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Estimates of large-scale purse seine, baitboat and longline fishing capacity in the Atlantic: An analysis based on a stock assessment of bigeye tuna

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1.0 Introduction

An external Technical Advisory Committee (TAC) to a FAO project on tuna fishing capacity has recommended that the Data Envelopement Analysis (DEA; see Kirkley and Squires 1999) be used to estimate capacity for tuna fleets. Reid et al. (2005) applied this approach to obtain estimates of capacity, capacity utilization and excess capacity of the purse seine fleet that targets tropical tunas (bigeye, skipjack and yellowfin) in the Atlantic Ocean. However, they found the available information to be largely inadequate because the data were highly aggregated. With the available data, it is not possible to associate vessel characteristics with each vessel's fishing effort and resulting catch at a detailed level, *e.g.*, in a particular trip or month. Miyake (2005), who estimated the capacity of the longline fleets operating worldwide in recent years, also noted that the available information for longliners in the Atlantic was highly aggregated. The situation is the same for other major gear types such as baitboats. Thus, alternative approaches to measure capacity may be necessary for Atlantic tuna fisheries in the absence of disaggregated data.

This paper presents an alternative approach based on the traditional definition of fishing capacity: "Capacity is ... the maximum yield in a given period of time that can be produced given the capital stock, regulations, current technology and state of the resource" (Kirkley and Squires 1999). The estimates of capacity are obtained based on inputs and outputs from a stock assessment of bigeye tuna (*Thunnus obesus*).

The quantitative approach presented here uses the available information from the assessment. Briefly, an algorithm that connects consecutive peaks is applied to estimated fishing mortality on a fishery-by-fishery basis to obtain time series of fishing capacity for each fishery. These are then used to infer, on the basis of the assessment results, the output capacity (in tons) for each fishery as well as the total. The assessment incorporates information about age-specific selectivity as well as time trends in fishing efficiency.

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[†] The conclusions presented in this paper do not necessarily represent the views of ICCAT

2.0 Methods

2.1 The assessment and data used

The stock assessment used is a 2004 application of MULTIFAN-CL (Fournier *et al*., 1998) to Atlantic bigeye tuna data. The basic data sets used and assumptions made are described in detail by Miyabe *et al*. (2005)*. The particular model run that was used in this paper was an update of the work of Miyabe *et al.* (2005) which was conducted during the last ICCAT stock assessment for bigeye (ICCAT, 2005). The model considered the following:

- 3 regions (1: North of 25ºN; 2: 25ºN-15ºS; and, 3: South of 15ºS)
- 14 fisheries: 3 purse seine, 5 baitboat (pole-and-line and other surface), and 6 longline
- Quarterly catch-effort and length-frequency data from 1961 to 2002
- Auxiliary tagging information
- Time trends in catchability for most fleets.

The MULTIFAN-CL model provided estimates of a large number of parameters related to abundance, movement rates, growth, and fishing mortality. The assessment outputs used for the calculations below were: observed and predicted catches, fishing mortality and exploitable population size, by fishery, year and quarter.

2.2 Fishing and output capacity

An *ad hoc* approach is used in this paper to estimate maximum fishing mortality as a measure of "fishing capacity".

One of the MULTIFAN-CL model results obtained was estimates of fishing mortality for each of the 14 fisheries, by year and quarter. In all cases, the observed catches and estimated fishing mortality values showed strong seasonal patterns.

Maximum fishing mortality for each fishery was estimated by assuming that, for a given quarter, the available fishing mortality should not change very much between consecutive annual peaks. A "peak" was defined as a value of fishing mortality that was higher than the preceding and subsequent values. The fishing mortality from a peak in a given year was assumed to remain available until the next peak some years later.

Let *m* be the time of a peak and *n* be the time of the next peak, *y* denote year, *q* denote quarter and *g* denote the fishery:

$$\hat{F}_{y,q,g} = F_{m,q,g} \qquad \text{for } y = m \text{ to } n\text{-}1$$

where F is the fishing mortality estimated by MULTIFAN-CL and $\hat{F}$ is the maximum fishing mortality in this paper.

Output capacity was estimated by applying the maximum fishing mortality estimates to the MULTIFAN-CL estimates of abundance (exploitable stock size for each fishery) in order to compute the potential catch that would have resulted.

* Available from http://www.iccat.int/Documents/CVSP/CV057_2005/no_2/CV057020177.pdf

2.3 Capacity utilization, MSY, excess capacity and overcapacity

Capacity utilization was calculated as the ratio of observed catch to output capacity; excess capacity was defined as the difference between output capacity and observed catch; over-capacity was estimated by subtracting estimates of maximum sustainable yield (MSY) from the overall (all gears combined) capacity output.

Although MSY is often though of as a constant, it is not so when there are a number of fisheries that target different age groups and whose relative intensity varies over time. In the case of Atlantic bigeye tuna, the history of the fishery has progressed in such a way that the average size in the catch (for all fisheries combined) has decreased considerably over time. Because selectivity affects yield-per-recruit, and yield-per-recruit in turn affects equilibrium yield, then the estimates of MSY could change substantially if the overall selectivity changes. In this paper, the approach explained in Restrepo *et al*. (1994) was used to estimate MSY.

3.0 Results

While the computations made for this study were carried out by fishery and quarter, the results were aggregated by gear type and year. This should suffice for the illustrative purposes of this paper.

3.1 Output Capacity

Figure 1 illustrates how the approach used to estimate available fishing mortality was applied using as an example the Japanese longline fishery in Region 2 (this was defined as fishery 10 in the MULTIFAN-CL analyses). Each of the panels shows the time series of relative fishing mortality for a given quarter.

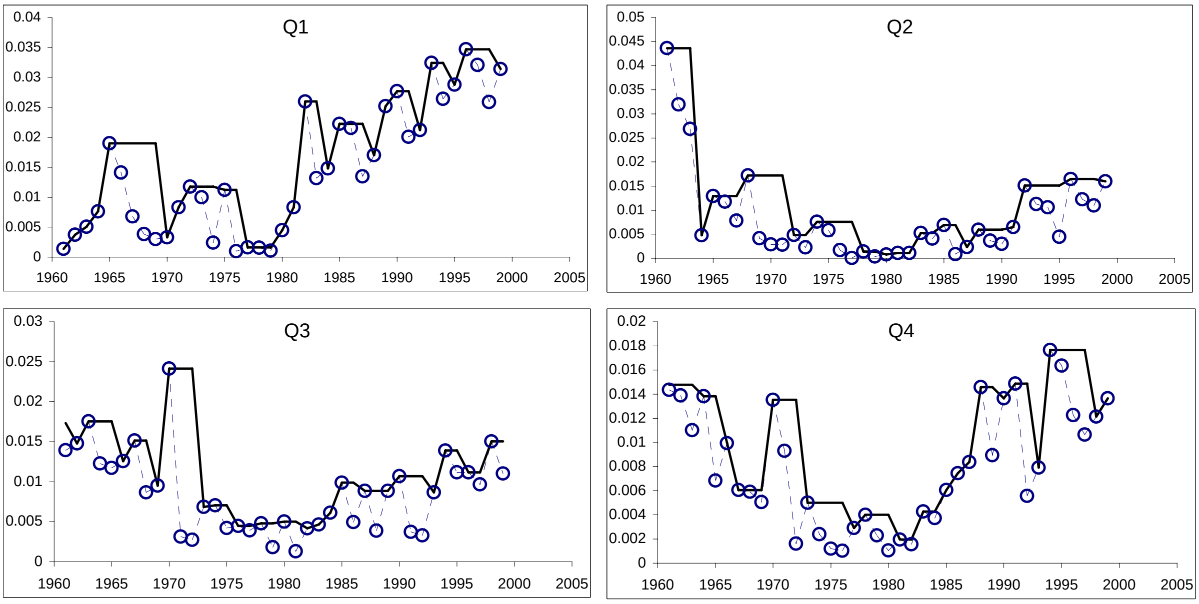

Figure 1. Example of how the methods to estimate maximum fishing mortality was applied. The circles are the outputs from MULTIFAN-CL and the solid line is the maximum *F*.

Figure 2 illustrates the corresponding estimates of output capacity for several of the 14 fisheries in the analyses. In all cases, the method tracked the observed seasonal pattern in fishing mortality and corresponding catches.

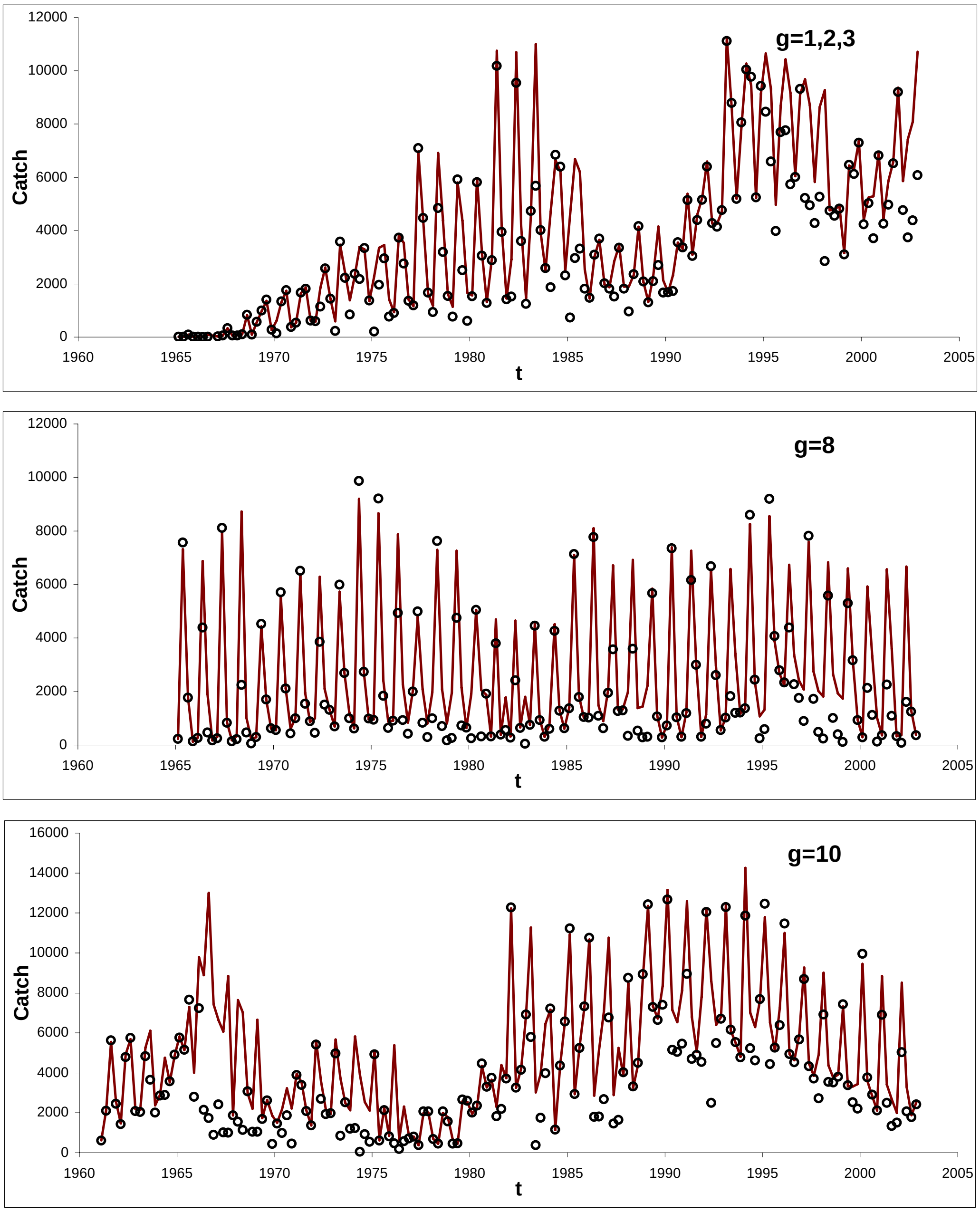

Figure 2. Example of how the approaches applied to estimate output capacity performed for several of the 14 fisheries examined. The open circles represent the observed catches, and the lines represent the estimates of capacity output. The top figure corresponds to 3 sequential purse seine fisheries in Region 2; the middle figure corresponds to miscellaneous baitboat fisheries in Region 2; the bottom figure corresponds to Japanese longliners in Region 2. Note: Region 2 is the area where the majority of catches occur.

The estimates of capacity output are presented in **Table 1**, together with the observed catches.

Table 1. Estimates of observed catch and capacity output for Atlantic bigeye tuna. Estimates are in thousand tons and aggregated by gear type.

	Purse Seine		Baitboat		Longline			
Year	Catch obs.	Capacity output	Catch obs.	Capacity output	Catch obs.	Capacity output	Tot. Catch obs.	Tot. Capacity output
1961	0.0	0.0	0.0	0.0	11.2	11.3	11.2	11.3
1962	0.0	0.0	0.1	0.1	15.9	16.3	16.0	16.3
1963	0.0	0.0	0.4	0.4	15.0	19.8	15.4	20.1
1964	0.0	0.0	0.1	0.4	17.8	20.0	17.9	20.4
1965	0.1	0.1	9.7	9.8	29.4	30.8	39.2	40.7
1966	0.0	0.1	5.3	9.3	19.7	54.1	25.1	63.5
1967	0.5	0.5	11.1	11.0	13.5	35.9	25.0	47.4
1968	1.1	1.1	3.1	12.0	19.5	35.1	23.7	48.2
1969	3.2	3.1	9.5	9.3	24.0	34.4	36.7	46.9
1970	3.6	4.0	10.3	11.6	28.4	36.5	42.3	52.1
1971	4.6	4.6	11.3	13.4	39.8	43.2	55.8	61.2
1972	5.7	6.5	8.3	14.8	33.2	46.5	47.2	67.7
1973	6.9	7.8	11.7	12.4	38.4	45.4	57.0	65.6
1974	9.3	10.3	15.3	15.3	39.5	51.8	64.1	77.4
1975	5.9	10.5	14.1	14.8	41.3	46.7	61.3	71.9
1976	8.7	9.7	8.7	13.9	27.8	50.5	45.3	74.1
1977	14.4	14.1	10.9	12.7	29.5	43.8	54.9	70.6
1978	10.5	14.1	13.4	16.3	28.8	35.3	52.7	65.7
1979	9.8	13.0	8.6	16.4	27.6	36.1	46.0	65.4
1980	11.7	12.0	10.3	13.6	41.7	43.1	63.6	68.8
1981	18.4	19.3	7.7	10.6	41.6	47.5	67.8	77.4
1982	15.9	19.2	5.8	10.6	51.8	60.5	73.5	90.3
1983	17.0	22.0	8.6	10.5	33.8	56.3	59.4	88.8
1984	17.4	20.0	10.3	11.2	43.3	47.7	71.1	78.9
1985	8.8	20.0	16.8	17.2	52.6	55.4	78.2	92.6
1986	10.3	10.1	15.2	17.5	40.0	55.9	65.4	83.5
1987	8.5	10.0	11.9	17.3	35.6	54.3	56.0	81.6
1988	9.6	10.4	8.5	16.5	47.8	53.7	65.8	80.7
1989	7.8	9.9	11.9	15.4	58.4	61.4	78.1	86.6
1990	10.3	10.9	17.5	18.9	56.5	65.4	84.3	95.2
1991	17.7	18.3	17.4	21.9	60.8	71.0	95.9	111.1
1992	19.6	19.8	15.9	22.2	63.5	75.0	99.0	117.0
1993	33.1	32.9	16.2	23.9	62.8	72.5	112.2	129.3
1994	34.5	34.1	20.0	25.5	77.7	87.1	132.2	146.7
1995	26.7	33.6	25.5	25.8	74.1	84.4	126.3	143.8
1996	28.8	34.7	18.8	26.2	73.5	79.8	121.2	140.7
1997	19.7	32.8	19.1	23.6	67.8	80.1	106.6	136.5
1998	17.0	23.8	21.1	27.6	71.8	80.0	109.9	131.4
1999	23.0	23.3	21.9	28.7	76.5	79.9	121.4	131.9
2000	19.8	21.8	11.0	24.6	71.0	81.6	101.7	128.0
2001	24.9	26.2	15.6	27.9	55.2	72.6	95.7	126.8
2002	18.9	32.1	10.4	26.6	46.2	64.1	75.5	122.7

Figure 3 presents the estimates of capacity output and utilization corresponding, aggregated by gear type and for all gears combined.

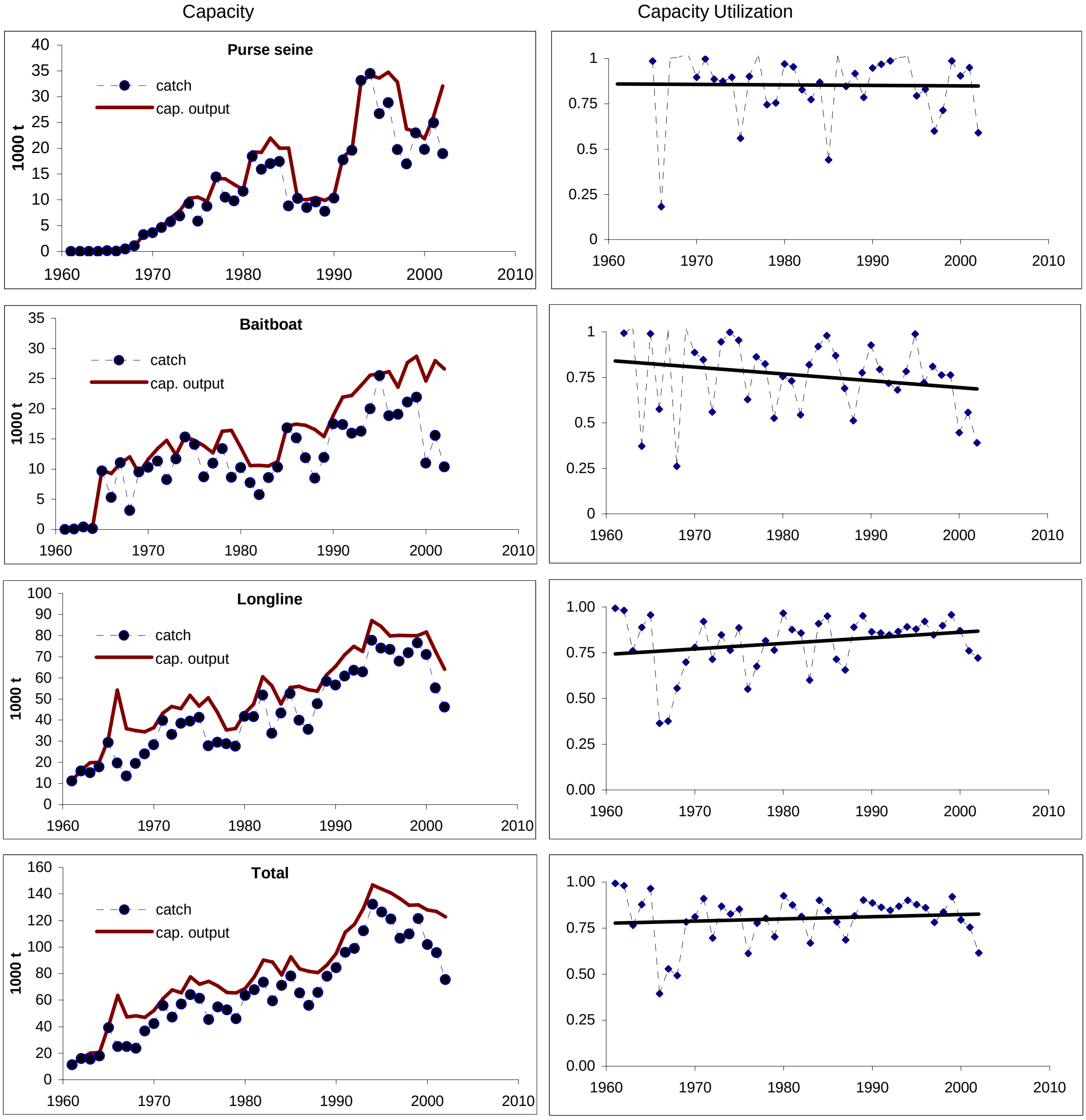

Figure 3. Estimated trends in catch and capacity output (left hand side) and capacity utilization (right hand side) by gear type and for all gears combined.

3.2 MSY

The relative mix of fisheries that target small bigeye and large bigeye in the Atlantic has changed considerably over time. As an example, **Figure 4** shows the selectivity patterns estimated by MULTIFAN-CL (fleets combined) in the 1960s and 1990s. The transition between predominantly longline fisheries targeting large fish (1960s) and mixed fisheries that include FAD-based purse seine fisheries targeting small fish in the 1990s is evident.

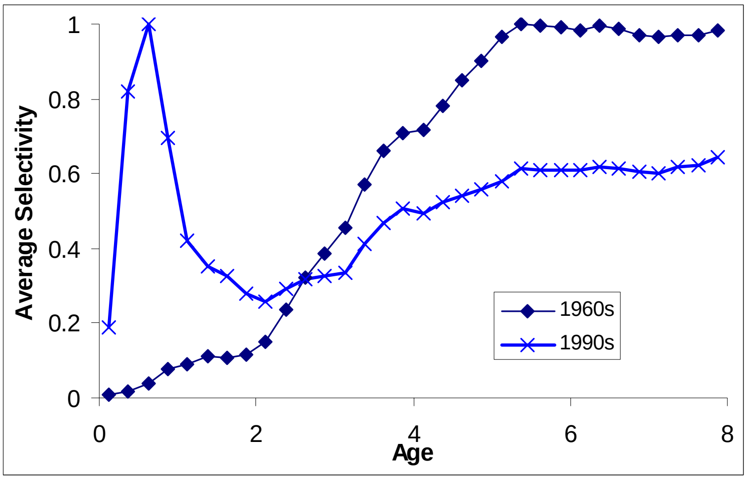

Figure 4. Average selectivity patterns (all fleets combined) estimated for bigeye tuna in two decades.

When selectivity changes as much as evidenced by **Figure 4**, the MSY will change as a function of changes in yield-per-recruit values. In this study, MSY was estimated for the entire time series in the assessment, assuming that parameters (growth, reproduction, selectivity, stock-recruitment relationship) would remain unchanged. **Figure 5** presents the estimates of MSY on a quarterly and annual basis. The figure suggests that MSY for Atlantic bigeye tuna has dropped considerably from about 190,000 t in the early 1960s, to just over 100,000 t in the 1990s.

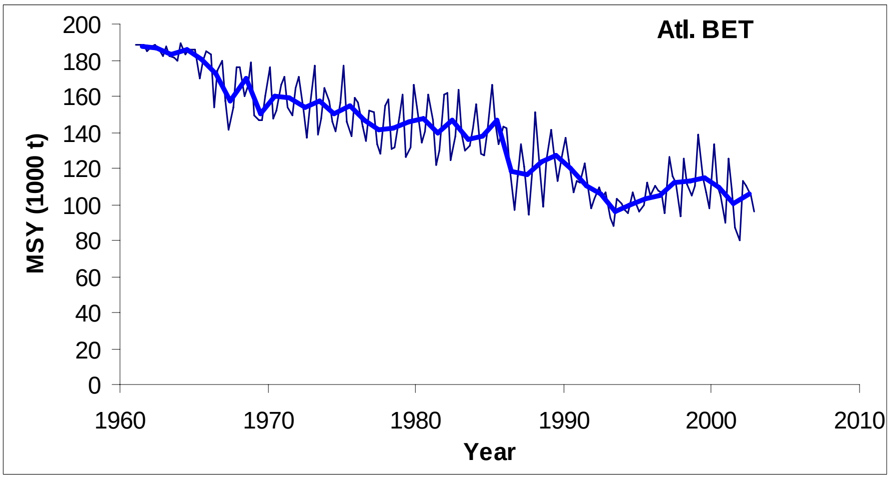

Figure 5. Estimated MSY for bigeye tuna over time, assuming that the selectivity pattern in each time period would remain constant in the long term (thin line: quarterly estimates multiplied by 4; thick line: aggregated estimates by year).

3.3 Excess capacity and overcapacity

In this paper, excess capacity is measured as capacity output, minus observed catch, and overcapacity is measured relative to MSY_y. **Figure 6** presents the estimates of excess capacity and overcapacity. From these, it could be concluded that output capacity exceeded the Atlantic bigeye stock's long-term productivity in the early 1990s. In absolute magnitude, the estimates of overcapacity during the last 10 years of available data (1993-2002) average 28,000 t.

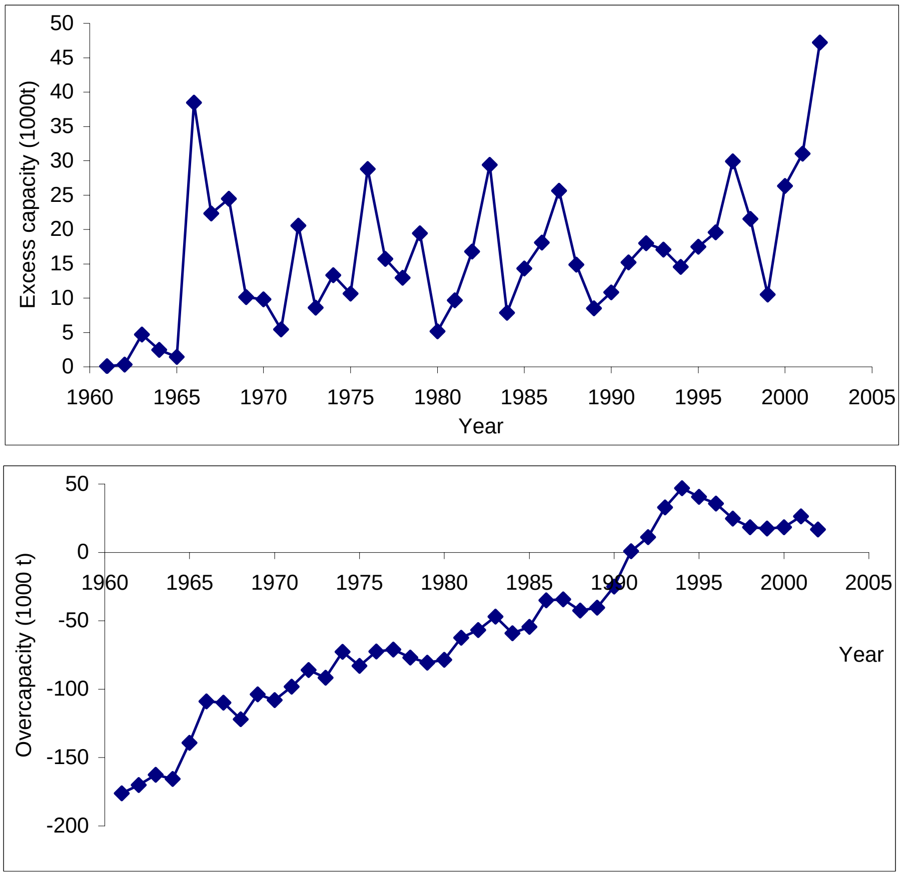

Figure 5. Estimated excess capacity (top) and overcapacity (bottom) for Atlantic bigeye tuna fisheries (all gears combined, in thousand tons).

4.0 Discussion

At present, it is not possible to use the DEA method to estimate capacity for all of the tuna fleets that operate in the Atlantic Ocean, primarily because the data available are highly aggregated. This paper presents an alternative approach to estimate capacity, based on the results of a stock assessment.

The approach used has some advantages and disadvantages. On the positive side, it is conceptually simple and uses information that is readily available from the stock assessment; it is not necessary to try to look for other types of information that may be difficult to obtain. Also, basing the analyses on the assessment may be appealing to fisheries scientists who, like the author, are already familiar with these types of data and parameters. On the negative side, the approach used to estimate maximum effort lacks a solid theoretical basis. Also, these are some alternatives that may perform more robustly, such as applying a piece-wise regression between peaks, rather than assuming that available fishing mortality remains constant between peaks.

A key assumption with the method proposed here is that whenever a high level of fishing mortality is estimated for a given time period, the same level is also plausible in the time periods that follow immediately after, until the next peak occurs. Thus, peaks in fishing mortality estimated by the assessment are not considered as "outliers" but rather as levels that are achievable by a given fleet in subsequent time periods. This assumption is conceptually similar to that made by DEA and other technical-economic approaches that estimate deterministic "frontiers" of maximum production. In the context of using MULTIFAN-CL for the assessment, the analyst would be able to control the level of variability in *F* allowed by the model, thus guarding against the possibility of abnormally high levels of *F* driving the results. Such an option was not explored in this paper, but it is reasonable to expect that lower variability in *F* will result in lower estimates of capacity output.

One potential problem with the method applied is that the maximum *F* levels lag behind the observed peaks in *F* (see **Figure 1**). A method in which the maximum *F* would be centered on the peaks might be a more reasonable alternative. One such alternative was applied (see **Appendix 1**). This alternative still makes the assumption that whenever a high level of fishing mortality is estimated in a given time period, that high level is also possible in the time periods immediately before and after the peak.

The analyses presented here for the fleets that target bigeye tuna suggest that output capacity exceeded the stock's potential long-term productivity since about 1992 (**Figure 6**). It is interesting to note that in 1998 ICCAT adopted a binding Recommendation which required all fleets catching more than 2000 t of Atlantic bigeye annually to limit their number of large scale vessels that target bigeye to the average number that operated in 1991 and 1992 (*1998 Recommendation by ICCAT on the Bigeye Tuna Conservation Measures for Fishing Vessels Larger than 24 m Length Overall*). This capacity limitation was reiterated in the 2004 *Recommendation by ICCAT on a Multi-Year Conservation and Management Program for Bigeye Tuna*, which implemented a comprehensive management plan that includes a Total Allowable Catch, individual catch limits for parties, closed season/areas and other additional management measures. The estimates of overcapacity in this paper appear to be in synchrony with the Commission's decision to limit fishing capacity.

For the purpose of providing management advice, it would be useful to investigate the relationship between variable inputs (e.g., fishing effort) and capacity or between fixed inputs (e.g., physical vessel characteristics) and capacity. The data available for this study did not include fixed inputs. The information available in ICCAT's statistical database is mostly on nominal fishing effort (e.g. fishing days, number of hooks) and the level of aggregation varies by fishery. The relationship between the capacity output estimates from this study and the fishing effort series used as inputs to MULTIFAN-CL is rather poor for most of the 14 fisheries examined (**Figure 7**). One of the reasons for this is that the MULTIFAN-CL model allowed for changes in catchability over time, both seasonally and annually. Thus, the underlying relationship between fishing effort and fishing mortality would not necessarily be expected to be linear. Another reason is that the estimates of capacity output in each time period are conditioned by the size of the resource at that time. In either case, on the basis of relationships such as shown in **Figure 7**, at first glance it would appear difficult to draw firm conclusions about the desired change in effort for most fisheries.

This paper deals only with the multi-gear nature of fisheries that exploit bigeye tuna in the Atlantic. A multi-species focus would be much more difficult to implement with the approach presented here because the stock assessments conducted by ICCAT are on a single-species basis.

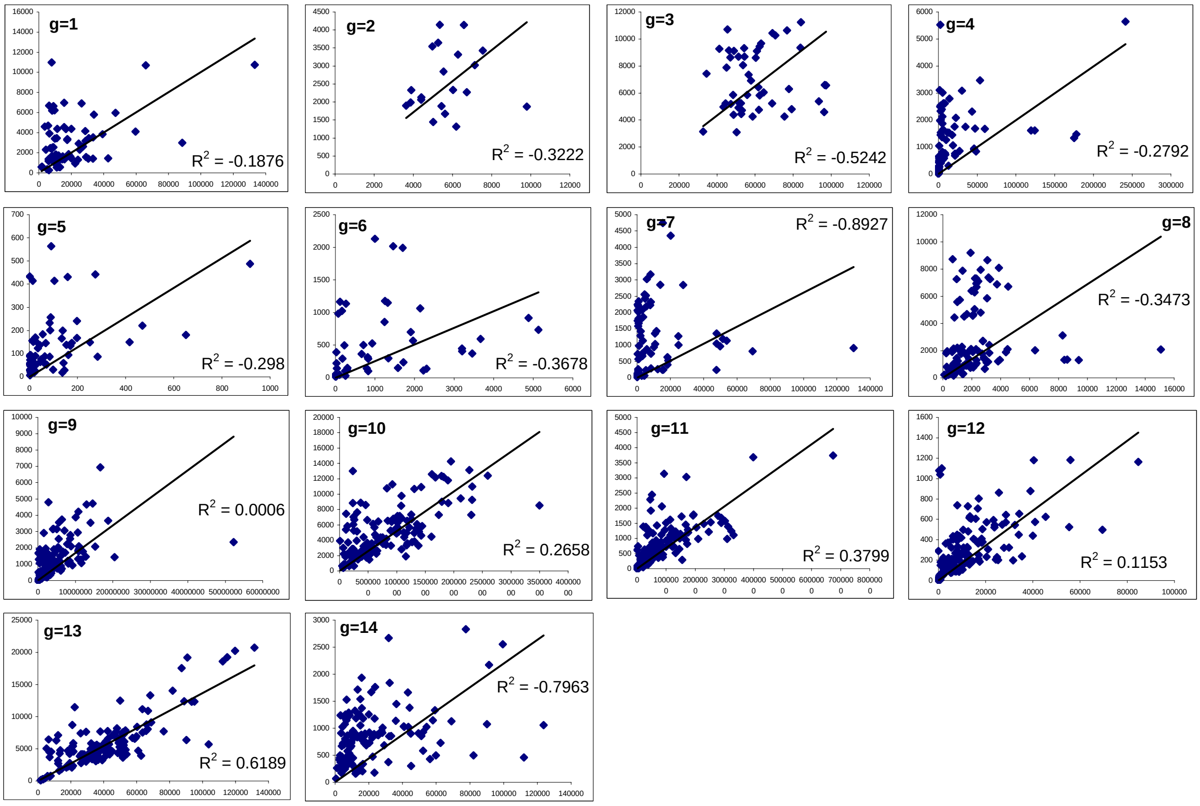

Figure 7. Relationship between estimated capacity output and fishing effort for the 14 fisheries in the analysis.

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Appendix 1

Results obtained with an alternative method to define maximum F

An alternative approach was used to estimate maximum *F* so that it would be centered around peaks. This consisted of fitting a nonparametric regression model to the *F* estimates from MULTIFAN-CL and using the results to predict fishing mortality by year and quarter. These predicted values were then applied to the estimated stock sizes in order to compute output capacity; in cases where the predicted catch from MULTIFAN-CL was greater, the predicted catch was taken as the value of output capacity.

The regressions used were fishery-specific Generalized Additive Models (GAMs) where *F* was modeled as a spline function of Year and as a factor for Quarter. The degrees of freedom specified for the splines were equal to the number of years in each series, divided by 5.

$$\hat{F}_{y,q} = s(y) + \beta q$$

The results obtained are illustrated by the following figures. Overall, these results are similar to those obtained with the "peak" method applied in the main section of the paper and presented at the Workshop. However, application of this alternative method suggests that over-capacity has been decreasing more rapidly in the more recent years than does the original method (see Figure **A4**). On the other hand, the most recent time period in the assessment is usually the most uncertain, so this comparison needs to be made with caution.

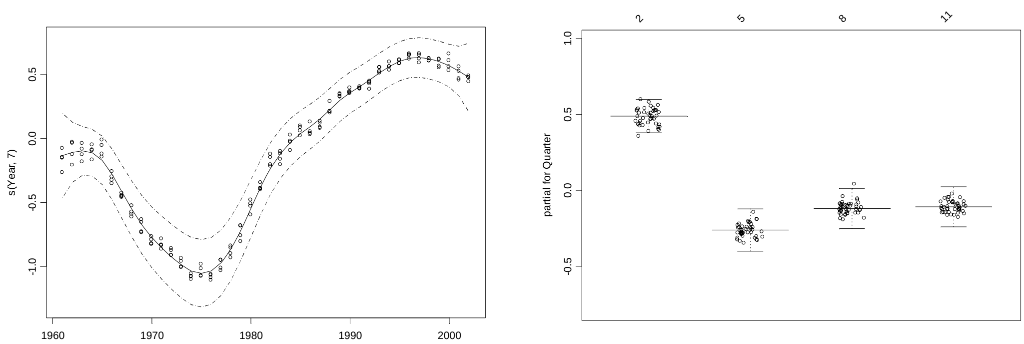

Figure A1. Partial GAM fit plots for Fishery 10 (Japanese longline, Region 2). Left: smooth nonparametric fit to the Year effect; Right: Factor effect for Quarter.

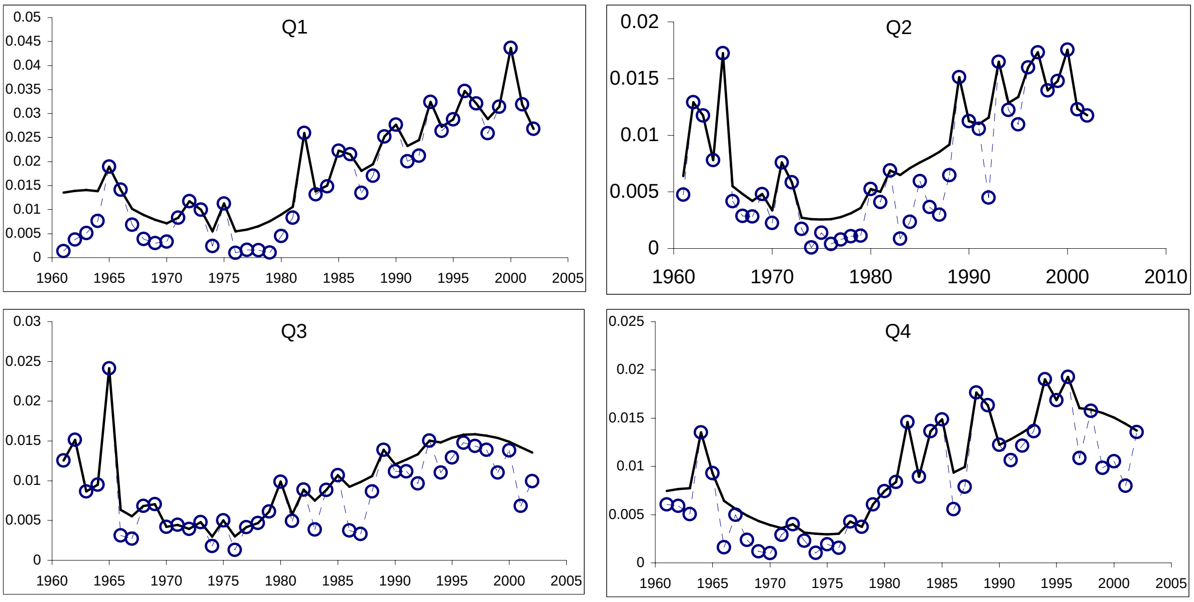

Figure A2. Example of how the methods to estimate maximum fishing mortality was applied. The circles are the outputs from MULTIFAN-CL and the solid line is the maximum of (a) fitted F from the GAM analysis, and (b) MULTIFAN-CL estimate. Japanese longline fishery in region 2, by quarter. The y-axis is relative fishing mortality.

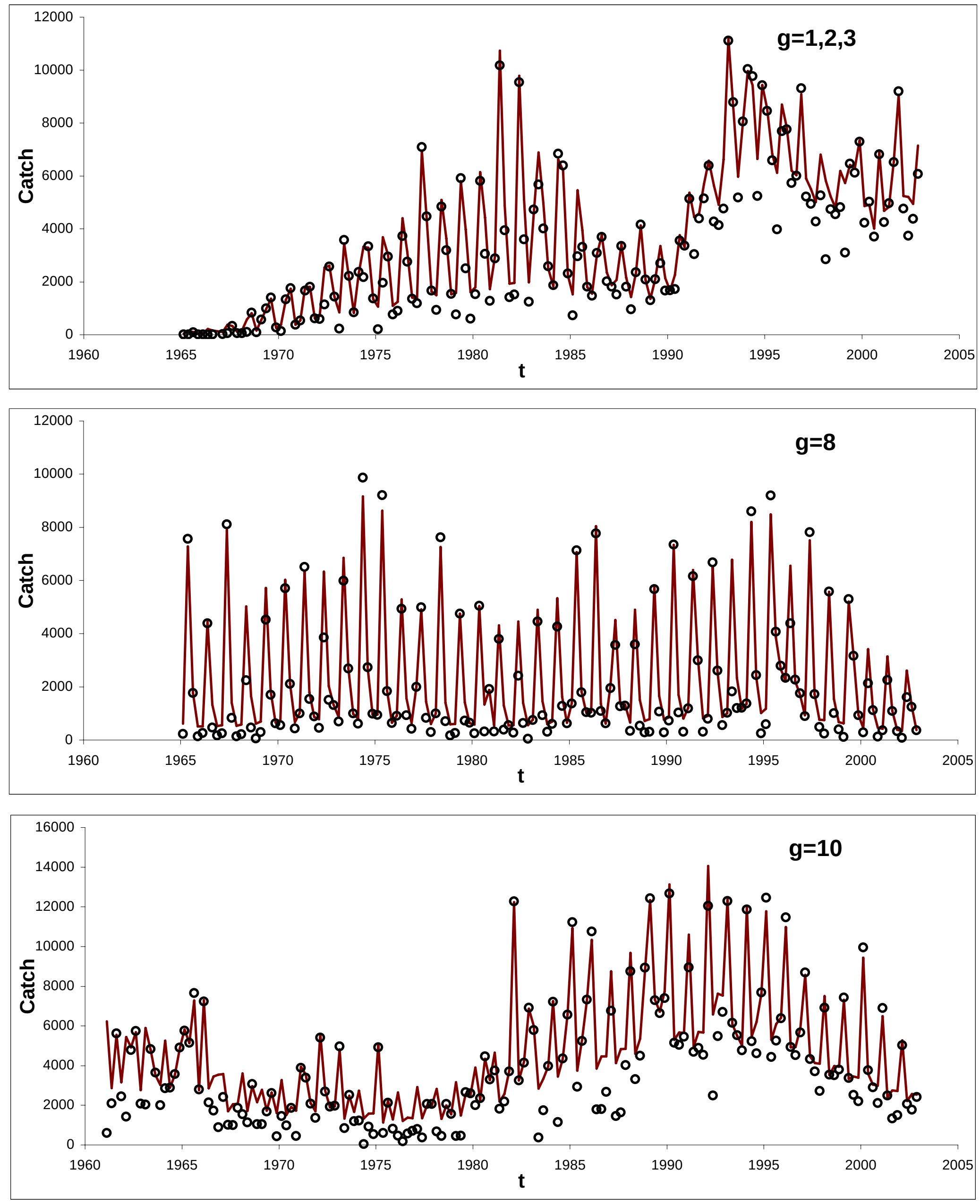

Figure A3. Example of how the approach applied to estimate output capacity performed for several of the 14 fisheries examined. The open circles represent the observed catches, and the lines represent the estimates of capacity output. The top figure corresponds to 3 sequential purse seine fisheries in Region 2; the middle figure corresponds to miscellaneous baitboat fisheries in Region 2; the bottom figure corresponds to Japanese longliners in Region 2. Note: Region 2 is the area where the majority of catches occur.

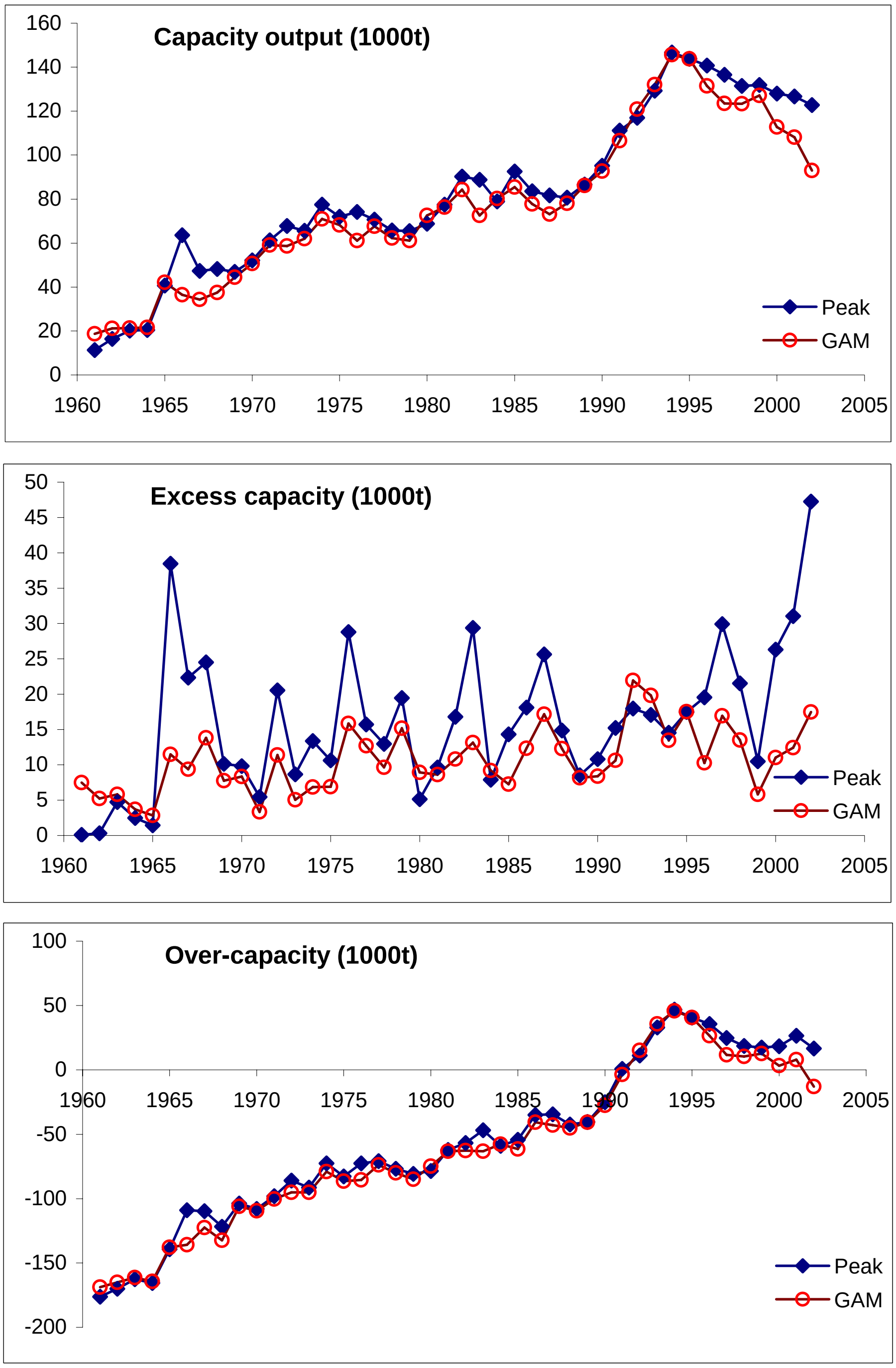

Figure A4. Comparison of the results obtained with the "peak" method used in the paper and the GAM approach applied in this Appendix. The results are presented for capacity output (top), Excess capacity (middle) and overcapacity (bottom).