Measuring Capacity of the New England Otter Trawl Fleet

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Measurement of capacity in marine fisheries is an important activity. An economic definition of capacity is the output level corresponding to the tangency between the long-run and short-run average cost curves. A technological-engineering definition is the maximum output per unit of time provided variable inputs are unrestricted. Although cost data to support an economic measurement of capacity in fisheries are not routinely available, data are typically available to support the technological-engineering measure of capacity. Our paper provides an assessment of the technological-engineering concept of capacity in the New England multispecies otter trawl fishing fleet. Based on Färe et al. (1994), we calculate capacity using Data Envelopment Analysis (DEA), a non-parametric technique which utilizes linear programming methods to evaluate the performance of individual firms. DEA is ideally suited to assess capacity in fisheries because it easily accommodates multiple output-multiple input technologies. The New England otter trawl fleet was used as a study fleet because it has a multi-product nature, and is comprised of a wide variety of vessel types and sizes.

Keywords: Capacity, Data Envelopment Analysis, New England Otter Trawl Fleet

1. INTRODUCTION

Fishing capacity and its measurement have become important issues both domestically and internationally. Because property rights are lacking in most managed fisheries worldwide, there is generally overinvestment in capital and other inputs used to harvest fish. The FAO Code of Conduct for Responsible Fisheries adopted in 1995 called on nations to reduce capacity levels to levels which were more aligned with available resources (Kirkley and Squires, 1999). Nationally, the Sustainable Fisheries Act (SFA) specifically required the Secretary of Commerce[1] to form a task force to study the role of the federal government in "subsidizing the expansion and contraction of fishing capacity in fishing fleets under the Magnuson Fishery Conservation and Management Act" (Federal Fisheries Investment Task Force Report 1999). This led to the formation of a National Marine Fisheries Service task force to develop definitions of capacity and tools which could be used to measure capacity in U.S. domestic fisheries. Based on the work of the task force, all federally managed fisheries will have a quantitative assessment of capacity completed by August 2000 for inclusion in a report to Congress.

[1] The National Marine Fisheries Service which is responsible for management of U.S. domestic fisheries is part of the Department of Commerce, making the Secretary of Commerce ultimately responsible for fisheries management decisions.

The New England otter trawl fleet is comprised of vessels which drag a net along the ocean floor to harvest a variety of different species off the northeastern coast of the United States. The majority of these species are managed under the Northeast Multispecies Fishery Management Plan prepared by the New England Fishery Management Council. These species include cod *(Gadus morhua)*, haddock *(Melanogrammus aeglefinus)*, yellowtail flounder *(Limanda ferruginea)*, pollock (*Pollachius virens)*, witch flounder *(Glyptocephalus cynoglossus)*, American plaice *(Hippoglossoides platessoides)*, windowpane flounder *(Scophthalmus aquosus)*, winter flounder *(Pseudopleuronectes americanus)*, white hake *(Urophycis tenuis)*, redfish *(Sebastes spp.)*, red hake *(Urophycis chuss)*, silver hake *(Merluccius bilinearis)*, and ocean pout *(Macrozoarces americanus)*. As part of the overall effort to quantify capacity in federally managed fisheries, capacity in the New England otter trawl fleet was estimated using Data Envelopment Analysis (DEA).

The purpose of this paper is to present the methodology and DEA results from this initial evaluation of capacity in the New England otter trawl fleet. This fleet harvests the majority of fish caught under the Multispecies FMP.

2. The New England Otter Trawl Fleet

The New England otter trawl fleet is very diverse in terms of vessel characteristics and operating practices. Vessels range in length from 17 to 123 feet, and from 2 to 500 gross registered tons. Engine sizes range from 42 to

1500 horsepower, and crew sizes vary between 1 and 9. Vessels land their catch in ports from Rhode Island to Maine, and fish in three different stock areas (the Gulf of Maine, Georges Bank and Southern New England). Besides groundfish species, New England otter trawl vessels also harvest monkfish (*Lophius americanus*), summer flounder (*Paralichthys dentatus*), squid (*Loligo pealeii*) and scup (*Stenotomus chrysops*).

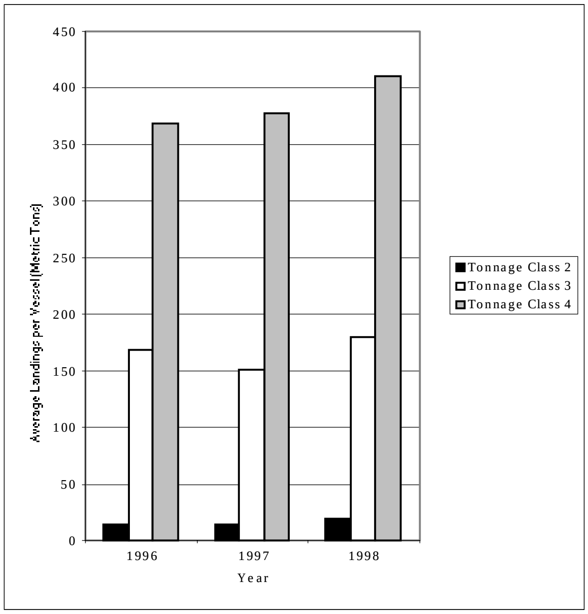

Figure 1. Average landings by New England otter trawl vessels from all species 1996-1998

Average landings from all species by New England otter trawl vessels between 1996 and 1998 depended on vessel size (figure 1). Ton class 2 vessels are less than 51 gross registered tons (grts), ton class 3 are vessels between 51 and 150 grts and ton class 4 vessels are greater than 150 grts. Class 4 vessels average more than twice the landings of class 3 vessels, and more than 20 times the landings of class 2 vessels. Between 1996 and 1998, class 4 vessels increased their average landings, while landings for the other two ton classes stayed relatively flat. Average revenue per vessel earned by New England otter trawl vessels between 1996 and 1998 showed the same trend as average landings (figure 2). Class 4 vessels earned over twice the revenue as class 3 vessels, and roughly twenty times the revenue as class 2 vessels. All three vessel classes had slightly higher nominal revenues in 1998 compared to 1996.

With the exception of pollock and haddock, class 3 vessels caught the largest percent of groundfish species between 1996 and 1998 (figure 3). Class 4 vessels landed nearly 80 percent of the pollock, while haddock landings were nearly evenly divided between ton class 3 and 4 vessels. The small mesh category includes species which can be landed with a smaller mesh size than other groundfish species (e.g., silver hake, red hake and ocean pout). The mixed category includes white hake and redfish.

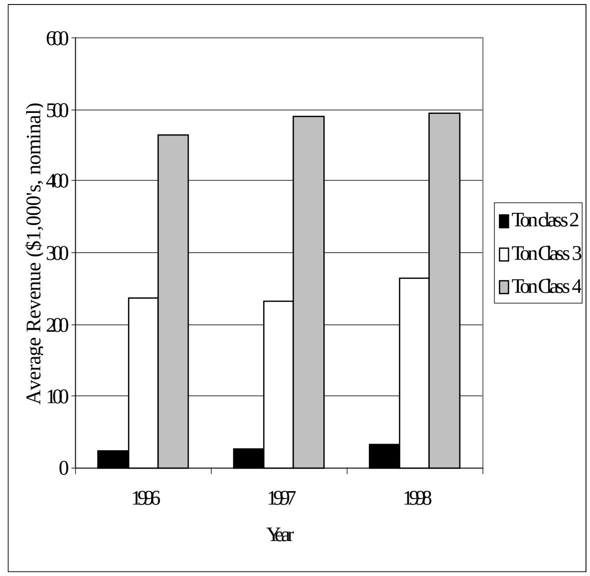

Figure 2. Average revenue for New England otter trawl vessels from all species 1996-1998

. Because of their size, both class 3 & 4 vessels have the ability to fish in areas that are further offshore, and catch a wider variety of species than ton class 2 vessels. This can be seen in the percent of groundfish and non-groundfish species landed by each vessel class during 1996-1998 (Figure 4). Class 2 vessels had the highest percent of their landings from groundfish species while class 4 had the least.

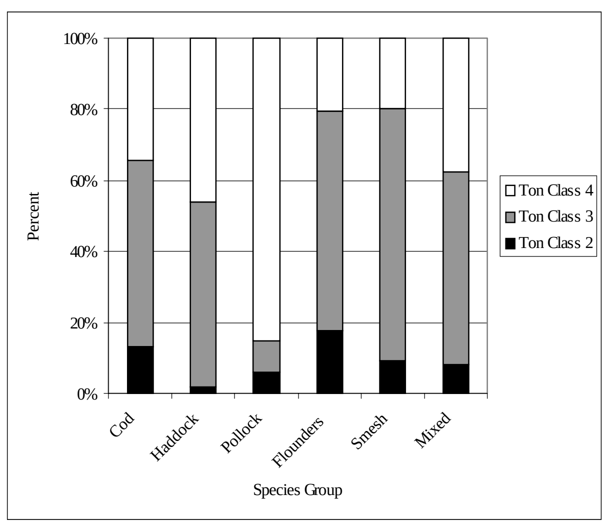

Figure 3. Composition of groundfish landings by species group and ton class 1996-1998

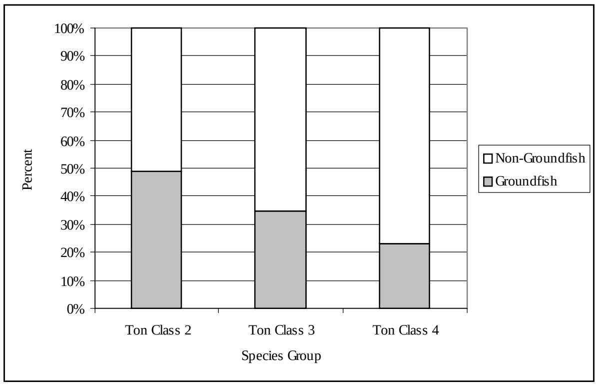

Figure 4. Percent of groundfish and non-groundfish species landed by ton class 1996-98.

Under Amendments 5 and 7 to the Northeast Multispecies Plan, otter trawl vessels have been subject to restrictive regulations in order to rebuild cod, haddock and yellowtail flounder stocks. Currently, all otter trawl vessels have an individual days at sea allocation which restricts the amount of fishing time during a year. Most vessels are allocated 88 days per year, although some can fish up to 164 days per year. Areas of the ocean have also been closed on a year round and seasonal basis to reduce fishing mortality and to protect spawning fish and juvenile fish aggregations. There is also limited entry so no new vessels can enter the fishery. These measures have led to improved conditions for cod, haddock and yellowtail flounder stocks on Georges Bank and in the southern New England fishing areas (NEFMC 1999). However, cod in the Gulf of Maine area has not increased.

3. Methods

Most definitions of capacity are based on either a physical measure of output, or an economic cost definition.

The Federal Reserve and the U.S. Bureau of Census use a physical definition of capacity to define "full production capability", which is the maximum level of output that a producing unit could reasonably expect to attain under normal operating conditions. Both organizations attempt to capture the concept of "sustainable practical capacity", which is the maximum level of production that a plant could reasonably expect to attain using a realistic employee work schedule, and the machinery and equipment in place (Bureau of the Census, 1997). Johansen (1968) also offers a physical definition of capacity which is similar to that used by the Federal Reserve Board and the U.S. Bureau of Census, viz. "Capacity is 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).

Three definitions of capacity that specifically relate to an economic foundation and have been widely used once developed by Morrison (1985) and Nelson (1989). These are: (1) capacity is the output corresponding to the tangency of the short- and long-run average cost curves; (2) capacity is the output corresponding to the minimum point on the short-run average cost curve; and (3) capacity is the output corresponding to the tangency between the long-run average cost curve and the minimum short-run average total cost curve; this latter point represents the long-run competitive equilibrium point.

The FAO Technical Working Group on the Management of Fishing Capacity proposed the following definitions of fishing capacity: (1) The ability of a stock of inputs (capital) to produce output (measured as either effort or catch); fishing capacity is the ability of a vessel or fleet of vessels to catch fish; (2) optimum capacity is the desired stock of inputs that will produce a desired level of outputs (e.g., a set of target fishing mortality rates for the species being harvested) and will best achieve the objectives of a fishery management plan (e.g., minimize costs); current optimal capacity may differ from long run optimal capacity, particularly if the fishery resource is currently depleted and the management strategy is to rebuild this depleted resource; and (3) fishing capacity is the maximum amount of fish over a period of time (year season) that can be produced by a fishing fleet if full-utilized, given the biomass and age structure of the fish stock and the present state of the technology.

Fishery managers and administrators generally prefer the physical or technological-engineering concept of capacity. Cost and earnings data which are necessary for calculating the economic concepts of capacity are seldom available for fisheries. A physical-based definition most closely conforms to fishing mortality in that the input levels (standardized fishing effort) corresponding to capacity output can be related to fishing mortality (Kirkley and Squires, 1999).

The New England multispecies otter trawl fleet is comprised of vessels which utilize multi-input, multi-output technology. That is, several different fixed and variable inputs are used to produce a variety of different outputs. Vessels in this fleet produce up to 13 different outputs. However, individual vessels only produce a subset of the outputs because of limiting factors such as distance from the fishing grounds and vessel size. As cost data is lacking for the majority of vessels, capacity for the New England otter trawl fleet is best estimated using a technological-engineering, or physical output based definition.

Data envelopment analysis (DEA) is particularly well suited for estimating capacity in a multi-species fishery. This is especially true as zero valued outputs can be handled without aggregating across products. Charnes et al. (1978) first introduced data envelopment analysis and extended the Farrell (1957) technical measure of efficiency for a single input, single output technology to a multiple input, multiple output process. Since then, DEA has been used to assess efficiency in many different areas, ranging from the public sector to natural resource based sectors such as the fishing industry.

DEA uses mathematical programming methods to extract information about the production process of each decision making unit (DMU, e.g. firm or fishing vessel) by calculating a maximal performance measure for each firm, and comparing this to a similarly calculated measure for all other firms. The performance measure for each firm traces out a "best practice frontier" and all DMUs must either lie on or below the frontier (Charnes et. al, 1994). A best practice frontier maps out the maximal levels of output (or minimal levels of input) that could be produced (or used) for any given level of input (output). The model used to estimate capacity in the New England otter trawl fleet is described by Färe et al. (1994) who modified an output technical efficiency model to measure capacity consistent with the Johansen (1968) definition

The Färe et al. (1994) output oriented technical efficiency model holds inputs constant and determines the maximal output that can be produced for any given input level. The output oriented technical efficiency model is the following:

where:

$$\underset{\theta, z}{\text{Max}}\,\theta \qquad (1)$$

s.t.

$$\theta u_{jm} \le \sum_{j=1}^{J} z_j u_{jm}, m = 1, 2, ..., M, \qquad (2)$$

$$\sum_{j=1}^{J} z_j x_{jn} \le x_{jn}, n = 1, 2, ..., N, \qquad (3)$$

$$z_j \ge 0, j = 1, 2, ..., J. \qquad (4)$$

is the output technical efficiency measure;
u_{jm} is the quantity of output m produced by DMU j;
x_{jn} is the quantity of input n used by DMU j; and
z_j is the intensity variable for DMU j.

The value of theta calculated by the model is a radial measure providing the maximum proportional expansion in output for each product. Equation 2 represents one constraint for each output, while equation 3 represents one constraint for each input. A 2-input, 2-output model would have four constraints. Equation 4 is the non-negativity condition on the z variables. The model is run once for each DMU in the data set.

To estimate capacity consistent with the Johansen (1968) definition, Färe et al. (1994), modified the vector of inputs found in equation 3 into two sub-vectors, one for fixed factors, and one for variable factors of production. Equation 3 remains the same, but only includes fixed factors. A third equation is added to handle the variable factors, as follows:

where: θ

$$\underset{\theta, z, \lambda}{\text{Max}}\,\theta \qquad (5)$$

s.t.

$$\theta u_{jm} \le \sum_{j=1}^{J} z_j u_{jm}, m = 1, 2, ..., M, \qquad (6)$$

$$\sum_{j=1}^{J} z_j x_{jn} \le x_{jn}, n \in \alpha, \qquad (7)$$

$$\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, n \in \hat{\alpha}, \qquad (8)$$

$$z_j \ge 0, j = 1, 2, ..., J, \qquad (9)$$

$$\lambda_{jn} \ge 0, n \in \hat{\alpha}. \qquad (10)$$

=capacitymeasure;
u_{jm} =quantity produced of output m by firm j;
x_{jn} =quantity of input n used by firm j;
$n \in \alpha$, inputs belonging to the set of fixed factors;
λ_{jn} input utilization rate by firm j of variable input n;
z_j =intensity variable for firm j.

Equation 8 sets constraints for the variable inputs, allowing them to vary so as not to constrain the model. Hence only the observed fixed factors of production found in equation 7 constrain the model. The variable λ_{jn} is the variable input utilization rate which measures the ratio of the optimal use of variable input x_{jn} to its observed level (Färe et al., 1994). Each output is multiplied by the level of theta returned by the model to estimate capacity output. This is consistent with the Johansen (1968) definition of capacity because only fixed factors constrain production.

The above model implicitly assumes constant returns to scale. However, the model can easily be revised to incorporate variable returns to scale by adding the following constraint to the model:

$$\sum_{j=1}^{J} z_j = 1 \qquad (11)$$

One criticism of DEA is that theta is a radial measure. This means all outputs produced by the firm are expanded proportionally. In a multi-output production process, radial expansion may not yield the highest level of production because of slacks in the linear programming model. To address this concern, the capacity output model can be modified to account for slacks by converting the inequality constraints to equality constraints and adding slack variables (for a full discussion of slack values see Intriligator (1971)) as follows:

$$\max_{\theta, z} \theta \qquad (12)$$

s.t.

$$\theta u_{jm} = \sum_{j=1}^{J} z_j u_{jm} - S_m, \; m = 1, 2, ..., M, \qquad (13)$$

$$\sum_{j=1}^{J} z_j x_{jn} + S_n = x_{jn}, \; n \in \alpha, \qquad (14)$$

$$\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, \; n \in \hat{\alpha} \qquad (15)$$

$$\sum_{j=1}^{J} z_j = 1 \qquad (16)$$

$$z_j \geq 0, \; j = 1, 2, ..., J, \qquad (17)$$

$$S_m \geq 0, \; m = 1, 2, ..., M, \qquad (18)$$

$$S_n \geq 0, \; n = 1, 2, ..., N. \qquad (19)$$

Equation 13 is a strict equality; it sets the value of theta times each output (left hand side) equal to the sum of the intensity variables (z_j) times each DMU's output level, minus the slack variable (right hand side). The non-negativity constraint (equation 18) requires that slack variables are either zero, or a positive value. When the left hand side of equation 13 equals the first term on the right hand side exactly, the value of the slack variable is zero. However, when the left hand term is less than the summation on the right hand side, the slack variable takes on a positive value such that the equality constraint holds. Adding the slack variable (S_m) each side of equation 13, yields the following for product m:

$$\theta u_{jm} + S_m = \sum_{j=1}^{J} z_j u_{jm} \qquad (20)$$

The z_j variables are intensity variables which map out the linear segments of the frontier (Färe et al., 1994)and determine frontier output. These are sometimes referred to as "peers" in the OR/MS literature.

The above model was used to estimate capacity output for the New England multispecies otter trawl fleet using the General Algebraic Modeling System (GAMS) language. GAMS was chosen because of its flexibility,, particularly for including slack variables and being able to directly estimate the value of lambda.

4. Data

Data for modeling fisheries problems are often limited because of the available data collection systems. Vessel physical characteristics, such as length, engine horsepower, hull type and gross registered tonnage are routinely collected in the Northeast region as part of the vessel permitting process. Landings and effort data are collected through dealer reports at the point of first sale and through mandatory vessel logbooks. However, important information on inputs such as fuel consumption is not routinely collected.

Fishing vessels are subject to a wide variety of environmental, operating and regulatory conditions which affect vessel output. For example, engine breakdowns, storms, enactment of new regulations and outbreaks of disease in fish populations can all limit output. Further, management measures are often designed to make vessels more inefficient in order to reduce fishing impacts, or for social reasons. For example, trip limits are often enacted

For each New England otter trawl vessel, total landings (live weight) of cod, haddock, yellowtail flounder, pollock, witch flounder, American plaice, windowpane flounder, winter flounder, white hake and redfish were aggregated over the 3 year period, 1996-1998. The species silver hake, red hake and ocean pout were not included because minimum net size regulations are different for these species.[2] Additionally, monkfish (*Lophius americanus*) landings were also included because monkfish are often caught along with the large mesh species. For each vessel, days at sea were summed over all trips in which any of the above 11 species were landed. Total landings of each species were then divided by total days at sea to derive landings per day at sea for each species. This was done for two reasons. First, it smoothed out any peaks or valleys in the data. Secondly, all vessels in the New England otter trawl fleet are regulated through an allocation of days at sea. Therefore, estimated daily capacity for each vessel was multiplied by its total available

[2] The 10 species included are considered "large mesh" species, while the three excluded are considered "small mesh" species.

days at sea to arrive at a final yearly capacity. This yields an estimate of yearly capacity which is conditional on the regulations in place at the time. If fishing time was not restricted, total capacity would be higher, provided the catch per day at sea stayed the same.

Vessels were grouped by tonnage class and then subdivided geographically into fleets based on where a vessel predominantly landed its catch during the 1996-1998 period. The ton class breakdown is typically how managers in the northeast region analyze fishery problems. Vessel size is also an important determinant of how far a vessel can travel safely offshore. Vessels were classified into fleets based in northern Maine, southern Maine, New Hampshire, northern Massachusetts, central Massachusetts, southern Massachusetts, Rhode Island and "Other". The group "Other" encompassed ports outside the New England region that are at the southern edge of the fishing grounds. Geographical segregation of vessels was accomplished to capture the influence of fishing grounds on capacity, with the assumption that vessels landing in the same geographic region are primarily fishing in the same area.[3] One concern raised in some of the DEA literature has been of data sparseness, or lack of observations (Pedraja-Chaparro et al., 1999). To account for this in the otter trawl fleet analysis, the rule of thumb suggested by Banker, et. al (1989) was adopted wherein the number of observations should be at least three times the number of inputs and outputs. This meant that if the number of observations for any fleet was less than 50, it was combined with the nearest fleet of similar sized vessels.[4] As a result, 9 distinct fleets were defined and evaluated.

5. Results

A total of 484 otter trawl vessels had their capacity estimated with the DEA model. Total capacity for the 13 large mesh species was slightly more than 38,000 metric tons, and for monkfish was roughly 11,500 metric tons. Average yearly landings for all ten large mesh species during the 1996-1998 time period was 15,705 metric tons, or 41% of total capacity. For monkfish, average yearly landings were 8,397 metric tons, or 73.2% of capacity output. On a species basis, average yearly landings for each of the ten large mesh species as a percent of maximum output ranged between 23% for yellowtail and winter flounder, to 65% for white hake (figure 5).

An examination of average groundfish and monkfish landings during the 1996-1998 time period, as a percent of total capacity, reveals differences between ton classes (figure 6). Class 2 vessels landed approximately 25 percent of their potential groundfish output, and nearly 50 percent of their potential monkfish output. Class 3 vessels landed a little more than 40 percent of their potential groundfish output, and 70 percent of their maximum monkfish output, while class 4 vessels landed roughly 60 percent of their maximum potential groundfish output, and 90 percent of their potential monkfish output. Intuitively, this is what one would expect given that ton class 2 vessels are not able to range as far offshore as the larger vessels and were probably impacted more by the temporary seasonal closures which took place in the 1996-1998 time period. Class 4 vessels are able to travel great distances in order to take advantage of fishing opportunities.

Excess capacity in an output oriented technological engineering model can be defined as the ability to produce above a desired or target level (Kirkley and Squires, 1999). Because there is no overall multispecies target TAC, excess capacity has to be measured against individual species or stock target TACs. In the New England multispecies fishery, each species/stock has a target TAC. Whether one looks at each species separately, or sums across all species, the DEA results indicate that the fleet had the ability to land much more than they did during the 1996-1998 time period. Many of the management measure implemented between 1996 and 1998 were designed to limit the harvest of cod. The total TAC for cod during 1998 for all stock areas was approximately 6,500 metric tons for all gear sectors (NEFMC, 1999). Ordering the vessels in the otter trawl fleet from greatest to least cod output, and then summing cod output, showed that the top 128 vessels had the ability to take the entire cod quota. These vessels comprised about one-quarter (26.4%) of the total number of active otter trawl vessels.

Latent effort can impact estimates of capacity. Latent effort refers to allocated days which vessels fail to use in a year. For example, a vessel may be allocated 88 days to fish in the multispecies fishery, but only use 40 of those days, and then fish the rest of the year in another fishery.

3

Alternatively, vessels could have been stratified by principal fishing ground. However, then assumptions would have to be made about how each vessel would allocate their allowable fishing time in a given year.

4

Sometimes the number of observations needed was less than 50 due to zero outputs. This happened when all vessels in a particular fleet did not land any pounds of a given species.

This is partially accounted for in the DEA analysis because each vessel has its daily capacity multiplied by its *allocated* days to estimate yearly capacity. However, some vessels have allocations which were not used at all in 1996-1998. Lacking records of fishing activity during the 3-year period means there is no direct way to get a daily estimate of capacity for these vessels. Based on permit data, there were 350 vessels authorized to fish in 1998, which received a days at sea allocation, but had no recorded landings between 1996 and 1998.

To indirectly estimate the potential capacity of these vessels, they were divided into ton classes, and the average capacity per day at sea for active vessels in that ton class was then multiplied by each inactive vessel's days at sea allocation to derive an estimate of total groundfish and monkfish capacity for the inactive vessels. This generated an additional 17,062 metric tons of groundfish capacity for inactive class 2 vessels, 2,541 metric tons for inactive class 3 vessels, and 1,103 metric tons for inactive class 4 vessels. There was also an additional 2,660 metric tons of potential monkfish output for inactive class 2 vessels, 783 metric tons for inactive class 3 vessels, and 493 metric tons for inactive class 4 vessels.

During 1996-1998 a total of 832 active and inactive otter trawl vessels possessed groundfish permits. The total estimated groundfish capacity for these vessels was 58.8 thousand metric tons, and 15.4 thousand metric tons for monkfish. Class 2 vessels had an estimated groundfish capacity of 26.1 thousand metric tons, and monkfish capacity of 4.1 thousand metric tons. Class 3 vessels had an estimated groundfish capacity of 23.7 thousand metric tons, and monkfish capacity of 7.3 thousand metric tons. Class 4 vessels had an estimated groundfish capacity of 9 thousand metric tons, and monkfish capacity of 4 thousand metric tons. On a per vessel basis, estimated groundfish capacity for class 2 vessels was 59 metric tons; for class 3 vessels , 79 metric tons; and for class 4 vessels it was 103 metric tons. Estimated monkfish capacity was 9 metric tons for class 2 vessels; 24 metric tons for class 3 vessels; and 46 metric tons for class 4 vessels. The differences between ton classes are expected given the size and operational characteristics of each tonnage class.

6. Summary and Conclusions

Capacity for the New England groundfish otter trawl fleet was estimated using Data Envelopment Analysis (DEA). Groundfish capacity was estimated on a day at sea basis and then multiplied by the days at sea allocation for each vessel to arrive at an estimate of total capacity. Results indicated excess capacity with respect to both groundfish and monkfish. Capacity levels were estimated to be far higher than average landings between 1996 and 1998. The total cod TAC could have been taken by 1/4 of the active otter trawl vessels.

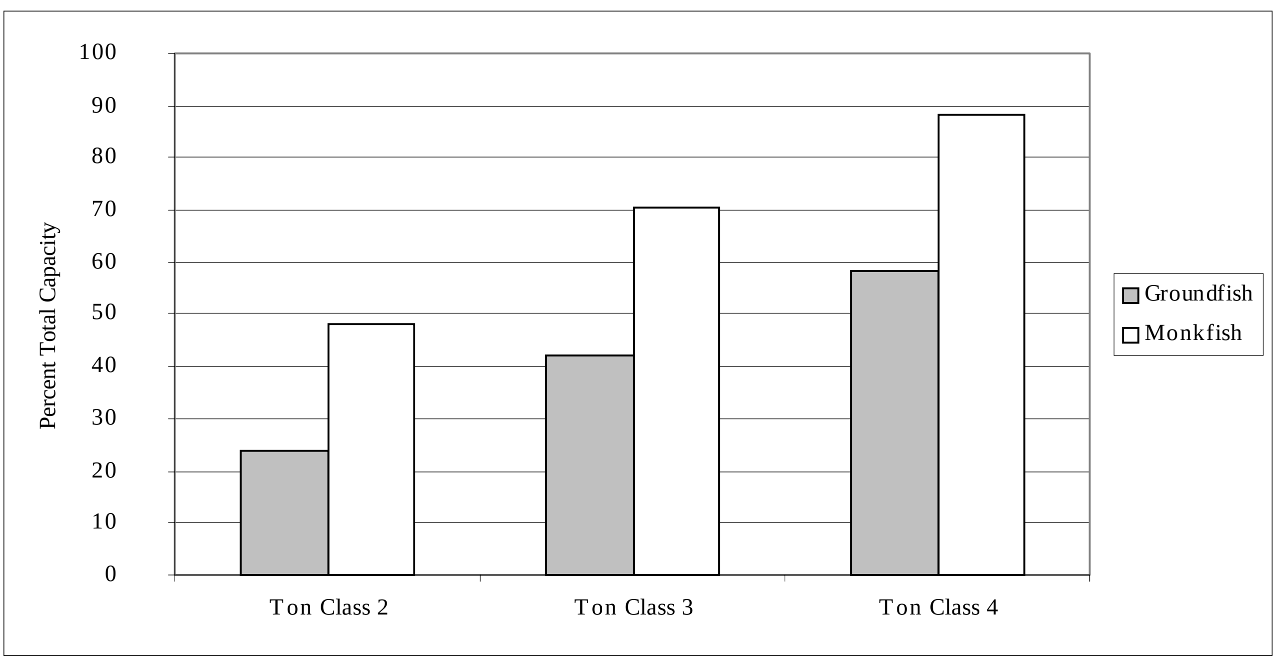

Figure 5. Average landings (1996-1998) of groundfish and monkfish as a percent of maximum potential output by ton class

The ability of DEA to address multiple-input, multiple-output production processes, and to handle zero valued outputs make DEA advantageous for estimating vessel capacity. DEA generally gave credible estimates of capacity based on our knowledge of the fishing fleet. However, there were also some problems, particularly that of latent effort. For vessels which had a landings history, but fished very little, this wasn't a problem because DEA provided an estimate of output per day at sea, which could then be multiplied by allocated days at sea. For vessels without a landings record, an average capacity value (based on active vessels) was multiplied by the vessel's days at sea allocation. Another alternative might have been to search back in time for a landings record, and use output from a prior time period in the DEA model. However, in the past, vessels have used different technologies and been subject to a different set of regulations than currently exist.

In our methods, no explicit constraints were included to handle stock biomass. However, such constraints would probably not be binding because fishing regulations are constructed so all vessels only harvest a portion of the biomass. Another important matter is how to interpret the DEA model results for a multi-species fishery. For example, it seems inappropriate to take an individual output such as cod, and derive an estimate for cod capacity. This is because vessels could discard or avoid cod, and increase the harvest of another species if the relative prices changed for the two species. Hence, capacity estimates for individual species should not be aligned with biological reference points such as MSY. However, aggregating across all species should provide an indication of maximum output from a multispecies complex.

DEA estimates of capacity presented in this paper are short-run concepts. That is, the Johansen definition we employed emphasized maximum output with "existing plant and equipment". Our capacity estimates reflect average yearly capacity given the capital which existed during 1996-1998. These estimates should not be used to align capacity with biological targets when stocks are recovered. What we can conclude is that given current stock conditions, and the regulatory environment, excess capacity exists in the New England otter trawl fleet.

7. References

Banker, R.D., A. Charnes, W.W. Cooper, J.Swarts and D. Thomas. An introduction to Data Envelopment Analysis with some of its models and their uses. Research in Government and nonprofit Accounting 5:125-163. 1989.

Charnes, A., W. Cooper and E. Rhodes. Measuring the efficiency of decision making units. *European Journal of Operational Research* 2(6): 429-444. 1978.

Charnes, A., W. Cooper, A. Y. Lewin and L.M. Seiford. Data Envelopment Analysis. Theory, Methodology and Applications. Boston: Kluwer Academic Publishers, 1994.

FAO. Assessing excess capacity at the world-wide level. Rome:Food and Agriculture Organization of the United Nations. 1998.

Färe, R., S. Grosskopf and C.A. Knox Lovell. Production Frontiers. New York: Cambridge University Press, 1994.

Farrell, M.J., The measurement of productive efficiency. *Journal of the Royal Statistical Society*, Series A, General, 120, Part 3, 253-81. 1957

Federal Fisheries Investment Task Force. Report to Congress. National Marine Fisheries Service, Silver Spring, MD. 1999.

Intrilligator, M.D., Mathematical Optimization and Economic Theory. Englewood-Cliffs:Prentice-Hall, 1971.

Johansen, L. Production functions and the concept of capacity, in Recherches recentes sur la fonction de production. Namur: Centre d'Etudes et de la Recherche Universitaire de Namur, 1968.

Kirkley, James and Dale Squires. Capacity and Capacity Utilization in Fishing Industries. Unpublished manuscript. Virginia Institute of Marine Sciences, Gloucester Point, VA 23062. April 1999.

Morrison, C.J. Primal and dual capacity utilization: An application to productivity measurement in the U.S. automobile industry. *Journal of Business and Economic Statistics* (3): 312-324. 1985.

Nelson, R. On the measurement of capacity utilization. *Journal of Industrial Economics*, 37:(3):273-286. 1989.

New England Fishery Management Council (NEFMC). Report of the multispecies monitoring committee. 1999.

Pedraja-Chaparro, F., J. Salinas-Jiménez and P. Smith. On the quality of the data envelopment analysis model. *European Journal of Operational Research* 50:636-644. 1999.

Resti, A. Efficiency measurement for multi-product industries: A comparison of classic and recent techniques based on simulated data. European Journal of Operational Research 121:559-578. 2000.

U.S. Department of Commerce, Bureau of the Census. Survey of plant capacity:1997. Current Industrial reports. MQ-C1(97).