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METHODS TO ESTIMATE FISHING CAPACITY, USING STOCK ASSESSMENT INFORMATION: SENSITIVITY TESTS AND APPLICATION TO PACIFIC, ATLANTIC AND INDIAN OCEAN TUNA STOCKS

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ABSTRACT

Peak-to-peak (PP) and general additive modeling (GAM) approaches were used to estimate fishing capacity and related quantities based on stock assessment information. Sensitivity tests revealed greater estimates of capacity output when the stock assessment data were most disaggregated. Further tests revealed that the estimates of overcapacity were lower when low variability in effort deviations was permitted in the stock assessment. The PP and GAM methods were applied to seven stocks of bigeye, yellowfin and skipjack tuna of the Pacific, Indian and Atlantic Oceans. The estimated trends in overcapacity with both methods were consistent across most of the stocks, showing increasing trends at the beginning of the time series and reaching maximum values during the late 1990s, followed by a decreasing trend after that. For most of the stocks analyzed, overcapacity was positive during part of the time series.

1. INTRODUCTION

In 1998, FAO organized a Technical Working Group on the Management of Fishing Capacity (Gréboval, 1999), that served as a basis for the development of an International Plan of Action (IPOA) for the Management of Fishing Capacity adopted in 1999. Since then, a considerable amount of effort has been devoted to the study of fishing capacity and related matters by FAO and other organizations (Gréboval, 1999; Cunningham and Gréboval, 2001; Joseph, 2003; Pascoe *et al.*, 2003; Pascoe *et al.*, 2004).

Although Data Envelopment Analysis (DEA) has been used to estimate the fishing capacity of some tuna purse-seine fleets in the Pacific Ocean (Bayliff *et al.*, 2005), attempts on Atlantic purse-seine and longline fisheries were less successful, due to the level of aggregation of the data for fleet characteristics (Miyake, 2005; Reid *et al.*, 2005). The situation is likely to be the same for other gear types, such as pole-and-line gear, and some other medium-scale fisheries. Thus, in the absence of disaggregated data on fleet characteristics not routinely collected by regional fisheries management organizations (RFMOs), alternative approaches to measure capacity may be necessary for most of the tuna fisheries.

Restrepo (2007) presented an alternative approach based on stock assessment inputs and outputs, which are available for a number of tuna stocks. His method consists on applying an algorithm that connects consecutive “peaks” of the estimated fishing mortality to estimate time trends of fishery-specific maximum fishing mortality as a measure of fishing capacity. The main assumption is that the (monthly/quarterly) fishing mortality from a peak in a given year remains available for several years. The estimates of fishing capacity, together with other input and output data from the assessments (such as yield, maximum sustainable yield (MSY) and stock abundance), make it possible to estimate capacity output, capacity utilization, excess capacity and overcapacity (defined in Section 2).

This method was applied to Atlantic bigeye tuna, assessed with MULTIFAN-CL, considering 3 regions, 14 fisheries and quarterly time steps and incorporating information about age-specific selectivity and time trends in fishing efficiency. The results of this approach were also compared to an alternative GAM approach to estimate maximum fishing mortality(*F*) trends, which consists essentially of fitting a non parametric regression model to time series of fishery-specific estimates of *F* and choosing, as a measure of fishing capacity, the maximum values between the predicted and observed values of *F*. One of the characteristics of the GAM approach was that, in contrast to the original approach, the estimates of *F* were centred around peaks, implying that whenever a high level of *F* is estimated in a given time period, that high level is also possible in the time periods immediately before and after the peak.

The original approach of Restrepo (2007) did not consider peak values of *F* as outliers, but as values that could be achieved by the fishery in subsequent time periods. In MULTIFAN-CL, the analyst would be able to control the level of variability in *F*, this choice probably having an impact on the estimate of fishing capacity. Restrepo (2007) noted the need to further investigate the sensitivity of the method to this kind of choice. He also suggested alternatives that may perform more robustly, such as a piece-wise regression between peaks, rather than assuming that the available fishing mortality remains constant between them.

The objective of this paper is to document some sensitivity analyses that have been conducted, and the results obtained by applying the methodology to different bigeye, yellowfin and skipjack tuna stocks in the Pacific, Indian and Atlantic Oceans, as food for discussion in the FAO "Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related-Information". Sensitivity analyses are conducted with respect to the level of aggregation in the data used for stock assessment, and also with respect to the variability of *F* allowed in the assessments (as also documented in Arrizabalaga *et al.,* 2009).

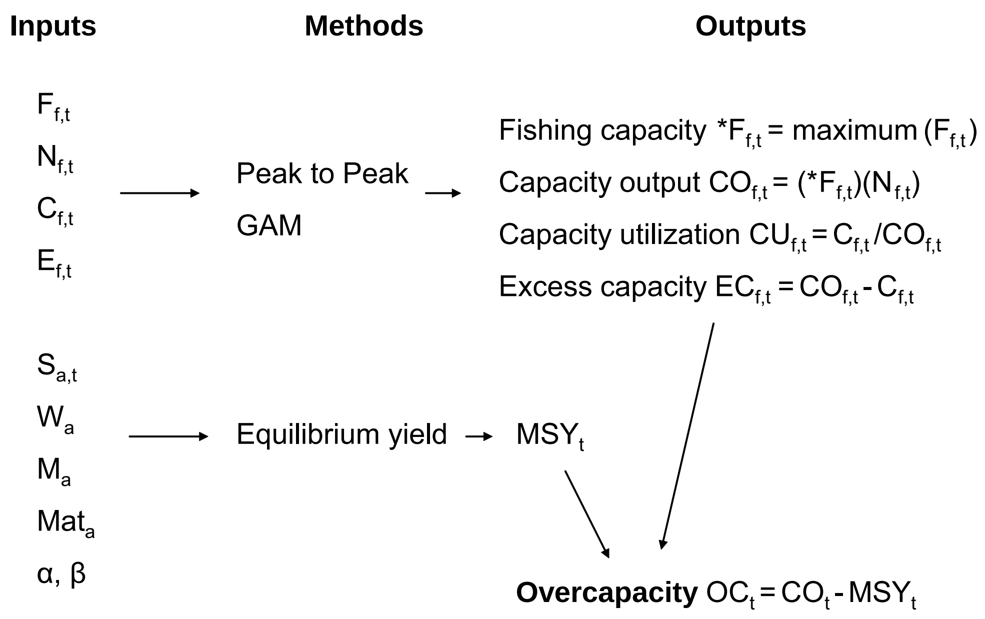
2. MATERIALS AND METHODS

Two approaches were considered to estimate maximum fishing mortality as a measure of fishing capacity (Figure 1):

- Peak-to-peak (PP) or piece-wise regression between peaks: For each fishery and quarter, peaks of *F* were connected by straight lines, taking the predicted values of the piece-wise regression as a measure of fishing capacity. Peaks were defined as values greater than those immediately preceding and following them in the time series. The *F* values before the first and after the last peak in the time series were not modified.
- Generalized additive models (GAM): The use of this method is explained in Appendix 1 of Restrepo (2007). For each fishery, *F* was modeled as a spline function of year (with the degrees of freedom equal to the number of years divided by 5) and as a factor for quarter.

Capacity output (CO), capacity utilization (CU), excess capacity (EC) and overcapacity (OC) were also defined and computed, following Restrepo (2007): CO is the potential catch that would have resulted from the estimated fishing capacity, given the exploitable stock size, for each fishery; CU is the ratio of the observed catch to the capacity output; EC is the difference between capacity output and the observed

FIGURE 1
Schematic of the calculations in the method



F, fishing mortality; N, exploitable biomass; C, catch; E, effort; S, selectivity; W, weights at age; M, natural mortality; Mat, maturity; α and β, parameters of the Beverton and Holt stock-recruitment relationship; GAM, general additive model; MSY, maximum sustainable yield. Subscripts $_f$, $_t$ and $_a$ stand for fishery, time and age, respectively.
Figure adapted from Arrizabalaga *et al*., 2009.

catch and OC is estimated by subtracting estimates of MSY from the overall (all gears combined) capacity output. MSY is estimated for every time step by the method of Restrepo *et al.* (1994).

Two sensitivity analyses were conducted using data for Atlantic bigeye tuna (see also Arrizabalaga *et al.*, 2009).

1. Sensitivity analysis with respect to the level of aggregation in the data

Atlantic bigeye tuna is assessed using MULTIFAN-CL software, and the input data are structured considering the existence of 14 fisheries and quarterly time steps. This was considered to be the most disaggregated case, and two alternative aggregation levels were tried. In the first case, the 14 fisheries were aggregated into three main gear categories (purse seine, longline and others, which consist mostly of pole-and-line fisheries) and quarters were aggregated into semesters (first and last six months of the year). In the second case, all fisheries were combined into a single one, and quarters were aggregated into years.

It should be noted that, given the difficulty of combining different effort measures in different fisheries, no new MULTIFAN-CL run was conducted with the aggregated data set. Instead, catch (*C*) and exploitable biomass (*N*) were aggregated according to the new strata and used to derive *F* by gear and time (as $F \sim C/N$). The PP and GAM methods were applied to estimate maximum *F* time series, corresponding capacity output and related quantities. This approach did not allow the estimation of new selectivity vectors, and thus new MSY estimates that would have been obtained if MULTIFAN-CL were run with the data aggregated at those levels. Thus, it does not allow comparison of the effect of the aggregation level in the data into estimates of overcapacity, but it does allow testing its effect on fishing capacity and capacity output estimated with the PP and GAM methods.

2. Sensitivity analysis with respect to the variability of fishing mortality allowed in the assessment model

In MULTIFAN-CL, the variability of fishing mortality can be increased by allowing a higher coefficient of variation (CV) in the effort deviation estimates, through fish flag 13 (Kleiber *et al.*, 2006). In the original MULTIFAN-CL run for the Atlantic bigeye assessment (Anon., 2005), flag values of p = 5, 10 and 20 were used for different fisheries (corresponding to approximate CVs of 0.32, 0.22 and 0.158, respectively, as $p \sim 1/(2CV^2)$). In this sensitivity analysis, the "high-*F* variability" scenario considered p values of 1, 2 and 3 in order to allow approximately twice the CVs in the original run. On the other hand, the "low-*F* variability" scenario considered p values of 20, 40 and 80 in order to allow approximately half the CVs in the original run (Table 1). MULTIFAN-CL was rerun with these new specifications, and the inputs and outputs were used to obtain fishing capacity and related variables following the PP and GAM approaches.

After the sensitivity analyses described above, the PP and GAM approaches to estimate fishing capacity and related variables were applied to seven stocks: Atlantic bigeye, Eastern Pacific bigeye, Western and Central Pacific bigeye, Indian Ocean bigeye, Eastern Pacific yellowfin, Western and Central Pacific yellowfin and Western and Central Pacific skipjack. (See Table 2 for a summary of the characteristics of

TABLE 1

P values used in fish flag 13 for the base case MULTIFAN-CL run for Atlantic bigeye (Anon., 2005) and the two sensitivity runs conducted (the p value in fish flag 13 controls the variability in effort deviations, $p \sim 1/(2CV^2)$)

Fishery	Gear	Nation	Region	p ("base case")	p ("high F variability")	p ("low F variability")
1	PS	Spain–France	2	10	2	40
2	PS	Spain–France	2	10	2	40
3	PS	Spain–France	2	10	2	40
4	PL	Ghana	2	5	1	20
5	PL	Other tropical	2	5	1	20
6	PL	Senegal	2	10	2	40
7	PL	Senegal	2	10	2	40
8	PL	Others	1	5	1	20
9	LL	Japan	1	20	3	80
10	LL	Japan	2	20	3	80
11	LL	Japan	3	20	3	80
12	LL	Unclassified	1	10	2	40
13	LL	Unclassified	2	10	2	40
14	LL	Unclassified	3	10	2	40

The "high ***F*** variability" run is intended to allow CVs approximately twice those in the base case, while the "low ***F*** variability" run is intended to allow CVs approximately half those in the base case. PS = purse seine; PL = pole and line; LL = longline.

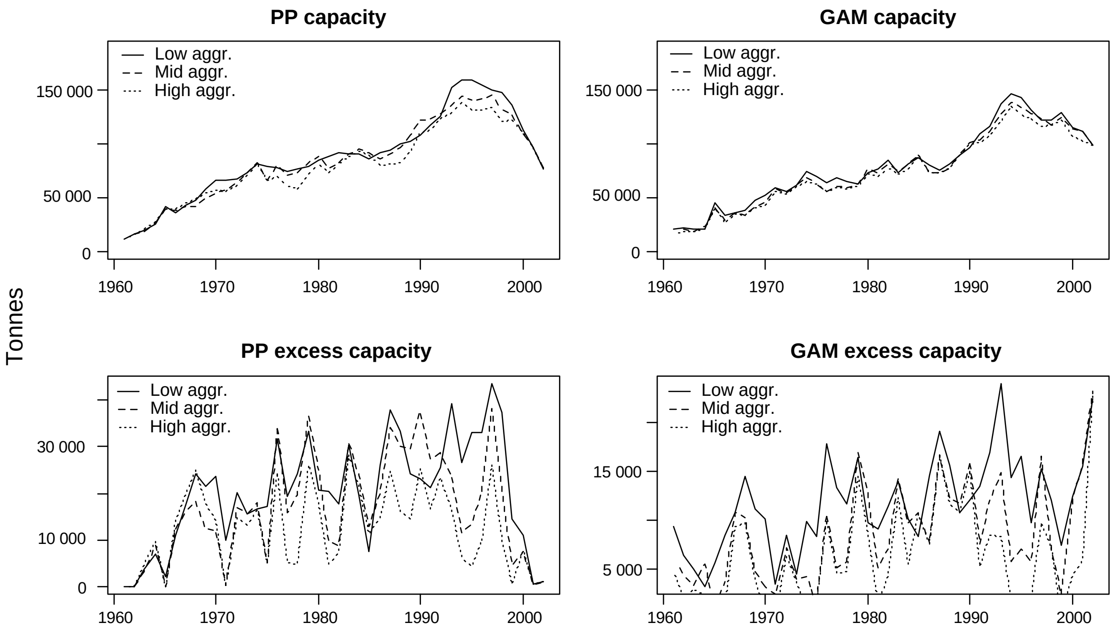
TABLE 2

Summary of stocks analyzed, stock assessment methods, numbers of fisheries and time steps considered

Stock	Ocean	Assessment method	Time step	Number of fisheries				Reference
				LL	PS	Other	Total	
Bigeye	Atlantic	MULTIFAN-CL	Quarter	6	3	5	14	Anon., 2005
Bigeye	Eastern Pacific	Stock Synthesis II	Quarter	2	11	-	13	Aires-da-Silva and Maunder, 2007
Bigeye	Indian	CASAL	Year	1	1	-	2	Hillary and Mosqueira, 2006
Bigeye	Western and central Pacific	MULTIFAN-CL	Quarter	13	4	3	20	Hampton *et al.*, 2006a
Yellowfin	Eastern Pacific	A-SCALA	Quarter	2	13	1	16	Maunder, 2007
Yellowfin	Western and central Pacific	MULTIFAN-CL	Quarter	13	4	2	19	Hampton *et al.*, 2006b
Skipjack	Western and central Pacific	MULTIFAN-CL	Quarter	3	7	14	24	Langley *et al.*, 2005

LL = longline; PS = purse - seine fisheries.

FIGURE 2
Sensitivity analysis with respect to the level of aggregation in the data



"Low aggr." corresponds to the original Atlantic bigeye analysis, with 14 fisheries and quarterly time steps. "Mid aggr." refers to the analysis with three main gears (purse seine, longline and others) and semi-annual time steps and "High aggr." refers to the analysis with a single fishery and annual time steps.
Figure adapted from Arrizabalaga *et al.* (2009).

their stock assessments in terms of model used, time steps and number of fisheries considered.) MSY was estimated by the method of Restrepo *et al.* (1994) for each time step. MSY varies in time in response to variations in the total selectivity vector, as the relative contributions of the various fisheries vary in time. These estimates were compared to the ones in the stock assessment report. If they were similar, estimates of F_{MSY} (the value of F corresponding to the MSY) were also used to estimate "dynamic MSY" (dMSY) as the yield obtained by fishing at F_{MSY} during the time series. Overcapacity was estimated, considering both MSY and dMSY. When MSY estimates obtained by the method of Restrepo *et al.* (1994) differed substantially from the ones in the assessment report, the latter were used.

3. RESULTS

• Sensitivity analysis with respect to the level of aggregation in the data

For most of the years in the time series, the greatest estimates of capacity output and excess capacity were obtained with the most disaggregated data (Figure 2), regardless of the method used (PP or GAM). The maximum relative differences between the estimates of capacity output in the most disaggregated (base case) and the most aggregated case ("High agg") were 24.9% and 22.1% for the PP and GAM methods, respectively, and the mean relative differences were 6.9% and 7.8%, respectively.

• Sensitivity analysis with respect to the variability of fishing mortality allowed in the assessment model

The estimates of capacity output and excess capacity for the scenarios with high and low variability in effort deviations were similar to those in the base case, the estimates using the PP method being slightly more sensitive than those using the GAM method (Figure 3). On the other hand, the estimates of excess capacity were not systematically greatest in the "High CV" scenario, as would be expected intuitively.

FIGURE 3

Sensitivity analysis with respect to the variability in effort deviations allowed in the assessment model: estimates of capacity output (upper panels), excess capacity (middle panels) and overcapacity (lower panels) under high, medium and low levels of variability in effort deviations

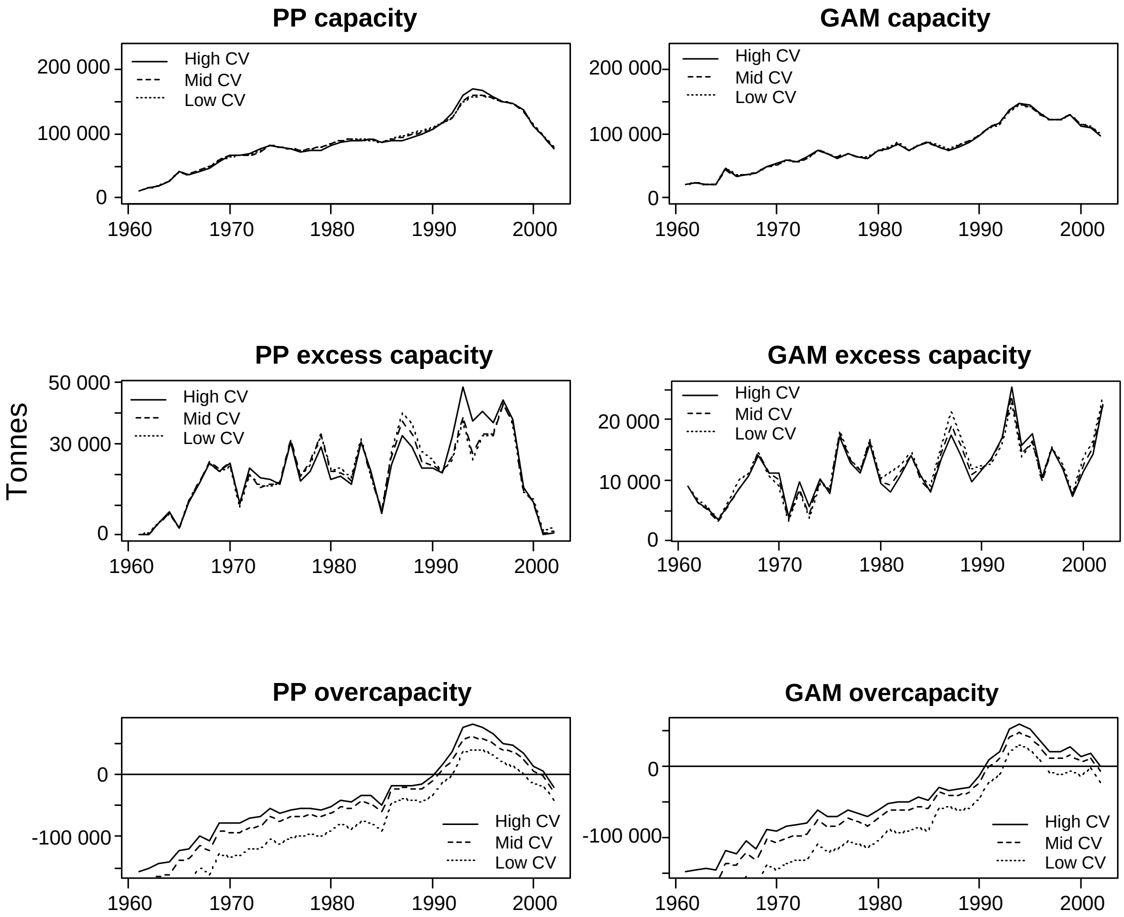


Figure adapted from Arrizabalaga *et al.* (2009).

However, the estimates of overcapacity were much more sensitive to flag settings about variability in effort deviations, low variability in effort deviations resulting in lower estimates of overcapacity. These results were driven by the sensitivity of the MSY estimates to effort deviation flag settings, low variability in effort deviations resulting in greater estimates of MSY (Figure 4).

- **Application of the PP and GAM methods to different stocks**

Summaries of the results obtained with the two methods are provided below in sets of four figures per stock:

- **Atlantic bigeye (Appendix Figures 1, 2, 3 and 4)**

Results similar to those obtained by Restrepo (2007) were obtained, with slightly greater differences between methods, which is likely due to the fact that the method based on PP analysis is essentially different. The estimates of overall capacity utilization were about 80%, and showed a slight increasing trend, especially those estimated with the GAM approach. Fishing mortality and associated catch for this stock has continuously increased during the time series. Moreover, the MSY showed a decreasing trend as the relative importance of surface fisheries increased. As a result, the PP and GAM approaches estimated increasing fishing capacity values and a positive overcapacity period during the 1990s, with average overcapacity estimates of 31 157 and 21 170 tonnes per year, respectively, during the last 10 years. However, the overcapacity estimates were close to zero during the most recent years (2000 onward). The estimated trends for dMSY and the magnitudes were quite similar to those for MSY during most of the time series, so the overcapacity estimates were not significantly affected by the definition of maximum sustainable yield used.

FIGURE 4

Sensitivity analysis with respect to the variability of fishing mortality allowed in the assessment model: estimates of MSY under high, medium and low variability in effort deviations

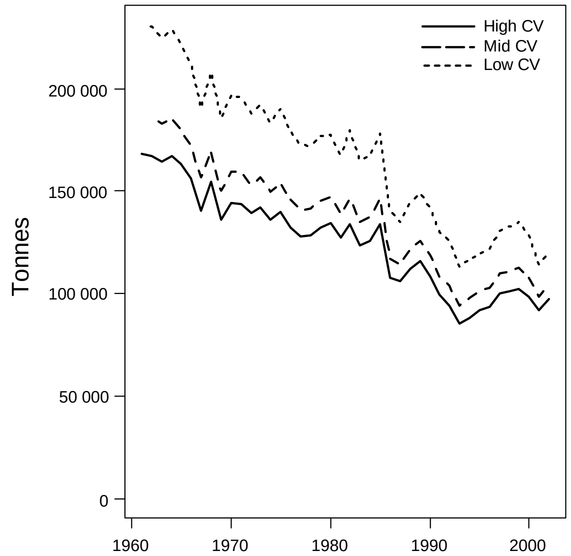


Figure adapted from Arrizabalaga *et al.* (2009).

• Western and Central Pacific bigeye (Appendix Figures 5, 6, 7 and 8)

The fishing mortalities for adult and juvenile bigeye tuna of the Western and Central Pacific Ocean (WCPO) have increased continuously since the beginning of industrial tuna fishing. The total biomass for the WCPO is estimated to have declined to about half of its initial level by about 1970, and has been fairly stable or subject to slight decline since then. However, the overall catch shows an increasing trend, sustained by strong recruitment since about 1980 (Hampton *et al.*, 2006a). The estimates of capacity utilization were relatively constant at about 80% throughout the time series. The estimates of MSY showed a decreasing trend as the relative importance of the surface fisheries increased, and, except for the first decade, the dMSY trends and magnitudes were comparable to those for the MSY. The PP and GAM methods indicated an overcapacity period beginning during the early 1990s and reaching a plateau at the end of that decade. The average overcapacity estimates for the last 10 years were 68 312 and 58 599 tonnes per year for the PP and GAM methods, respectively.

• Eastern Pacific bigeye (Appendix Figures 9, 10, 11 and 12)

The fishing mortality for bigeye tuna in the Eastern Pacific Ocean (EPO) has increased substantially since 1993, especially for the younger fish (Aires-da-Silva and Maunder, 2007). Since then, the estimates of MSY have been significantly less, due to the overall change in the selectivity pattern. The biomass reached its greatest level in 1986, which explains the maximum dMSY value. After that, the biomass decreased to an historic low at the beginning of 2005, but the recruitment during the last 10 years has been generally above average, except for 1999–2000, when the recruitment was well below average.

The estimated capacity utilization decreased from about 90% to about 80% during the time series, mainly due to longline gear, as the purse seine capacity utilization increased from about 60% to about 80%. Overcapacity began during the mid-1990s, coinciding with the decrease in the MSY, reaching a peak in 2000, with a declining trend after that. The average overcapacity estimates for the last 10 years were 81 508 and 52 947 tonnes per year for the PP and GAM methods, respectively. The overcapacity trend based on dMSY is less variable, with a slightly increasing trend prior to the mid-1990s, when it became positive, and then stabilized after that.

• Indian Ocean bigeye (Appendix Figures 13, 14, 15 and 16)

Because the data for Indian Ocean bigeye tuna were strongly aggregated (in comparison to those for the other stocks of tunas), and because fishing mortality has shown an almost continuous increase, with very few peaks and valleys, the estimates of fishing capacity are relatively close to those of fishing mortality, and the estimates of excess capacity are relatively low. The estimated capacity utilization increased from about 80% to more than 90% during the time series, the increase being due to both longline and purse seine gears. Except for two years during the 1990s, when the estimates of maximum capacity output were slightly above the MSY estimates calculated by Hillary and Mosquiera (2006), using CASAL, no overcapacity was estimated for this stock during the time series. The average overcapacity estimates for the last 10 years were 56 329 and 58 466 tonnes per year for the PP and GAM methods, respectively.

• Eastern Pacific yellowfin (Appendix Figures 17, 18, 19 and 20)

The yellowfin tuna stock of the EPO has experienced two, or possibly three, different recruitment regimes (1975–1982, 1983–2001 and 2002–2006), corresponding to periods of low, high and intermediate recruitment. The recruitment regimes correspond to regimes in biomass, higher-recruitment regimes producing greater biomass levels. Strong cohorts entered the fishery during 1998–2001, and these cohorts increased the biomass during 1999–2001 (Maunder, 2007). This coincided with the start of a 3-year period of maximum catches and maximum estimates of dMSY, which basically was parallel to the total catch, while the estimated MSYs remained fairly stable during the time series.

The estimated overall capacity utilization remained stable at about 80% during the time series, and the estimates of excess capacity were relatively high due to the variability in fishing mortality, especially during the years with the greatest catches (2001–2003). Both the PP and GAM methods indicated that the output capacity had exceeded the stock's long term productivity from the mid-1980s until 2005, with negative overcapacity in 2006. The differences in the absolute overcapacity estimates were greater for this stock than for any other. During the last 10 years, the estimated average overcapacities for PP and GAM methods were 169 298 and 108 427 tonnes per year, respectively. However, these overcapacity estimates were very highly correlated with excess capacity (R^2 = 59.8% and 85.6% for the GAM and PP methods, respectively), suggesting that the output capacity that exceeded the actual catch was not utilized. When considering dMSY, the overcapacity was positive for the entire time series, but much less variable and of lesser magnitude in the later years relative to the estimates of overcapacity based on MSY.

• Western and Central Pacific yellowfin (Appendix Figures 21, 22, 23 and 24)

The biomass of the stock of yellowfin of the WCPO declined during the initial period to a low level during the early to mid-1970s, before increasing in the mid-1970s. The biomass levels remained relatively stable during the 1980s, but have declined steadily since 1990. The fishing mortalities of adult and juvenile yellowfin tuna are estimated to have increased continuously since the beginning of industrial tuna fishing (Hampton *et al.*, 2006b). It is obvious that the trend in dMSY is influenced by the trends in biomass, and the MSY shows a continuous decreasing trend due to changes in selectivity toward juvenile fish.

While the estimated capacity utilization for purse seine gear increased from about 50% to about 80%, the capacity utilization for other gears decreased, so that the overall capacity utilization remained stable at about 80% during the time series. Both the PP and GAM methods indicated regularly increasing trends in capacity output since the early 1970s. The PP method produced slightly positive overcapacity estimates for the late 1990s, but the GAM method did not produce positive overcapacity estimates for any year of the time series. The overcapacity estimates corresponding to dMSY were greater than those corresponding to MSY at the beginning of the series, but the estimates converged after 1980, with slightly positive values at the end of the time series.

• Western and Central Pacific skipjack (Appendix Figures 25, 26, 27 and 28)
The greatest estimates of biomass for skipjack in the WCPO occurred for the 1983–1988 and 1998–2000 periods, immediately following periods of sustained high recruitment (Langley *et al.*, 2005). The catch increased continuously during the time series. The overall capacity utilization showed slightly decreasing trends, from about 80% to about 70%, during the time series. Except for one year in the late 1990s, when the maximum capacity output estimates for the PP method were slightly greater than the MSY estimates obtained by Langley *et al.* (2005), using MULTIFAN-CL, no overcapacity was estimated for this stock in the time series. The estimates of the output capacity obtained with the GAM method did not reach the estimates of MSY during the entire time series.

4. DISCUSSION

The estimated time trends in overcapacity were quite consistent across stocks and methods (PP vs GAM): overcapacity increased progressively to maximum values around the late 1990s, and then, in most cases, a decreasing trend was observed. For most of the stocks analyzed, overcapacity was positive during some years. The increase in overcapacity during the time series was due to both an increase in capacity output and a decrease in MSY, due to changes in selectivity. However, when dMSY is used instead of MSY as a measure of maximum sustainable yield, lower estimates of positive overcapacity were obtained for the more recent years. In some cases, this was due to higher recruitment, leading to greater abundance and catch at F_{MSY}.

Restrepo (2007) suggested that user-defined options in the assessment were likely to influence capacity output estimates. Intuitively, one would expect to get greater estimates of fishing capacity if greater variability were allowed for estimates of F in the stock assessments, especially when using a method that connects peaks (which could actually be outliers). The sensitivity test that was conducted suggests that MSY may be more sensitive than capacity output to such user-defined options, and brings attention to the need to consider all assumptions that are made in assessments that may affect estimates of MSY.

This is linked to the first sensitivity analysis of the methods to estimate fishing capacity with respect to levels of data aggregation. In this analysis, no new estimates of MSY were computed with the aggregated data, due to the difficulty of aggregating different types of measures of effort. However, this limits the extent of the sensitivity analysis to impacts on estimates of output capacity, as the impacts on overcapacity through MSY estimates are not accounted for. This sensitivity analysis suggests that the capacity output and the estimates of overcapacity for Indian Ocean bigeye tuna may be underestimated with respect to estimates that would be obtained if the data for the assessment were more disaggregated. This also applies to capacity output and estimates of overcapacity that are likely to be obtained from assessments based on yearly data and not stratified by fishery, a common situation in many stock assessments.

In general, comparison of different methods for estimating fishing capacity is encouraged, as different methods can lead to different results (Lindebo, 2004). In these analyses, I compare PP and GAM approaches, showing that the estimates of output capacity are consistently greater with the PP method than with the GAM method, except in the first and last years, before the first and after the last peak, for which the capacity output predicted by the PP method (as implemented in this study) is simply equal to the predicted catch in the assessment. The relative difference between the estimates of the two methods depends on the shape of the F time series to be analyzed. The differences are maximized if the time series has many consecutive high "peaks" and "valleys" (*e.g.* Appendix Figure 17 for Eastern Pacific yellowfin), and minimum if the F time series is rather smooth (*e.g.* Appendix Figure 13 for Indian Ocean bigeye).

On the other hand, the estimates of the capacity output obtained with the PP method could be more sensitive if the peaks were defined over a wider temporal range (*e.g.* over several years before and after a given time period, if it is believed reasonable to assume that capacity remains available that long), or, in an extreme case, if peaks were connected in a way that the estimated fishing capacity would show a single peak over the entire time series. This would also affect the estimates of capacity utilization, which, with the methods implemented here, were usually about 80%, generally showing slight trends or no trends at all.

Finally, Restrepo (2007) showed that the relationship between capacity output and fishing effort was rather poor for most of the Atlantic bigeye fisheries, mostly because the assessment model allowed for deviations from linear relationships between effort and fishing mortality, and because capacity output would also depend on the stock size at each time step. The analyses conducted for seven stocks of tunas confirm this lack of clear linear relationship between effort and capacity output (Appendix Figures 4, 8, 12, 16, 20, 24 and 28), making it difficult to draw firm conclusions about the desired changes in effort for most fisheries.

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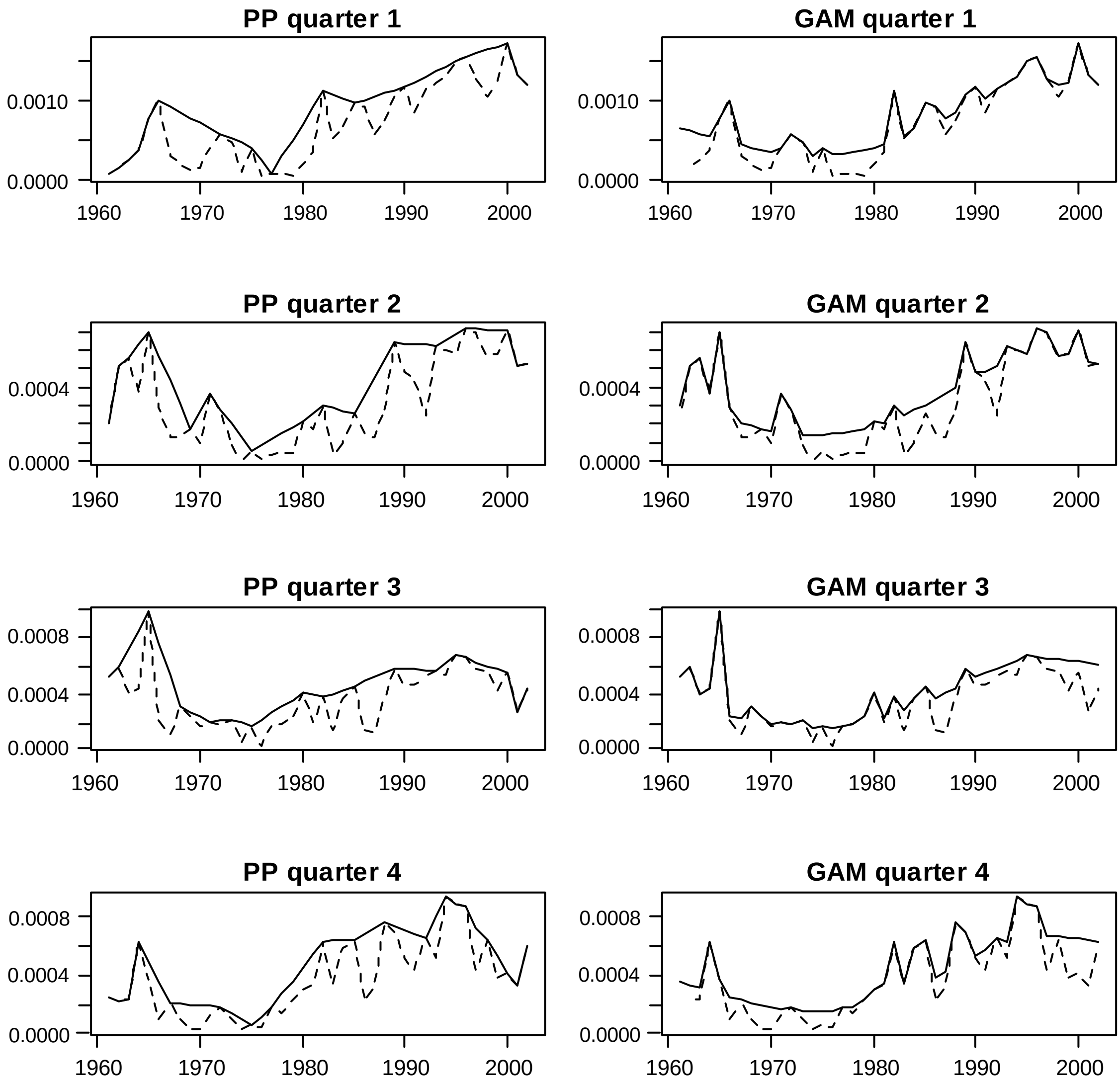
APPENDIX

FIGURE 1

Atlantic bigeye tuna. Example of application of PP and GAM methods to quarterly fishing mortality of Fishery 10 (Japanese longline in Region 2)



The dark lines are the outputs from MULTIFAN-CL and the dashed line is the estimate of fishing capacity.
Figure adapted from Arrizabalaga *et al.* (2009).

FIGURE 2

Atlantic bigeye tuna. Estimated trends in capacity utilization by gear type and for all gears combined

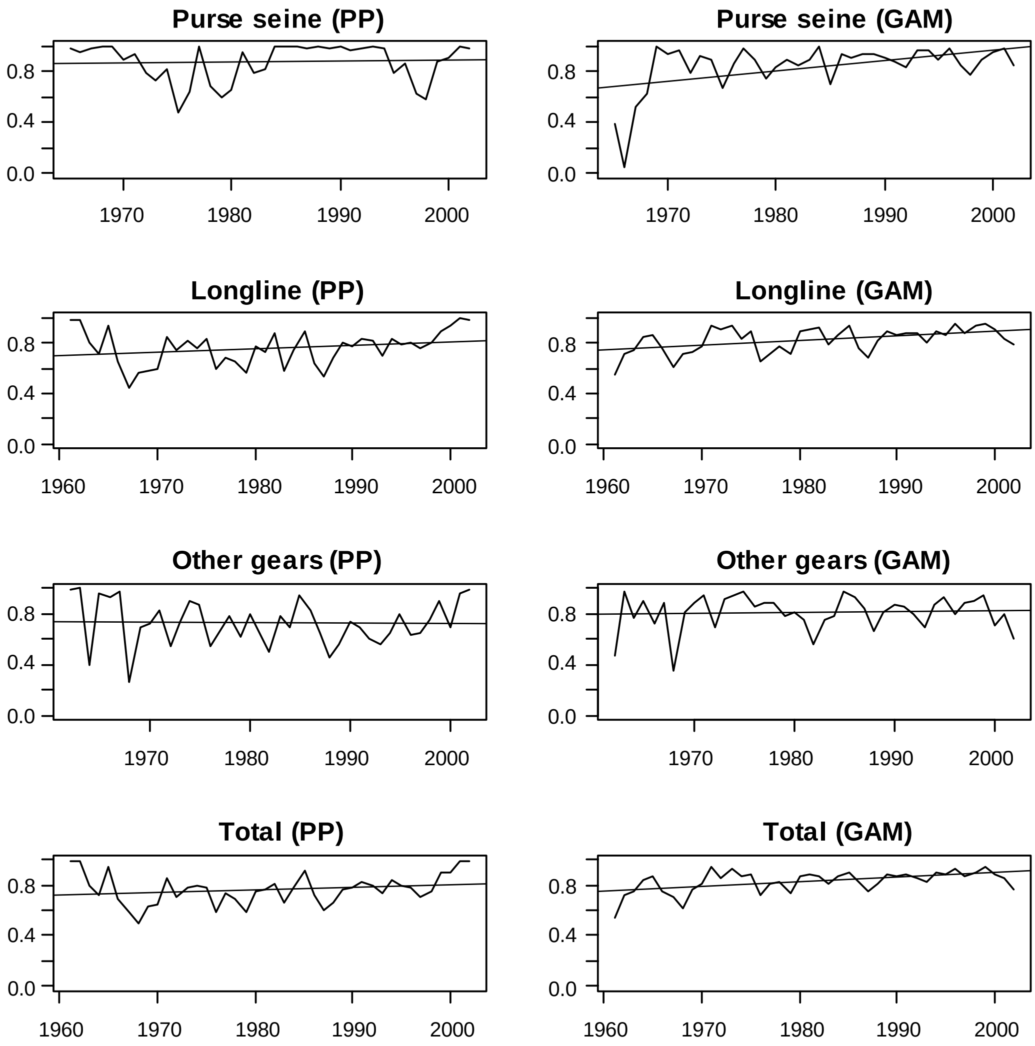


FIGURE 3

Atlantic bigeye tuna. Estimated trends of capacity output, excess capacity (EC) and overcapacity (OC), with the PP and GAM methods. dOC: overcapacity estimated as the difference between capacity and "dynamic MSY" (dMSY)

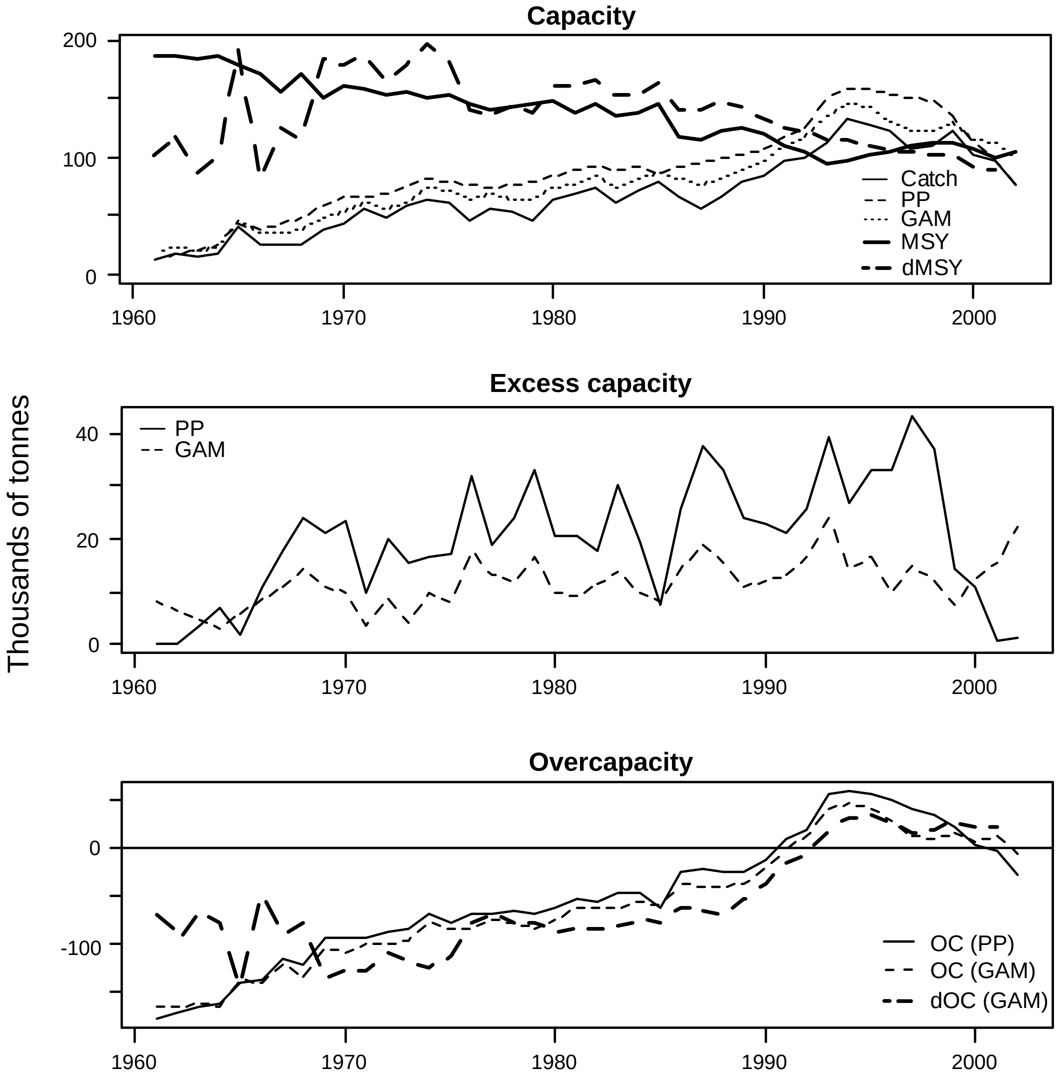


FIGURE 4

Atlantic bigeye tuna. Relationship between estimated capacity output (Y axis) and fishing effort (X axis), by fishery (number at the top of each panel)

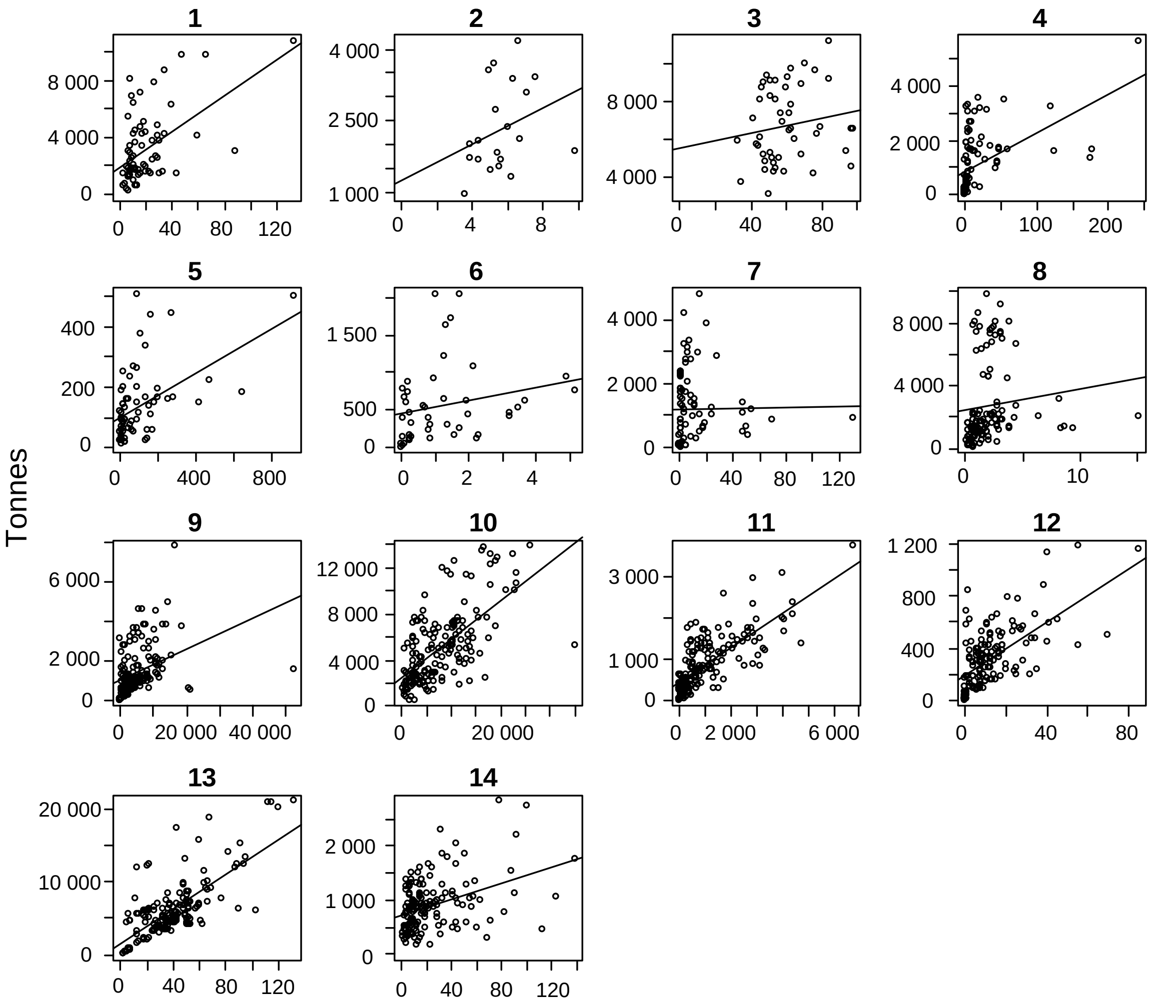
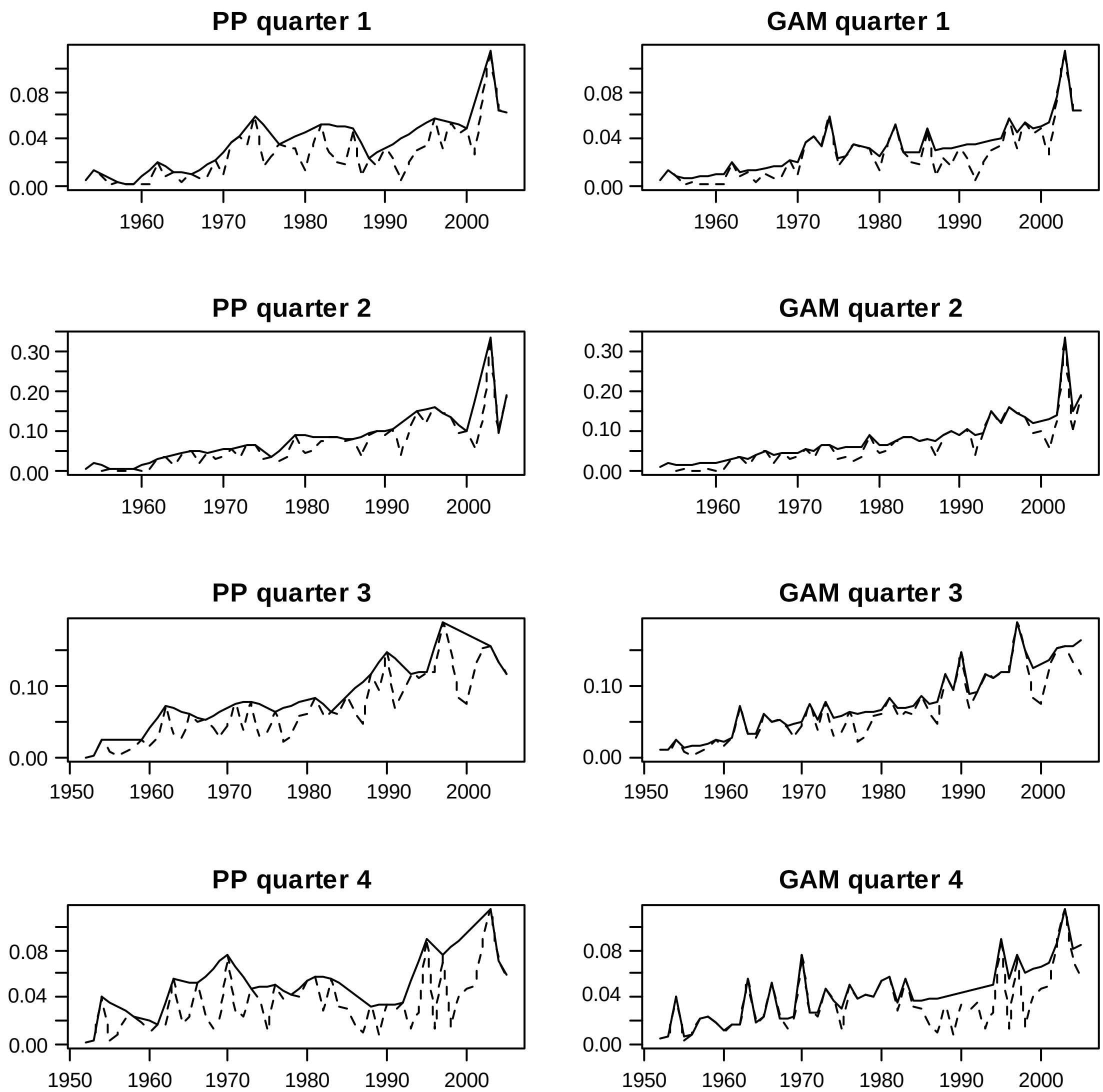


FIGURE 5

Western and Central Pacific bigeye tuna. Example of application of PP and GAM methods to quarterly fishing mortality of Fishery 10 (all longline except that of Australia in Region 5)



The dark lines are the outputs from MULTIFAN-CL and the dashed line is the estimate of fishing capacity.

FIGURE 6

Western and Central Pacific bigeye tuna. Estimated trends in capacity utilization by gear type and for all gears combined

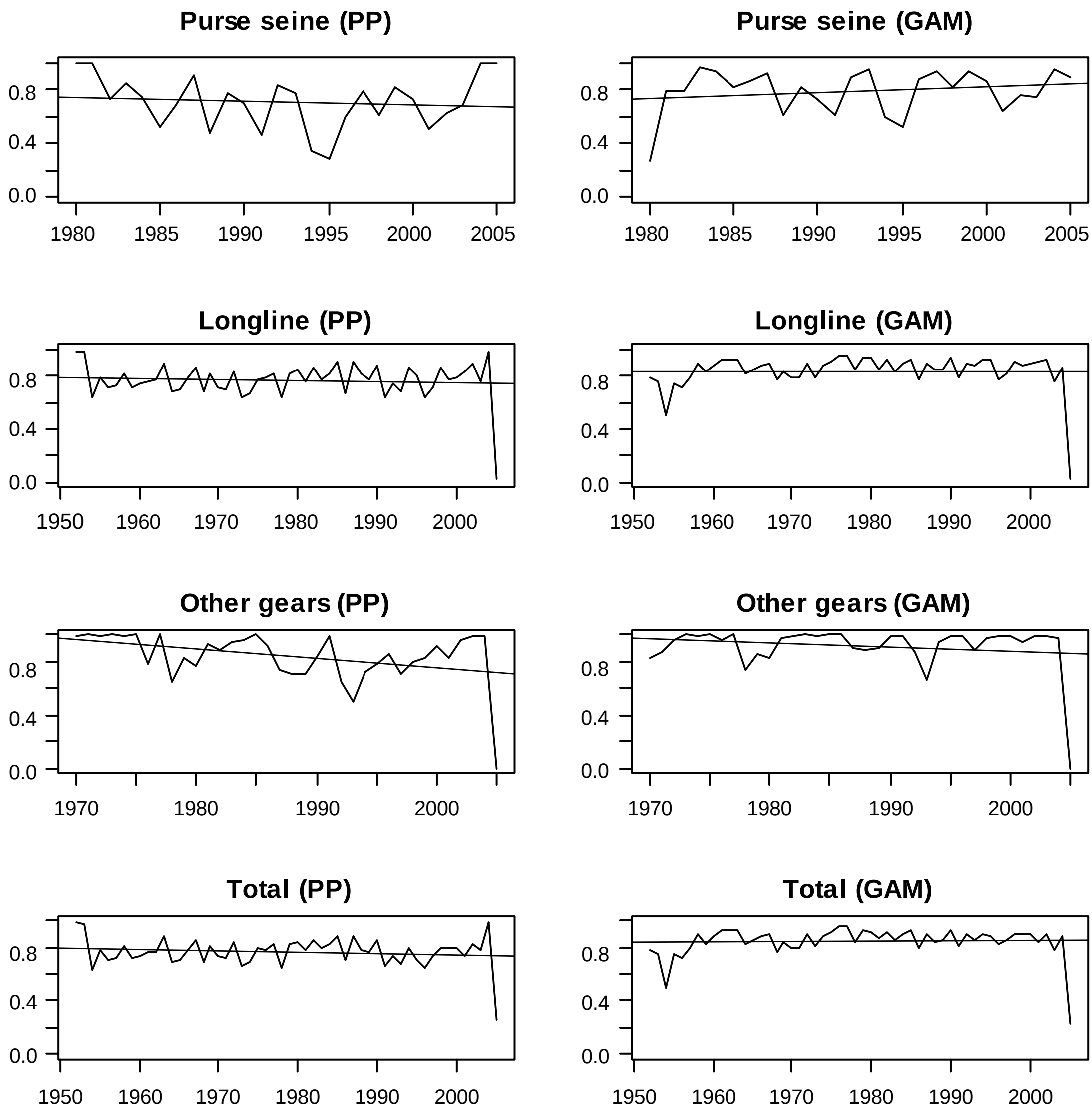


FIGURE 7

Western and Central Pacific bigeye tuna. Estimated trends of capacity output, excess capacity (EC) and overcapacity (OC), with the PP and GAM methods. dOC: overcapacity estimated as the difference between capacity and "dynamic MSY" (dMSY)

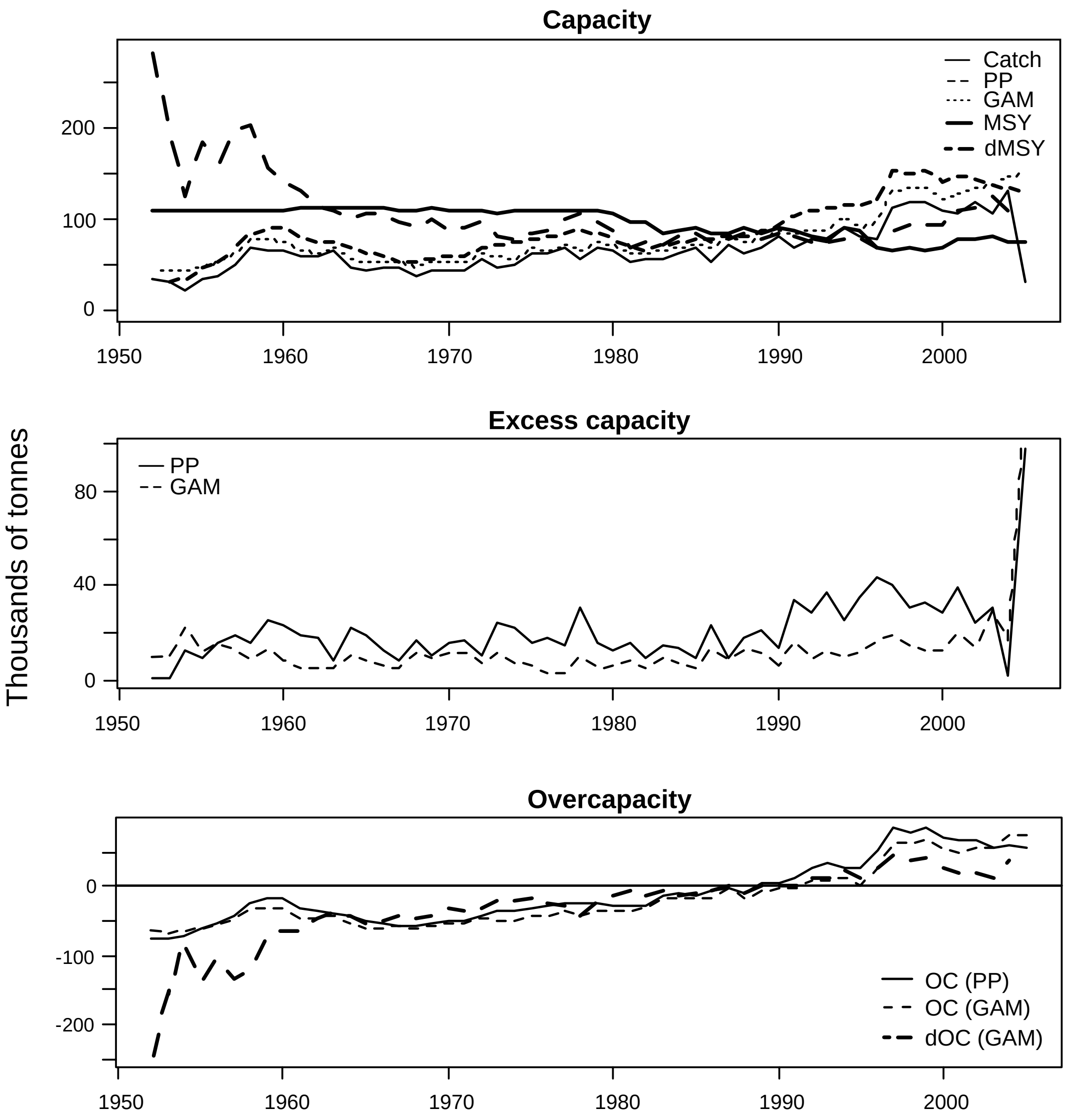


FIGURE 8

Western and Central Pacific bigeye tuna. Relationship between estimated capacity output (Y axis) and fishing effort (X axis), by fishery (number at the top of each panel)

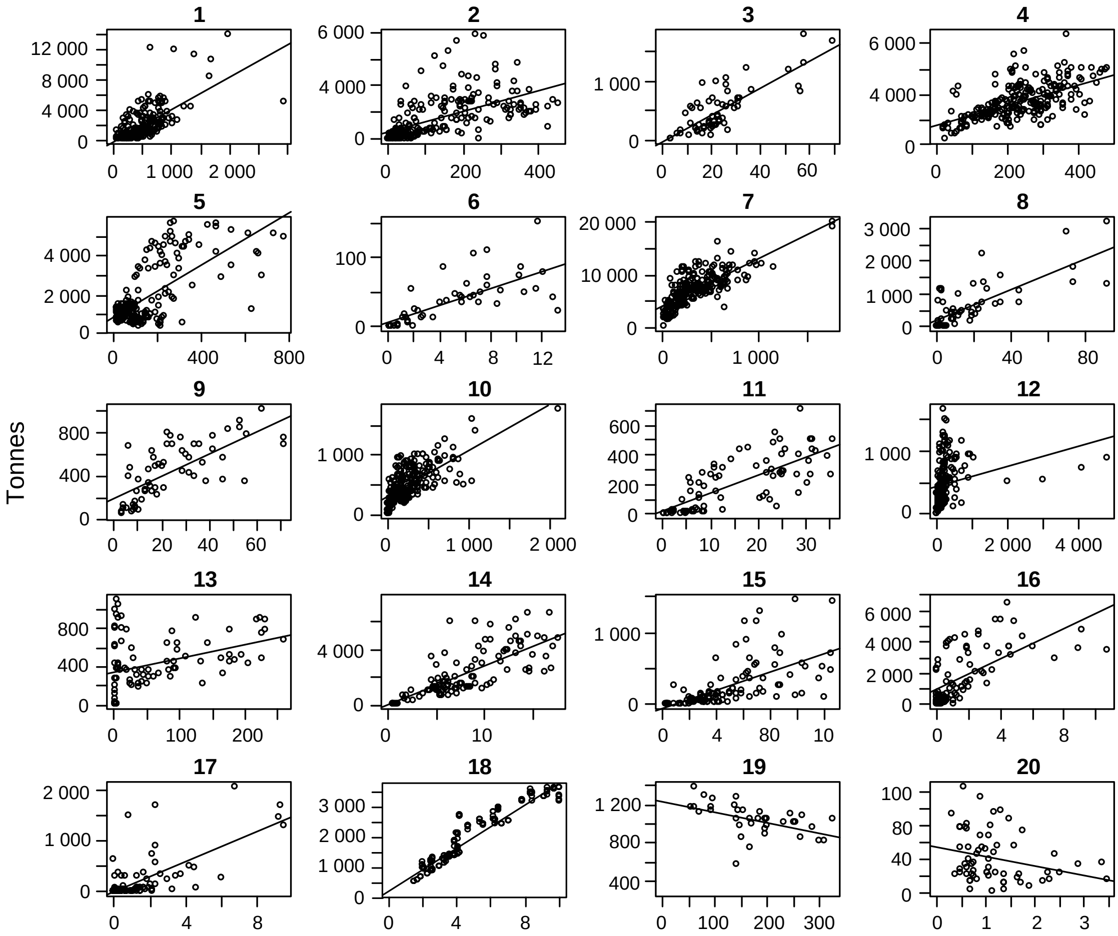
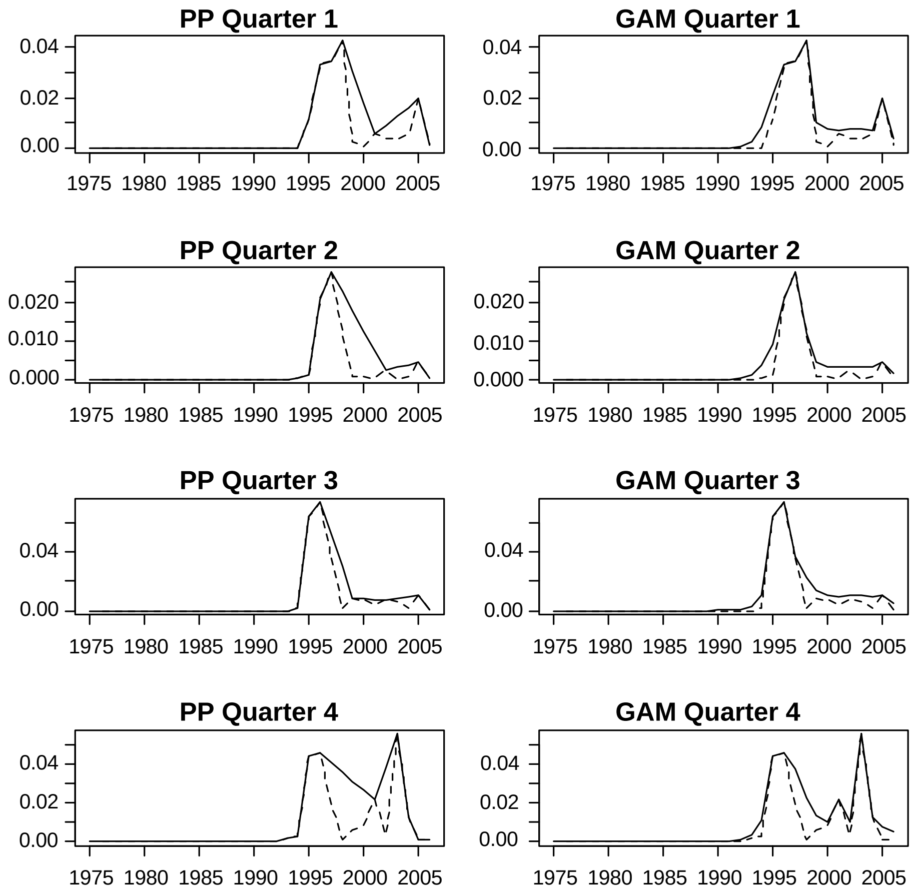


FIGURE 9

Eastern Pacific bigeye tuna. Example of application of PP and GAM methods to quarterly fishing mortality of Fishery 10 (purse-seine gear operating on floating objects in Regions 11 and 12)



The dark lines are the outputs from MULTIFAN-CL and the dashed line is the estimate of fishing capacity.