potential Harvest vs composite input – Atlantic Inshore Fisheries

Based on the CRS results, the estimated desired level of fishing vessels at the 1991 harvest level is 27 066 (technology-adjusted). This represents a 15 percent reduction from the 1991 level of 31 883. Comparing to the desired reduction of 40 percent in inshore groundfish licences, a 15 percent reduction in vessels for the total inshore fishery seem to indicate that over-capacity problem would appear to be less severe in a multiple-species fishery than a single-species fishery even though it is understood that not every inshore fisher and vessel is engaged in multiple-species operation and the ground fishery itself consists of many different species. Further, in terms of actual number of vessels, the 15 percent reduction translates into 23 610 vessels. This combined with the estimated desired level of 50 829 fishers suggest that, assuming a future production at the 1991 level of 711 102 tonnes, the current (1997) numbers of 43 837 fishers and 22 643 fishing vessels appear to be headed in the right direction towards more responsible and efficient fisheries.

7.8 World Capture Fisheries

Garcia and Newton (1994) presented a generalized bio-economic model to assess the global over-capacity problem in the world capture fisheries. The fisheries data used involve annual landings and technology-adjusted GRT for 1970, 1975, 1978 and 1980-1989 as shown in Figure 16a. In this paper, the same data is used to test the applicability of DEA for assessment of global fishing capacity. Further, the number of decked fishing vessels (FAO, 1991) is used in addition to GRT as an alternative capacity indicator, which is also technology-adjusted as shown in Figure 16b. It can be seen that both landings and fishing fleet have undergone considerable growth during 1970-1989.

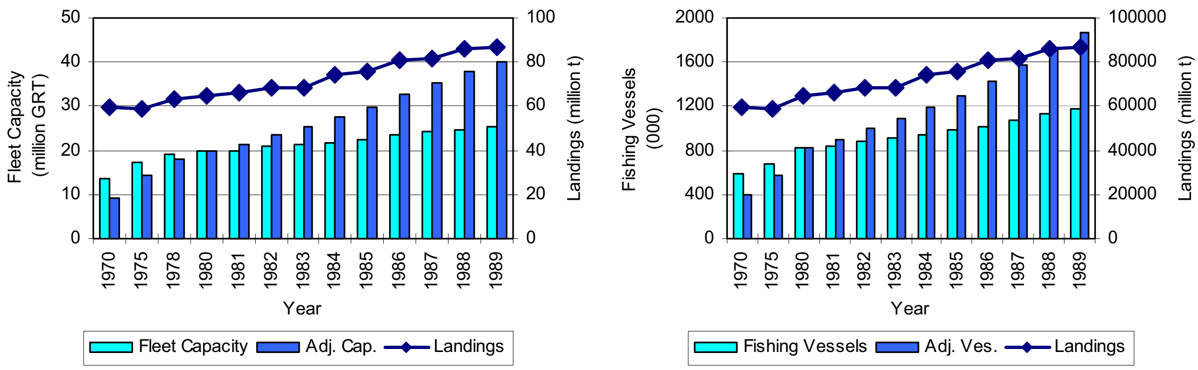


Figure 16. World Fisheries, 1970-1989 a) landings and total GRT; b) landings and vessels

The DEA results based on GRT as input are presented in Figure 17. The VRS frontier follows a rather flat curve which appears to resemble the top portion of the production function derived by Garcia and Newton. It also implies that the world capture fisheries may have reached its long-term production limit of 86.4 million tonnes with the 1989 capacity of 40.2 million GRT. The most efficient period appear to fall in 1970 with the maximum productivity of 6.4 t/GRT. Given this maximum efficiency, the CRS estimates indicates that the 1989 global harvest of 86.4 million tonnes can only maintain an effort level of 13.6 million GRT while the 1989 effort level of 40.2 million GRT can reap a potential harvest of 255.9 million tonnes without resource constraint. In terms of fishing vessels, the VRS estimates shown in Figure 18 exhibit a similar form of production function and point to a possible production limit corresponding to the 1989 global harvest of 86.4 million tonnes and

1 864 000 vessels (technology-adjusted). The CRS results suggest that, operating with maximum efficiency, only 588 000 vessels would be required to achieve the 1989 catch level and the 1989 level of 1 864 000 vessels can potentially reach a harvest level of 273.7 million tonnes. It is interesting to note that GRT-based and vessel-based CRS estimates arrive at comparable capacity utilization rates for 1989, i.e. 34 percent and 32 percent respectively.

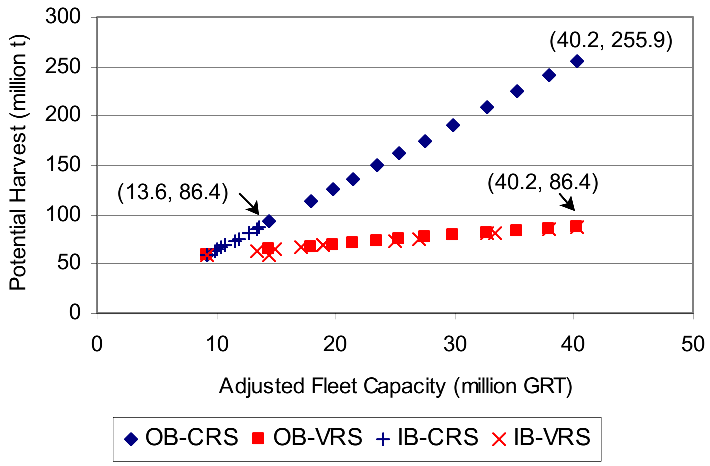


Figure 17. Potential Harvest vs GRT – World Fisheries

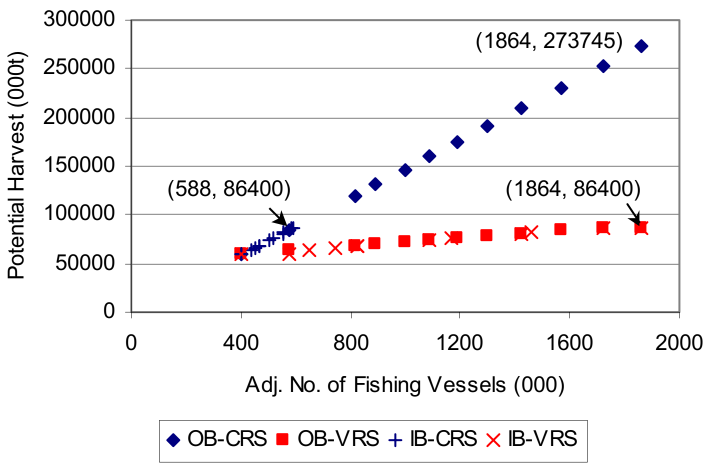


Figure 18. Potential Harvest vs vessels – World Fisheries

The world fisheries data is further used to test the DEA profit maximization scheme (Equation 7). It turns out that both CRS and VRS models yield exactly identical results as compared to those from the input minimization approach. This is expected, as stated earlier, because the profit maximization approach estimates the frontier production based on minimum cost along the frontier. In addition, it also provides information on economic capacity in terms of break-even point and maximum profit given the price-cost structure. The average price and unit cost information is taken from Garcia and Newton: US$862/t and US$2 895/adjusted GRT. The maximum profit curve along the production frontier is shown in Figure 19. It can be seen that net economic loss would be expected beyond the break-even effort level of 21 million GRT, which is in line with the 19 million GRT estimated by Garcia and Newton. The maximum profit, however, appears to realize at the most efficient effort level of 9.3 million GRT.

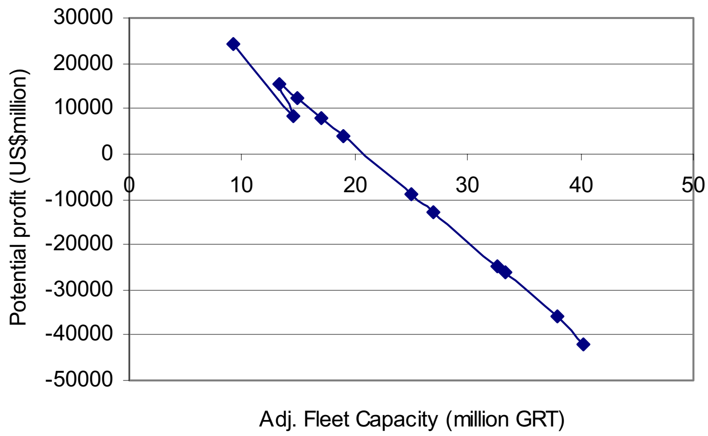


Figure 19. Potential Profit vs GRT – World Fisheries

8. SENSITIVITY ANALYSIS

The following sections present the preliminary findings from various DEA runs to assess the sensitivity of model results to vessel size, geographic area, gear type and study duration. The sensitivity analysis uses the data on Atlantic inshore groundfishery. Vessel size is classified into four LOA categories: < 35’, 35’ - 44.9’, 45’ - 64.9’ and 65’ - 99.9’. Geographic breakdown of area includes Gulf of St. Lawrence, east coast of Newfoundland and Scotia-Fundy region. Gear type consists of fixed gear and mobile gear. Two study periods are used to assess sensitivity to duration: 1984-1991 and 1986-1991.

8.1 LOA effect

The frequency distribution of inshore groundfish licences by LOA is given in Figure 20. It can be seen that over 99 percent of licences are attached to vessels less than 65 ft and approximately 70 percent accounted for by vessels under 35 ft.

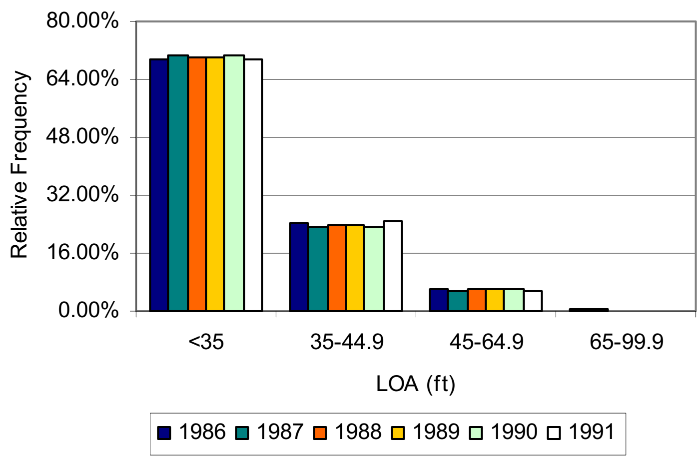


Figure 20. Atlantic Inshore Groundfish Licences by LOA

The harvesting productivity increases almost exponentially with LOA and is the highest among the 65'-99.9' group with the productivity over 400 t/licence most of the time compared to approximately ten t/licence for the <35' group (Figure 21). With such a drastic difference in fishing productivity among fleet sectors, one would expect a noticeable discrepancy between the capacity estimates with and without LOA stratification. DEA was carried out for each of the fleet sectors and results summed and compared to those based on the total inshore fleet as shown in Table 2. It turns out that the differences are quite moderate within five percent and the estimate of desired capacity for 1991 based on the total inshore fleet is only overestimated by 1.6 percent. This could be attributed to the fact that larger and highly productive vessels only accounts for less than one percent of the total inshore fleet and consequently does not exert much influence in determining the capacity level of the total inshore fleet.

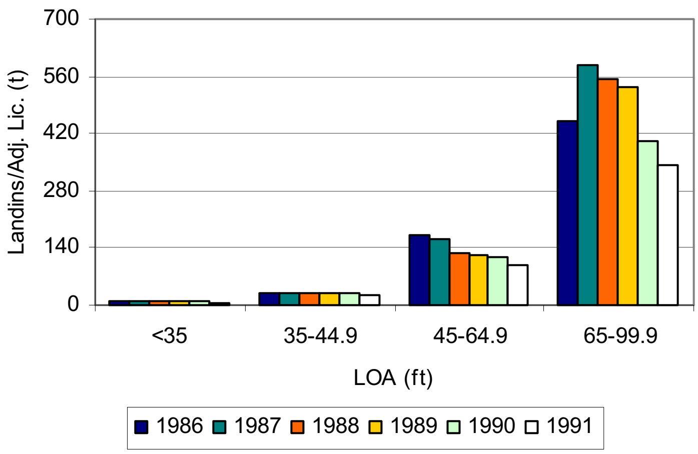


Figure 21. Harvesting Productivity by LOA Atlantic Inshore Groundfish

Table 2. Effect of LOA on Capacity Estimation - Licences (Tech. Adj.), Atlantic Inshore Groundfish

Year	Without LOA Stratification	With LOA Stratification	Percentage Difference
1986	15 909	15 562	2.23%
1987	15 924	15 834	0.57%
1988	14 990	15 521	-3.42%
1989	14 646	14 744	-0.66%
1990	14 644	15 331	-4.48%
1991	12 167	11 978	1.58%

8.2 Area effect

The area distribution of groundfish licences is presented in Figure 22. During 1986-1991, east coast of Newfoundland leads with over 45 percent of licences, followed by Gulf (35 percent) and Scotia-Fundy (20 percent). On the other hand, Scotia-Fundy fleet exhibits the highest productivity around 40 t/licence while the productivities of the Gulf and E. Nfld. fleets are comparable in the 20 t/licence range (Figure 23). The comparison of capacity estimates with and without area stratification are given in Table 3. Again, the differences are within five percent. By examining Figures 22 and 23, it shows that although productivities are quite different between Scotia-Fundy and rest of the Atlantic regions, the area distributions of licences remain relatively unchanged over time and the productivity trends are similar between the regions. As a result, both grouping scenarios display similar productivity trend patterns. This explains the little differences between the two sets of capacity estimates.

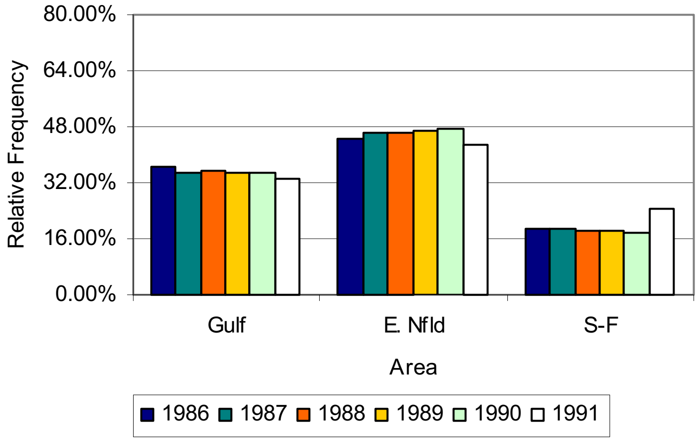


Figure 22. Atlantic Inshore Groundfish Licences by Area

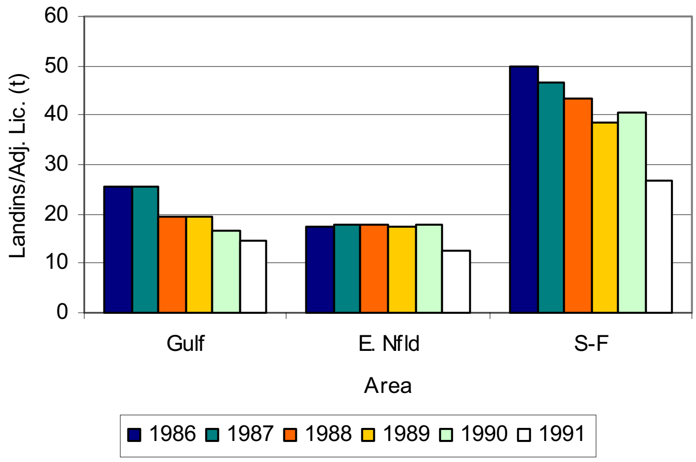


Figure 23. Harvesting Productivity by Area - Atlantic Inshore Groundfish

Table 3. Effect of Area on Capacity Estimation - Licences (Tech. Adj.), Atlantic Inshore Groundfish

Year	Without Area Stratification	With Area Stratification	Percentage Difference
1986	15 909	15 636	1.74%
1987	15 924	15 898	0.16%
1988	14 990	15 187	-1.30%
1989	14 646	15 174	-3.48%
1990	14 644	15 154	-3.37%
1991	12 167	11 892	2.31%

8.3 Gear effect

The frequency distribution of groundfish licences by gear type is shown in Figure 24. The dominance of fixed gear licences is evident throughout 1986-1991 averaging over 85 percent. The number of mobile gear licences dropped from 15 percent to seven percent since 1988. The fixed gear sector has experienced declining productivity from 17-18 t/licence in

1986-87 to around 10 t/licence in 1991 (Figure 25). The mobile gear fleet conversely showed a significant increase in productivity from around 70 t/licence in 1986-87 to 122 t/licence in 1988 and then a gradual decline to 102 t/licence in 1991. This productivity trend in the mobile gear sector is different from the trend exhibited by the total inshore fleet, which is more in line with the fixed gear sector. Consequently, capacity estimates based on the total inshore fleet show a consistent overestimation averaging slightly over five percent compared to those with gear stratification as shown in Table 4.

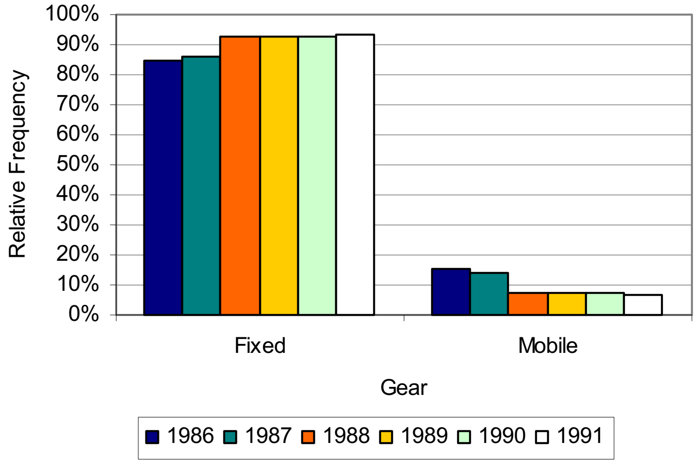


Figure 24. Atlantic Inshore Groundfish Licences by Gear

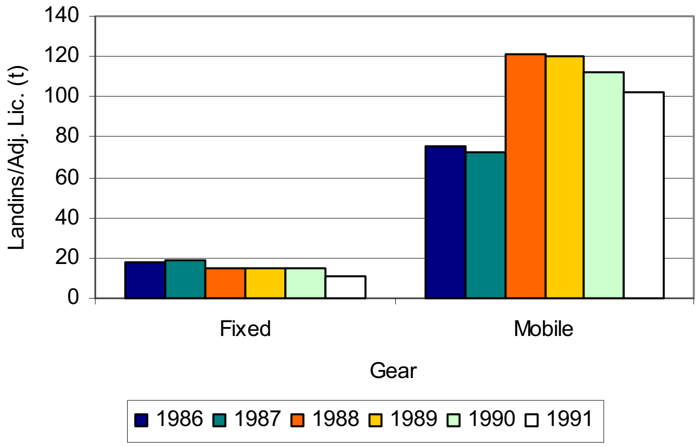


Figure 25. Harvesting Productivity by Gear Atlantic Inshore Groundfish

Table 4. Effect of Gear on Capacity Estimation - Licences (Tech. Adj.), Atlantic Inshore Groundfish

Year	Without Gear Stratification	With Gear Stratification	Percentage Difference
1986	15 909	14 280	11.41%
1987	15 924	15 278	4.22%
1988	14 990	14 423	3.93%
1989	14 646	14 200	3.14%
1990	14 644	14 455	1.31%
1991	12 167	11 394	6.79%

8.4 Duration effect

The harvesting productivity trend for the total inshore groundfish fleet from 1984 to 1991 is displayed in Figure 26. It shows a decline from 27.3 t/licence in 1984 to 16.7 t/licence in 1991. When the entire 1984-1991 period is used for analysis, the maximum productivity in 1984 is the basis for estimating annual capacities in both peak-to-peak analysis and DEA CRS model. When the study period is confined to 1986-1991, the maximum productivity during this period occurred in 1986 at 26.4 t/licence. As a result, capacity estimates based on the 1986-1991 data are consistently overestimated by 3.6 percent compared to those obtained using 1984-1991 data as shown in Table 5.

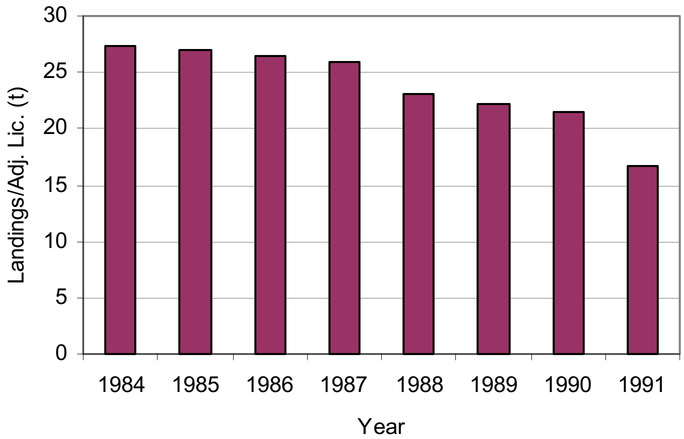


Figure 26. Harvesting Productivity 1984-1991 - Atlantic Inshore Groundfish

Table 5. Effect of Duration on Capacity Estimation - Licences (Tech. Adj.) Atlantic Inshore Groundfish

Year	1986-1991 Duration	1984-1991 Duration	Percentage Difference
1986	15 909	15 355	3.60%
1987	15 924	15 370	3.60%
1988	14 990	14 468	3.60%
1989	14 646	14 137	3.60%
1990	14 644	14 135	3.60%
1991	12 167	11 744	3.60%

9. CONCLUSIONS

Capacity measurement is not a precise science. It may bear different definitions to biologists, economists and resource managers while conducting businesses in their respective disciplines. Nevertheless, there is seldom contradiction in describing capacity trends in relative terms. This leads to the notion that a set of indicators could be developed to provide a consistent yet reasonable indication of capacity level over time regardless of capacity/fisheries management regimes in place. In Canada as well as most developed fishing nations, governments are moving away from an interventionist approach to one that promotes co-management/partnership with industry towards responsible and sustainable fisheries. A practical and effective capacity monitoring system would be useful in providing a preliminary indication of fishing capacity relative to the level of fishery resources. Based on this information, government and industry may decide on further information and research required which would lead to appropriate actions according to the conservation, economic and social objectives on hand.

Based on the preliminary results presented above, it appears that, while more complex physical or economic data are required for better understanding of fishing capacity, with careful interpretation a coordinated use of simple indicators could serve as a minimum requirement for estimating actual and desired capacity level and trends in capacity utilization over time. The following summarizes some methodological and data issues worth noting in the measurement of fishing capacity.

Capacity only makes sense when defined in terms of both input and output. It can be defined as either the potential output given certain inputs or the optimal input given certain outputs. The number of licences, vessels, GRT etc. alone does not give any indication on the level of fishing capacity without the concurrent knowledge of current resource use and potential output in units of catch. The preliminary results appear to indicate that the number of species licences, vessels, fishers and GRT are potential input indicators which would yield reasonable estimates of capacity level. LOA is also an alternative indicator because of the high correlation between GRT and LOA. As for the output indicators suitable for capacity estimation, annual landings by species are recommended in lieu of landed values. Landed values are often influenced by highly fluctuating market conditions and cannot be used as a meaningful indicator of the resource level. Finally, it is clear that technology coefficients affect the level of estimated capacity. To ensure meaningful and comparable capacity estimates worldwide, there is also a need for consistent application of a standard methodology for measuring technology coefficients, which is currently lacking.

Both peak-to-peak analysis and DEA prove to be a practical tool that makes coordinated use of input and output indicators to derive estimates of fishing capacity. DEA, however, offers more flexibility in that it can deal with multiple inputs and outputs and address a variety of economic optimization problems. It is important to note that no model can reveal information beyond what is contained in the given data. In other words, maximum efficiency and capacity estimates from both methods are confined in the period under study and constrained by the details of the data. Also, the results presented in this paper are mainly based on the maximum technical or economic efficiencies. If other objectives, e.g. equitable access to resources, are of primary concern, they could be incorporated in the model formulation and would result in a different set of capacity estimates.

It appears that the peak-to-peak analysis and DEA CRS estimates give an indication of instant catchability at maximum efficiency while the DEA VRS estimates provide information on long-term potential yields. It is important to keep in mind that DEA only models the rising limb of a frontier production function with a constant slope or where the effect of diminishing marginal product prevails. As such, the results would be meaningless for overexploited fisheries beyond the long-term production limit, other than a mere indication of a troubled resource in the presence of a downward sloping. Because of the short time series involved and the various input/out control regimes in place, these estimates would likely be conservative and must be used with discretion.

The fisheries data presented in this paper all involve multiple species and stocks. If DEA is to be used to estimate a more meaningful biological production function, stock-specific analysis and a better input indicator such as fishing effort would be required. On the other hand, the model results also appear to indicate that the multiple-species analysis would result in a higher level of capacity utilization than that based on the single-species analysis. This is somewhat expected as multiple-species fisheries usually provide required diversification and complementary sources of raw material and incomes to make most use of the existing capacity.

The results of sensitivity analysis seem to suggest that a macro-level assessment of capacity using either method would generally suffice. More detailed analysis with data stratification would be required if there is strong evidence of heterogeneity in distributions of inputs or productivity trends. On the safe side, however, some broad data stratification would be desirable provided that such effort would not cause undue computational burden. Also, longer time series whenever available should always be used to obtain better estimates of fishing capacity.

10. REFERENCES

Afriat S.N. 1972. Efficiency estimation of production functions. *International Economic Review*, 13(3): pp. 568-598.

Auditor General of Canada. 1997. Chapter 15, Fisheries and Oceans Canada – rationalization and renewal: Atlantic groundfish. Report of the Auditor General of Canada, Ottawa.

Ballard K. & Blomo, V. 1978. Estimating the structure of capacity utilization in the fishing industry. *Marine Fisheries Review,* 40(8): pp. 29-34.

Ballard K. & Roberts, J. 1977. Empirical estimation of the capacity utilization rates of fishing vessels in 10 major Pacific coast fisheries. National Marine Fisheries Service, Washington D.C.

British Columbia Job Protection Commission. 1998. Fishing for money: challenges and opportunities in the BC salmon fishery. Final Report. Prepared by G.S. Gislason & Associates Ltd., Vancouver.

Coelli T.J. 1995. Recent developments in frontier modelling and efficiency measurement. *Australian Journal of Agricultural Economics*, 39(3): pp. 219-245.

Coelli T. & Perelman, S. 1996a. Efficiency measurement, multiple-output technologies and distance functions: with application to European railways. *CREPP Working Paper* 96/05, Université de Liège.

Coelli T. & Perelman, S. 1996b. A comparison of Parametric and non-parametric distance functions: with application to European railways. *CREPP Working Paper* 96/11, Université de Liège. FAO. 1995. Code of conduct for responsible fisheries. Rome, FAO.

DFO Economic and Commercial Directors Committee. 1990. Report of the working group on capacity measurement. Canada Department of Fisheries and Oceans, Ottawa.

Färe R., Grosskopf, S. & Kokkelenberg, E.C. 1989. Measuring plant capacity, utilization and technical change: a nonparametric approach. *International Economic Review*, 30(3): 655-666.

FRCC (Fisheries Resource Conservation Council). 1997. A report on gear technology in eastern Canada. Report of the Gear Technology Subcommittee FRCC.97.R.1, Ottawa.

Fitzpatrick, J. 1996. Technology and fisheries legislation. Pages 191-200 *in* Precautionary approach to fisheries, part 2, scientific papers. *FAO Fisheries Technical Report* 350/2, Rome, FAO.

FAO. 1991. Bulletin of fisheries statistics – *Fishery Fleet Statistics,* No. 30. Rome, FAO.

FAO. 1995. Code of conduct for responsible fisheries. Rome, FAO.

FAO. 1998. Report of FAO technical working group on the management of fishing capacity, 15-18 April 1998, La Jolla,. United States. Rome, FAO.

Garcia S. M. & Newton, C. 1994. Current situations, trends, and prospects in world capture fisheries. Paper presented at the Conference on Fisheries Management, 14-16 June, Seattle, United States.

Gardner Pinfold Consulting Economics Ltd., and Canning & Pitt Associates Inc. 1994. Final evaluation of the Northern Cod Adjustment and Recovery Programme. Canada Department of Fisheries and Oceans, Ottawa.

Kirkley, J.E. & Squire, D. 1999. Measuring Capacity and Capacity Utilization in Fisheries. In: Gréboval, D (Ed). Managing Fishing Capacity: Selected Papers on Underlying Concepts and Issues. *FAO Fisheries Technical Paper* No 386. pp. 75-200. Rome, FAO.

Smith C. L. & Hanna, S. 1990. Measuring fleet capacity and capacity utilization. *Canadian Journal of Fisheries and Aquatic Sciences*, 47: pp.2085-2091.

Wallace D., & Dion, R. 1993. Industry capacity utilization rates in Canada – new methodology. *Statistics Canada Working Paper*, Ottawa.