

Methodological Workshop On the Management of Tuna Fishing Capacity

La Jolla, CA, USA, May 8 to 12, 2006

Document P13/A8

Tara Scott, James E. Kirkley, Ronald Rinaldo, and Dale E. Squires

Assessing Capacity in the U.S. Northwest Atlantic, Pelagic, Longline Fishery for Highly Migratory Species with Undesirable Outputs

Table of Contents

1.0 Introduction.....	1
2.0 Definitions and Concepts	2
3.0 The Pelagic Longline Fishery, the Good and Bad Outputs, and the Data.....	4
4.0 Methodology, Data Envelopment Analysis, and Directional Vectors	4
5.0 Results: Estimates of Capacity Output Under Different Assumptions	6
6.0 Conclusions	8
7.0 References.....	9

1.0 Introduction

Although excess capacity has been recognized by the United Nations Food and Agriculture Organization (FAO) and member nations as an issue of global concern, the FAO and member nations have also widely recognized the problem of the incidental or inadvertent capture of non-marketable bycatch (i.e., bycatch discards). To date, most assessments of capacity, however, have ignored the potential relationship between capacity output and undesirable bycatch (i.e., capture of other species for which either their retention is prohibited or they cannot be marketed). If undesirable bycatch reduction is one objective of capacity reduction programs, failure to consider bycatch in the estimation and assessment of capacity will result in overestimating capacity output. Alternatively, estimates of capacity output, which exclude the potential for reducing undesirable outputs, will be larger than estimates of capacity, which attempt to directly incorporate reductions in undesirable outputs.

In this paper, we expand the traditional data envelopment analysis (DEA) approach for estimating capacity to explicitly allow for the reduction or non-expansion of undesirable outputs. Instead of using the conventional output distance function approach described

in Kirkley and Squires (1999) and Pascoe et al. (2003), we introduce the notion of a directional distance vector, which allows for the estimation of capacity relative to desirable outputs while simultaneously allowing for the reduction of undesirable outputs. We illustrate the methodology using set-level data obtained from gear experiments conducted by pelagic longline gear operations in the U.S. northeast distant water area. The results, although limited relative to depicting capacity representative of the entire fleet, do indicate that capacity output, when estimated conditional on reducing undesirable outputs, is considerably less than estimates of capacity output, which ignore reducing the levels of undesirable outputs.

2.0 Definitions and Concepts

The Food and Agriculture Organization (FAO) has formally defined capacity as *the amount of fish (or fishing effort) that can be produced over a period of time (e.g., a year or a fishing season) by a vessel or a fleet if fully utilized and for a given resource condition*. This same concept of capacity is utilized in this paper. As such, it is a technological-economic measure of capacity output (Kirkley et al. 2002).

Unlike previous assessments of capacity, however, we differentiate two types of outputs in this paper. First, we consider the conventional notion of desirable or marketable outputs (i.e., legal commercially landed product). Next, however, we consider undesirable products or those products which cannot be marketed either because of the absence of a market or have regulations prohibiting their capture and/or landing. Because of the inclusion of undesirable outputs, we modify the basic definition of capacity output to specifically include the notion of reducing or preventing the capture of undesirable outputs. Alternatively, capacity output is the amount of fish that can be produced over a period of time by a vessel or a fleet if full utilized, given resource conditions, and adjusted to reflect the potential reductions in undesirable outputs.

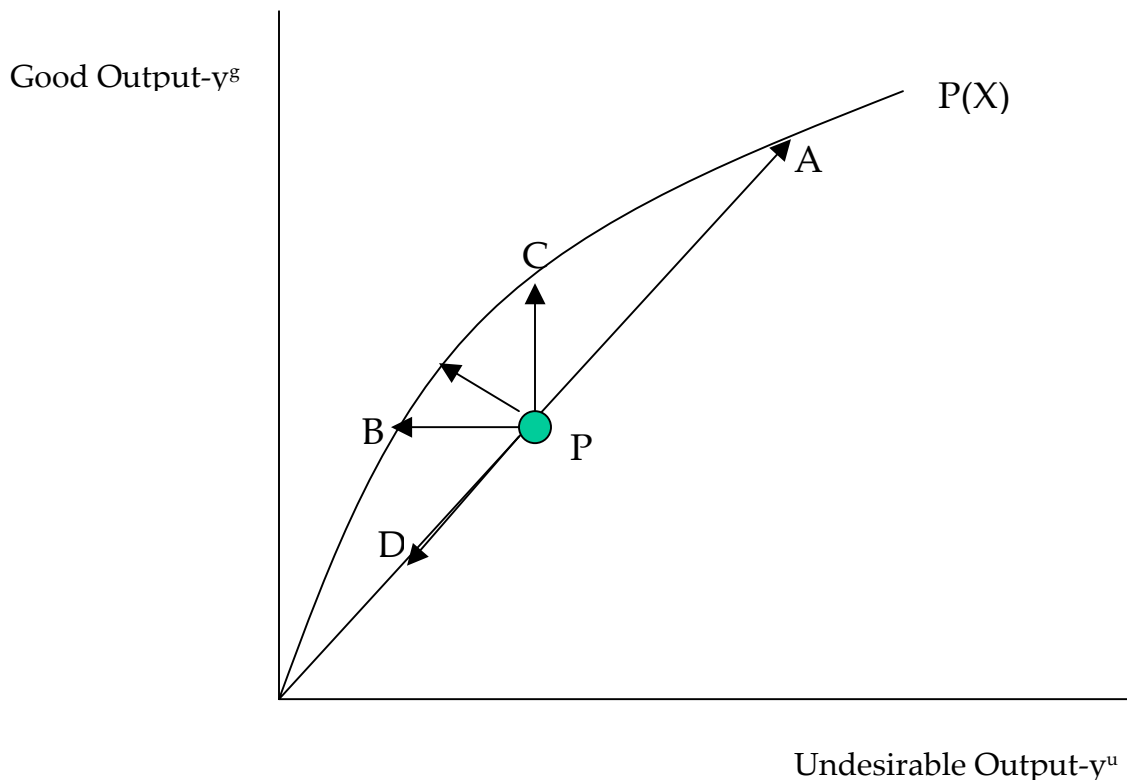
We also introduce an alternative notion of the distance function—the directional distance function. In previous DEA-based assessments of capacity, an output distance function was estimated to determine the potential expansion in outputs, given the fixed factors (e.g., vessel size and engine horsepower) of production. In the present study, a directional distance function is estimated, which explicitly allows for the expansion of desirable or good outputs and contraction of undesirable or bad outputs subject to the constraints of the fixed factors.

To gain a better understanding of the differences in using the output vs. directional distance function approach, consider figure 1. A production possibilities frontier (i.e., maximum output levels for a given level of inputs) is depicted as $P(X)$. One good and one bad output are produced in the example. The production level of the good output is depicted on the vertical or y-axis, and on the horizontal x-axis, the production level of a bad output is depicted. Note that in this example, good outputs cannot be produced

without some level of bad outputs; this is referred to as the null-joint property. Let point P be a point representing levels of good and bad outputs. With the conventional approach of using the output distance function to estimate capacity, we seek to determine the maximum expansion of both good and bad outputs subject to the limitations imposed by the fixed factors (e.g., point A in figure 1).

With the directional vector approach, however, we can determine expansions (or contractions) of good outputs and contractions or no changes in the level of bad or undesirable output. That is, solutions can be determined that are in the direction of B (increase in good output and decrease in bad output) and C (increased in good output and no change in bad output), or in the direction of D (decrease in the level of production of both good and bad outputs).¹ In this paper, we primarily seek expansions of good outputs and contractions of bad outputs in the direction between B and C. For comparative purposes, however, we also estimate capacity output for the case of contracting good outputs along with bad outputs (i.e., direction D).

Figure 1. Range in Directions for Expanding (Contracting) Outputs



¹ Lee et al. (2002) provide a comprehensive overview of selecting the direction of directional distance vectors in the estimation and analysis of technical efficiency.

3.0 The Pelagic Longline Fishery, the Good and Bad Outputs, and the Data

The Northwest Atlantic, pelagic, longline fishery is a multi-species fishery, which can change gear styles, and make small changes to the gear configuration to promote the best economic opportunity for each individual trip. The fishery operates between Maine and Florida, but the majority of the catch is taken in the Mid-Atlantic region.² The fishery primarily targets swordfish and tuna, but also captures and lands various sharks. There are approximately 171 vessels active in the entire Atlantic and Gulf of Mexico fisheries. The targeted or desirable outputs are swordfish, albacore tuna, bigeye tuna, yellowfin tuna, bluefin tuna, and sharks. The undesirable or bad outputs are loggerhead and leatherback sea turtles; in the analysis, however, the two are linearly aggregated (i.e., the number of loggerhead turtles plus the number of leatherback sea turtles equals the total number of turtles caught).

The estimation and assessment of capacity in this fishery utilized data obtained from numerous at-sea experiments conducted in 2002 and 2003, and designed to assess the performance of different hook sizes and types (J vs. circle hook), different types of bait, and the usage of lightsticks.³ The experimental data were from the Northeast Distant Water area, which is area off the coast of New England and extends down to the Mid-Atlantic region. This resource area has been closed to commercial fishing for several years. Landings data were in terms of dressed weight, and the sea turtle catch was in terms of the numbers of animals caught. Information was available on the following inputs: (1) engine horsepower, (2) vessel length, (3) soak duration, (4) haul duration, (5) set duration, (6) gangion distance, (7) mainline length, (8) number of hooks, (9) number of lightsticks, (10) number of floats, and (11) number of radio beacons. For the purpose of estimating capacity output, engine horsepower and vessel length were considered to be the only limiting or fixed factors; all the other factors of production or inputs were considered to be variable inputs. Since the estimation requires the assumption of null-jointness (i.e., there must be at least one good output and at least one bad output for each observation), the estimation of capacity was restricted to 251 observations or experimental sets. More than 1,900 experimental sets were actually made over the course of the experiment.

4.0 Methodology, Data Envelopment Analysis, and Directional Vectors

Although there is no officially sanctioned or internationally accepted method for estimating capacity output in fisheries, the most widely used approach, to date, has been data envelopment analysis or DEA (Pascoe et al. 2003; Kirkley et al. 2004). Furthermore, only the output-oriented version of DEA, or an output only directional vector approach, have been used to estimate capacity in fisheries.⁴ Since the details of the conventional

² The Gulf of Mexico pelagic longline fishery harvests the majority of landings in the highly migratory species (HMS) pelagic longline fishery.

³ The details of the experiments and data are provided in Watson et al. (2002 and 2003).

⁴ The output orientation directional vector approach is the directional vector approach in which

output-oriented approach have been widely published in various FAO publications (e.g., Kirkley and Squires 1999; Pascoe et al. 2003), we present only the details of the directional distance function approach.

The directional distance vector approach is quite similar to the traditional output-oriented DEA approach. We seek to determine the maximum expansion, but only for the good outputs, while conditioning the expansion on the same proportional reduction in bad outputs (e.g., if it is determined that the capacity output of tuna is 25.0% more than the existing level of observed landings of tuna, then the level of bad outputs is reduced by 25.0 %).

With the traditional output-oriented model, capacity is estimated according to the model formulation and restrictions of Färe (1984) and Färe et al. (1989). This is a mathematical programming problem, which seeks to determine the maximum proportionate expansion in all outputs, given no change in the fixed factors of production, but allowing for changes in the variable factors (e.g., fuel and labor) of production. The proportionate expansion is estimated by solving for the inverse value of an output distance function; this is done for each and every observation included in the analysis.⁵

The directional vector approach also seeks to determine the maximal expansion in good outputs, but subject to contractions of the bad outputs. In this study, we impose the condition that the proportionate maximal expansion of good outputs is also equal to the proportional maximum contraction of bad outputs (e.g., a 25 % increase in good outputs relative to observed levels is accompanied by a 25 % decrease in bad outputs relative to their observed levels).⁶

The following mathematical programming problem was specified and used to estimate capacity output such that good outputs and bad outputs are required to expand and contract, respectively, by the same proportion, β :

only outputs are allowed to increase, given that inputs are held constant, and reductions in bad outputs are not allowed. This approach yields the same estimates of capacity as does the more traditional output-oriented DEA approach.

⁵ An output distance function is the mathematical distance between an observed output bundle (or output in a single output case) and the output bundle corresponding to the potential maximum or frontier output. The maximum potential output is a benchmark level of production determined by vessels of similar sizes. This is similar to the concept of efficiency ratings used to rank appliances of a particular type (e.g., hot water heaters). Initially, energy consumption is calculated for a group of appliances of similar sizes and price rangers; energy consumption of all, except the most energy efficient appliance, are compared to the energy consumption of the most energy efficient appliance, and a rating is assigned.

⁶ This is not a requirement of the directional vector. It is possible to determine different levels of expansion for each good output and different levels of contraction for each bad output; this is referred to as the Pareto-Koopmans (1951) concept of efficiency.

$$\begin{aligned} \vec{D}_o(x^j, y^j, u^j; g) &= \underset{\beta, z}{\text{Max}} \beta \\ \text{s.t.} \\ \sum_{j=1}^J z_j y_{jm} &\geq y_{jm} + \beta g_m, m = 1, \dots, M \\ \sum_{j=1}^J z_j u_{jk} &= u_{jk} + \beta g_k, k = 1, \dots, K, \\ \sum_{j=1}^J z_j x_{jn} &\leq x_{jn} \quad n = 1, \dots, N, \\ \sum_{j=1}^J z_j &= 1.0, \\ z_j &\geq 0, j = 1, \dots, J. \end{aligned}$$

where \vec{D}_o is the directional vector; x is a vector of fixed factors (vessel length and engine horsepower); y is a vector of good outputs (weights of desirable outputs of swordfish, tunas, and sharks); u is a vector of bad outputs (number of sea turtles); the g functions are the directions of the distance vectors (1.0 for good outputs and -1.0 for bad outputs); there are J observations, M good outputs, K bad outputs, and N inputs or fixed factors; β is the value of the directional distance vector, and equals 0.0 if the observed good (bad) output cannot be increased (decreased), and is > 0.0 if the observed good (bad) output can be expanded (contracted) (the level of expansion (contraction) equals the value of β); and the constraint, $\sum z_j = 1.0$ imposes variable returns to scale.

The equality constraint, $\sum_{j=1}^J z_j u_{jk} = u_{jk} - \beta g_k, k = 1, \dots, K$, requires additional

consideration. This constraint imposes what is referred to as weak subvector disposability. Weak subvector disposability, in contrast to strong disposability, imposes the condition that it is not costless to catch and dispose of undesirable or bad outputs; alternatively, in this formulation, it explicitly recognizes that labor must be reallocated to dispose of undesirable outputs and reductions in bad outputs may cause reductions in good outputs. In the traditional framework for assessing capacity, strong disposability, or the conditional that there is no cost of disposing of undesirable outputs, is imposed on the technology. This is straightforward mathematical (linear) programming problem, and is solved for each observation. The solution yields values of β , which indicates the percentage by which good and bad outputs, respectively, may be expanded and contracted.

5.0 Results: Estimates of Capacity Output Under Different Assumptions

The previously discussed DEA model was estimated under three basic assumptions: (1) both good and bad outputs could expand, and the cost of disposing of bad outputs was 0.0 (i.e., strong disposability was imposed); (2) good outputs could expand according to allowable capacity levels, while bad outputs had to be reduced (subvector weak disposability); and (3) both good and bad outputs had to be reduced (global weak disposability). In the first case, the directional functions equaled 1.0 in value; in the

second case, the directional distance of the good output equals 1.0 in value, and the directional distance of the bad output equaled -1.0 ; and in the last or third case, the directional function for the good and bad output equaled -1.0 in value, thus forcing reductions in both the good and bad outputs. Estimation was accomplished using user-written code available in LINGO (2002).

Capacity was estimated using the 251 observations obtained from the experiments to assess options for reducing sea turtle bycatch in the pelagic longline fishery. Twelve vessels are included in the observations, and the observations pertain to experiments conducted in 2002 and 2003. Given the limited number of observations, the results should not be viewed as being representative of the entire pelagic longline fleet, but only representative of the 12 vessels participating in the experiments. Vessel size ranged from 58 to 85 feet (17.7 to 25.9 m), and engine horsepower varied between 265 and 850 horsepower (hp) (Table 1). Vessel and engine size for the entire northwest Atlantic and Gulf of Mexico pelagic longline fleet equaled, respectively, 59.0 feet and 441 horsepower. Landings of swordfish per set varied between 0.0 and 4,415 pounds, with an average landings per set of 954 pounds, and the average landings per set of albacore, yellowfin, bigeye, bluefin, and sharks, equaled, respectively, 17, 5, 97, 21 and 567 pounds.

Table 1. Summary Statistics Per Set of Pelagic, Longline, Experimental Data^a

Statistic	Horsepower	Length	Swordfish	Albacore	Yellowfin	Bigeye	Bluefin	Shark	Turtles
Mean	465	68	954	17	5	97	21	567	1
N	251	251	251	251	251	251	251	251	251
Minimum	265	58	0	0	0	0	0	0	1
Maximum	850	85	4,415	272	411	1,122	490	2,648	18
Total Over N			239,345	4,205	1,175	24,386	5,384	142,353	376

^aWeights for desirable species are in pounds, and the output of sea turtles is measured in terms of number of turtles caught.

We next consider the potential expansions and contractions of desirable and undesirable outputs. The desirable outputs are swordfish, albacore, yellowfin, bigeye, bluefin, and sharks, and the undesirable outputs are sea turtles. Based on the conventional approach for estimating capacity, we observe that capacity output for swordfish, bigeye, and sharks is almost double or slightly more than double the observed levels of production; and capacity output is only slightly higher for albacore, yellowfin and bluefin (Table 2). There is, however, a 169 % increase in the number of sea turtles captured. When good outputs are allowed to expand, but the undesirable outputs must be decreased or remain unchanged, capacity output is only slightly higher for all of the desirable outputs, and there is a decline in the number of sea turtles caught. If it is assumed that all products are complements (desirable and undesirable outputs must jointly increase or decrease) and the only way that sea turtle catch can be reduced is to reduce the

desirable outputs, capacity output is decreased to levels less than the observed levels. This last condition also yields the largest reduction in the capture of sea turtles—from 376 to 255 turtles.

Table 2. Observed and Estimated Capacity Output of Desirable and Undesirable Outputs^a

Allowable Expansion and Contraction	Swordfish	Albacore	Yellowfin	Bigeye	Bluefin	Sharks	Sea Turtles
Observed Levels	239,345	4,205	1,175	24,386	5,384	142,353	376
Conventional Approach: Expand Good and Bad	564,809	6,252	1,391	46,790	7,257	318,584	1,012
Directional Vector: Expand Good and Contract Bad	265,525	4,471	1,179	26,322	5,669	155,161	337
Directional Vector: Contract Good and Bad	207,569	3,582	880	21,113	4,250	118,630	255

^aWeights for desirable species are in pounds, and the output of sea turtles is measured in terms of number of turtles caught.

6.0 Conclusions

In this brief study, it was demonstrated that if managers desire estimates of capacity conditional on recognizing that the production of undesirable outputs should be reduced, the conventional DEA approach or the strict output-orientation yields higher estimates of capacity than do procedures designed to incorporate a reduction in undesirable outputs. The notion of a directional vector or directional distance function was introduced, and used to demonstrate a method for estimating capacity when there is a need to consider the reduction of undesirable outputs.

In this study, there were six desirable and one undesirable output. The desirable outputs included swordfish, albacore, yellowfin tuna, bigeye tuna, bluefin tuna, and sharks, and the undesirable output was the number of sea turtles caught in experimental sets. The analysis was based on data obtained from at-sea experiments conducted in the Northeast Distant Water area and relating to pelagic longline activities. Since only 251 observations over 12 vessels were included in the data set, it is not possible to draw representative conclusions about the entire pelagic longline fleet, either in the Northwest Atlantic or the Gulf of Mexico.

This paper, thus, mostly offers an alternative methodology for estimating capacity as opposed to an empirical study or examination of capacity for an entire fleet. Fisheries management around the world, however, is increasingly emphasizing reductions in the capture or interactions of undesirable outputs (e.g., marine mammals, sea birds, juvenile

species, non-marketable species, and sea turtles). Management agencies are also concerned about the destruction of essential fish habitat. The approach offered in this paper is one way to assess capacity while incorporating such concerns. In addition, as management agencies increasingly collect more data on discards, etc., through log-books, at-sea observers, and other procedures, it will become increasingly easier to examine the relationship between capacity output and undesirable outputs.

7.0 References

Färe, R. (1984). On the existence of plant capacity. *International Economic Review*, 25 (1): 209-213.

Färe, R., Grosskopf, S. & Kokkelenberg, E. (1989). Measuring plant capacity, utilization and technical change: a nonparametric approach. *International Economic Review* 30 (3): 656-66.

Kirkley, J.E. & Squires, D. 1999. Measuring capacity and capacity utilization in fisheries. In D. Gréboval, ed. *Managing fishing capacity: selected papers on understanding concepts and issues*. FAO Fisheries Technical Paper 386, Rome.

Kirkley, J., Morrison-Paul, C.J. & Squires, D.E. 2002. Capacity and capacity utilization in common-pool industries. *Environmental Resource Economics*, 00:1-27.

Kirkley, J., Morrison-Paul, C.J. & Squires, D.E. 2004. Deterministic and stochastic capacity estimation for fishery capacity reduction. *Marine Resource Economics*, 19, 3: 271-294.

Koopmans, T.C. 1951. An analysis of production as an efficient combination of activities. In Koopmans, T.C. *Activity analysis of production and allocation*, Cowles Commission for Research in Economics, Monograph No. 13. New York: Wiley.

Lee, J.D., Park, J.B. & Kim, T. 2002. Estimation of shadow prices of pollutants with production/environment inefficiency taken into account: a nonparametric directional distance function approach. *Journal of Environmental Management*, 64: 365-375.

Lindo Systems, Inc. 2002. LINGO: The modeling language and optimizer.

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

Watson, J.W., Foster, D.G., Epperly, S., & Shah, A. 2002. Experiments in the western Atlantic Northeast Distant Waters to evaluate sea turtle mitigation measures in the pelagic longline fishery: report of experiments conducted in 2001.

www.mslabs.noaa.gov/mslabs/docs/watson1.pdf.

Watson, J.W., Foster, D.G., Epperly, S., & Shah, A. 2003. Experiments in the western Atlantic Northeast Distant Waters to evaluate sea turtle mitigation measures in the pelagic longline fishery: report of experiments conducted in 2001-2003.

www.mslabs.noaa.gov/mslabs/docs/watson4.pdf.