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Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related Information

14–16 May 2007
La Jolla, California, United States of America

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A view of a purse-seine operation.
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Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related Information

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Preparation of this document

These Proceedings present an outcome of the highly-technical Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related Information. The Workshop was hosted by the Inter-American Tropical Tuna Commission (IATTC) in La Jolla, California, USA, from 14 to 16 May 2007.

FAO's Japan-funded Project on the "Management of Tuna Fishing Capacity: Conservation and Socio-economics" organized the Workshop in collaboration with and with in-kind support from several international and national fisheries institutions involved in tuna fisheries research and management.

Shortly after its commencement, the Project established an external Technical Advisory Committee (TAC) composed of experts affiliated with the tuna agencies and programmes and some other institutions involved in tuna fishing, fisheries research and fisheries management to foster the collaboration with these institutions.

At the First Meeting of TAC, which took place in Rome, Italy, from 26 to 28 March 2003, the Project was organized to:

- review methods for the estimation of fishing capacity and their data requirements;
- determine the applicability of these methods for tuna fisheries; and
- finalize proposals of the Studies to be carried out by the Project.

The subjects of these Studies were to be:

- tuna resources and fisheries;
- the quantification of tuna-fishing capacity;
- the demand for tuna raw materials and products and their prices; and
- the management of tuna fisheries, particularly through controlling fishing capacity.

From 15 to 18 March 2004, the Second Meeting of TAC was held in Madrid, Spain, to:

- review the outcome of the Studies implemented by the Project and
- make recommendations on tuna fishing capacity management and future activities of the Project.

The papers resulting from the Studies were published in 2005 as FAO Fisheries Proceedings No. 2, which was entitled "Proceedings of the Second Meeting of the Technical Advisory Committee of the FAO Project Management of Tuna Fishing Capacity: Conservation and Socio-Economics".

As a result of recommendations of the Second Meeting of TAC, the Project organized the Workshop on Methodological Workshop on the Management of Tuna Fishing Capacity: Stock Status, Data Envelopment Analysis, Industry Surveys and Management Options. It was hosted by the Inter-American Tropical Tuna Commission (IATTC) in La Jolla, California, United States of America, from 8 to 12 May 2006. Its objectives were to:

- develop a method for the estimation of tuna-fishing capacity from stock assessment-related information;
- determine the feasibility of: (i) routinely collecting input data for the so-called Data Envelopment Analysis (DEA); and (ii) performing industry surveys of tuna fishing capacity utilization;
- relate DEA estimates of fishing capacity utilization to traditional estimates of fishing capacity;

- review the factors affecting fishing capacity (such as the number of vessels and their physical characteristics) that could be regulated by fisheries authorities;
- review the existing measures for managing tuna fishing capacity and, possibly, to identify additional options for such measures in the context of the outcome of addressing the above-mentioned objectives;
- prepare a Statement of participants of the Workshop; and
- formulate recommendations of the Workshop to the FAO Project on the Management of Tuna Fishing Capacity, FAO and the other institutions participating in the Workshop.

The Statement was presented at the Meeting of Tuna Regional Fisheries Management Organizations (RFMOs), which was held in Kobe, Japan, from 22 to 26 January 2007. The Report of and the papers presented at the Methodological Workshop were published as FAO Fisheries Proceedings No. 8, which were entitled “Methodological Workshop on the Management of Tuna Fishing Capacity: Stock Status, Data Envelopment Analysis, Industry Surveys and Management Options”.

The Methodological Workshop recommended that the method for the estimation of tuna fishing capacity from stock assessment-related information, which was developed as a result of that Workshop, be tested and applied. That testing and application of the method was carried out at the Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related Information, which is the subject of these Proceedings. Some of the related information is given in a prime publication (Arrizabalaga, H., Restrepo, V.R., Maunder, M.N., & Majkowski, J. 2009. Using stock assessment information to assess fishing capacity of tuna fisheries. ICES Journal of Marine Science).

Abstract

These Proceedings include (i) the Report of and (ii) the paper presented at the Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related Information. The Workshop was hosted by the Inter-American Tropical Tuna Commission (IATTC) in La Jolla, California, USA, from 14 to 16 May 2007. It was organized by FAO's Japan-funded Project on the "Management of Tuna Fishing Capacity: Conservation and Socio-Economics" in collaboration with and with in-kind support of several international and national fisheries institutions involved tuna fisheries research and management.

The paper presented at the Workshop describes peak-to-peak (PP) and general additive modeling (GAM) approaches to estimate fishing capacity and related quantities from stock assessment information. 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 decreasing trends after that. For most of the stocks analyzed, overcapacity was positive during a part of the time series. 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 Report of the Workshop outlines the discussions carried out at the Workshop, some proposals for further research, recommendations and conclusions of the Workshops.

Bayliff, W.H.; Majkowski, J. (eds.)
Estimation of tuna fishing capacity from stock assessment-related information: Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related Information. La Jolla, California, United States of America, 14–16 May 2007.
FAO Fisheries and Aquaculture Proceedings. No. 16. Rome, FAO. 2009. 53p.

Acknowledgements

The organization of the Workshop, the outcome of which is presented in these Proceedings, would not have been possible without FAO's Project on the Management of Tuna Fishing Capacity: Conservation and Socio-Economics. This Project was financed by the Government of Japan.

Shortly after its commencement, the Project established an external Technical Advisory Committee (TAC) composed of experts affiliated with the Tuna Agencies and Programs and some other institutions involved in tuna fishing, fisheries research and fisheries management to foster the collaboration with these institutions. The TAC recommended the organization of the Workshop.

The FAO Project on the Management of Tuna Fishing Capacity organized the Workshop in collaboration with and with in-kind support from several international and national fisheries institutions involved in tuna fisheries research and management. This support included the hosting of the Workshop by the Inter-American Tropical Tuna Commission (IATTC).

Dr Haritz Arrizabalaga of the Marine Research Division of the AZTI Tecnalia (Herrera Kaia Portualdea z/g 20110 Pasaia (Gipuzkoa), Spain) has carried out substantial analyses that are reported in these Proceedings. They were the basis of discussions of the participants of the Workshop.

The editors of these Proceedings are grateful to the Government of Japan, the institutions and persons that contributed to the organization and outcome of the Workshop, the author of the paper included in these Proceedings and all the participants of the Workshop for their collaboration and support. It would not have been possible to produce these Proceedings without this collaboration and support.

Contents

Report of the Workshop

1. OPENING

On behalf of the Food and Agriculture Organization of the United Nations (FAO) and its Project on the Management of Tuna Fishing Capacity, Dr Jacek Majkowski, the Coordinator of the project and the Convenor of the Workshop, opened the Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related Information. He welcomed the participants, thanking them for their attendance at the Workshop and expressing gratitude to the countries, institutions and persons who contributed to its organization.

In particular, he pointed out that:

- Through the FAO Project, the Government of Japan has provided funds for the organization of the Workshop.
- The Inter-American Tropical Tuna Commission (IATTC) has kindly offered to host it.
- The subject of the Workshop is a method developed by Dr Victor Restrepo of the International Commission for the Conservation of Atlantic Tunas (ICCAT) that he presented at the Methodological Workshop on the Management of Tuna Fishing Capacity (La Jolla, California, USA, 8–12 May 2006).

Dr Haritz Arrizabalaga of AZTI-Tecnalia/Marine Research carried out various analyses, using the new method, which are described in his paper presented at the Workshop of 14–16 May 2007.

2. INTRODUCTION OF PARTICIPANTS

Dr Majkowski introduced Dr Robin Allen, Director of the Inter-American Tropical Tuna Commission (IATTC), who would serve as Chairman of the Workshop. Dr Allen asked the participants of the Workshop to introduce themselves. The participants are listed in Appendix I.

3. ADOPTION OF THE PROVISIONAL AGENDA

The Provisional Agenda (Appendix II) was adopted without any changes.

4. LOGISTIC ARRANGEMENTS FOR THE WORKSHOP

Dr Allen summarized the various logistic arrangements for the Workshop.

Dr Majkowski suggested the following participants as Rapporteurs.

Agenda Items 1 to 5 – Jacek Majkowski
Agenda Item 6 – Robin Allen
Agenda Item 7 – Mark Maunder and Iago Mosqueira
Agenda Item 8 – Mark Maunder
Agenda Item 9 – SungKwon Soh
Agenda Items 10 and 11 – Yukio Takeuchi
Agenda Items 12 and 13 – Jacek Majkowski
Overall coordination – Haritz Arrizabalaga and Jacek Majkowski

5. FAO'S ACTIVITIES ON THE MANAGEMENT OF TUNA FISHING CAPACITY: PROGRESS REPORT

Dr Majkowski outlined the activities of the FAO's Project on the Management of Tuna Fishing Capacity, emphasizing those of direct relevance to the Workshop. He pointed out that the Project, which was financed by the government of Japan, commenced its activities in the second half of 2002. To foster the collaboration of the regional fisheries management organizations (RFMOs) concerned with tunas and other institutions involved in tuna fishing and fisheries research and management, the Project established an external Technical Advisory Committee (TAC) composed of experts affiliated with these institutions.

At the first meeting of the TAC, held in Rome, Italy, on 26–28 March 2003, the objectives were to:

- review methods for the estimation of fishing capacity and their data requirements,
- determine the applicability of these methods for tuna fisheries and
- finalize the proposal for the studies to be carried out by the Project.

The subjects of these studies were:

- tuna resources and fisheries,
- quantification of tuna fishing capacity,
- demand for tuna raw materials and products and their prices and
- management of tuna fisheries, particularly through controlling fishing capacity.

At the second meeting of the TAC, held in Madrid, Spain, on 15–18 March 2004, the objectives were to:

- review the outcome of the studies implemented by the Project and
- make recommendations on tuna fishing capacity management and future activities of the Project.

The participants in the second meeting of TAC also prepared a statement, which was presented at the Technical Consultation to Review Progress and Promote the Full Implementation of the International Plan of Action (IPOA) to Prevent, Deter and Eliminate IUU [Illegal, Unreported and Unregulated] Fishing and the IPOA for the Management of Fishing Capacity. (Rome, Italy, 24–29 June 2004). The papers resulting from the studies were published as the 336-page FAO Fisheries Proceedings No. 2 (Second Meeting of the Technical Advisory Committee of the FAO Project "Management of Tuna Fishing Capacity: Conservation and Socio-Economics", Madrid, Spain, 15–18 March 2004).

As a follow up to the second Meeting of TAC, the Project organized the Methodological Workshop on the Management of Tuna Fishing Capacity, which was hosted by the IATTC in La Jolla, California, USA, on 8–12 May 2006. The Workshop was organized by the Project in collaboration with and with financial and in-kind support of (1) most tuna agencies and programs, (2) some other international and national fisheries institutions, including those of the tuna fishing industry and (3) some universities. These included:

- the Forum Fisheries Agency, the IATTC, ICCAT, the Indian Ocean Tuna Commission, the Secretariat of the Pacific Community,
- the Japan Federation of Tuna Fishermen's Association, the U.S. National Marine Fisheries Service, the National Research Institute of Far Seas Fisheries of Japan, the World Tuna Purse-Seine Organization,
- the College of William and Mary and the University of California, San Diego.

The objectives of the workshop were:

- to develop methods for the estimation of tuna fishing capacity from stock assessment-related information,
- to determine the feasibility of (1) routinely collecting input data for performing Data Envelopment Analysis (DEA) and (2) performing industry surveys of tuna fishing capacity utilization,
- to relate DEA estimates of fishing capacity utilization to traditional estimates of fishing capacity,
- to review the factors affecting fishing capacity (such as the numbers of vessels and their physical characteristics) that could be regulated by fisheries authorities,

- to review the existing measures for managing tuna fishing capacity, and possibly to identify additional options for such measures in the context of the outcome of addressing the above-mentioned objectives,
- to prepare a statement of the participants in the Workshop, and
- to formulate recommendations of the Workshop to the FAO Project on the Management of Tuna Fishing Capacity, FAO and the other institutions participating in the Workshop.

The method mentioned in the first objective of the previous Workshop was developed, but not tested and applied comprehensively to tuna stocks on a global scale. For that reason, the present Workshop was held.

The papers from the previous Workshop and its Report have been edited, and will be published as an FAO Fisheries Proceedings. The Statement of the previous Workshop was presented to the meeting of tuna RFMOs and their members, which was held in Kobe, Japan, in January 2007.

6. MEETING OF TUNA REGIONAL FISHERIES ORGANIZATIONS AND THEIR MEMBERS (KOBE, JAPAN, 22–26 JANUARY 2007): DEVELOPMENTS RELATED TO THE MANAGEMENT OF TUNA FISHING CAPACITY

Dr Allen reported on the discussions on tuna fishing capacity at the meeting of tuna RFMOs and their members. Fleet capacity was discussed under the agenda item concerning specific actions to improve the functions of each RFMO, including coordination and collaboration among the RFMOs. The results of the 2006 Methodological Workshop on Fishing Capacity were presented, together with a statement from a related IATTC Workshop on Regional Economic Cooperation in the Pacific Fishery for Tropical Tunas. The course of actions agreed by the Kobe Meeting included the following actions on tuna fishing capacity.

- Development, where appropriate, and application of equitable and transparent criteria and procedures for allocation of fishing opportunities or level of fishing effort, including provisions to allow for new entrants.
- Controls, including fishing capacity reduction as appropriate, to ensure that actual total catch, fishing effort and capacity are commensurate with available fishing opportunities in order to ensure sustainability of tuna stocks while allowing legitimate fishery development of developing coastal states, particularly small island developing states and territories.

7. ESTIMATION OF TUNA FISHING CAPACITY FROM STOCK ASSESSMENT-RELATED INFORMATION

a) Outline of the method

In a paper presented at the Methodological Workshop on the Management of Tuna Fishing Capacity, held in La Jolla, California, USA, on 8–12 May 2006. Restrepo (2007) presented a method for the estimation of fishing capacity on tuna fisheries based on estimates of fishing mortality obtained from stock assessments. In contrast to economic methods of capacity estimation (Kirkley and Squires, 1999), this method does not require disaggregated data and uses information readily available for most tuna stocks.

In brief, an algorithm connects consecutive peaks, defined here as values larger than the two nearest ones, of fishing mortality by quarter and on a fishery-by-fishery basis. These are then used to infer the output capacity (in tonnes) for each fishery. Information on age-specific selectivity and trends in fishing efficiency is also incorporated. The original document presented an application of the method to Atlantic bigeye tuna.

The author highlighted the simplicity of the approach, but also recognized the lack of a sound theoretical basis and the multiple methodological choices available for its implementation. For example, a Generalized Additive Modeling approach was suggested in an appendix, and a piece-wise regression between peaks was suggested as an alternative to the peak analysis conducted.

Presentation: "Thoughts on capacity and its estimation", prepared by Victor Restrepo
A presentation based on that prepared by Dr Restrepo for ICCAT's Working Group on Methods (Madrid, Spain, 19–23 March 2007) was given by Dr Arrizabalaga. The main points of the method were covered, and the calculation procedure was explained in detail (Figure 1).

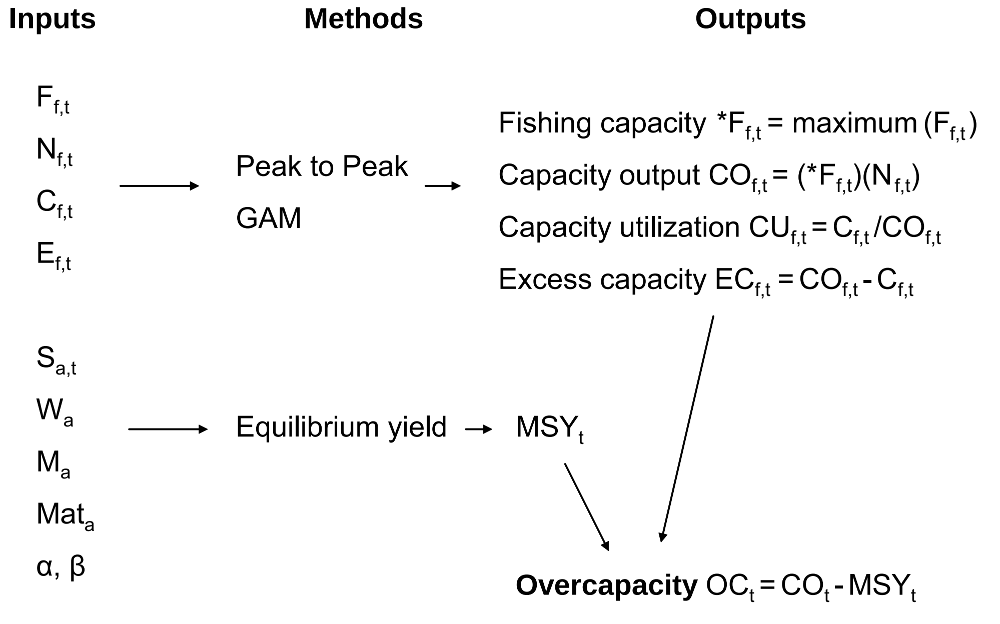
Discussion
A general discussion on the merits and possible shortcomings of the method brought out some issues that might warrant further investigation. Both methods assume that peak *F*s are measured without error. It was pointed out that the influence of the quality of the estimates of *F* on the results obtained is an important consideration.

Although the method incorporates yearly values of maximum sustainable yield (MSY), in the examples presented these vary only due to changes in selectivity. It might be necessary to incorporate changes in the ecosystem, such as the regime shifts observed in the past in the Eastern Pacific Ocean, that would switch the system to a different MSY level.

The impact of management measures, such as closures, on *F* must be considered carefully. If fishing effort, and hence fishing mortality, is restricted through management measures, the analysis would likely interpret it as a decrease in fishing capacity. If, in fact, there has been no reduction in fishing capacity, a possible solution would be to adjust the values of *F* for the effect of management regulations, for the appropriate period of time, before fitting the model.

The possible impact of fleets switching between stocks on the estimates of capacity based on fishing mortality was discussed. For example, fleets moving between the

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.

Western and Central Pacific and Eastern Pacific areas would decrease fishing pressure on one of the stocks, this change being reflected in estimates of fishing mortality and fishing capacity. However, the effective fishing capacity may remain at the previous level, as those fleets may be permitted to return to the initial stock.

b) Application and testing of the method

Presentation: "Methods to estimate fishing capacity using stock assessment information. Sensitivity tests and application to Pacific, Atlantic and Indian Ocean tuna stocks" by Haritz Arrizabalaga

An example of implementation of the method outlined above was presented by Dr Arrizabalaga. Capacity analyses were carried out for seven stocks (Atlantic bigeye, Eastern Pacific bigeye, Western and Central Pacific bigeye, Indian Ocean bigeye, Western and Central Pacific yellowfin, Eastern Pacific yellowfin and Western and Central Pacific skipjack).

Sensitivity analyses were also conducted to assess the impact on the estimates of capacity of the level of aggregation of the input data and of the variability on the estimates of fishing mortality allowed in the Multifan-CL model fits. For the first case, three levels of time-gear aggregation on an assessment of Atlantic bigeye conducted using Multifan-CL were considered:

- Fourteen fisheries were considered in quarterly time steps, as in the original assessment.
- The data were aggregated around three fisheries, purse seine, longline and others, and by semester.
- All fisheries were combined into a single fishery, and the data were considered in yearly time steps.

The effect of the given variability in estimates of fishing mortality in Multifan-CL was investigated by redoing the Atlantic bigeye assessment with three levels of variability (measured as $p = 1/(2*CV^2)$):

- The original values of p = 5, 10 and 20
- A high F variability scenario with p = 1, 2 and 3
- A low F variability scenario with p = 20, 40 and 80

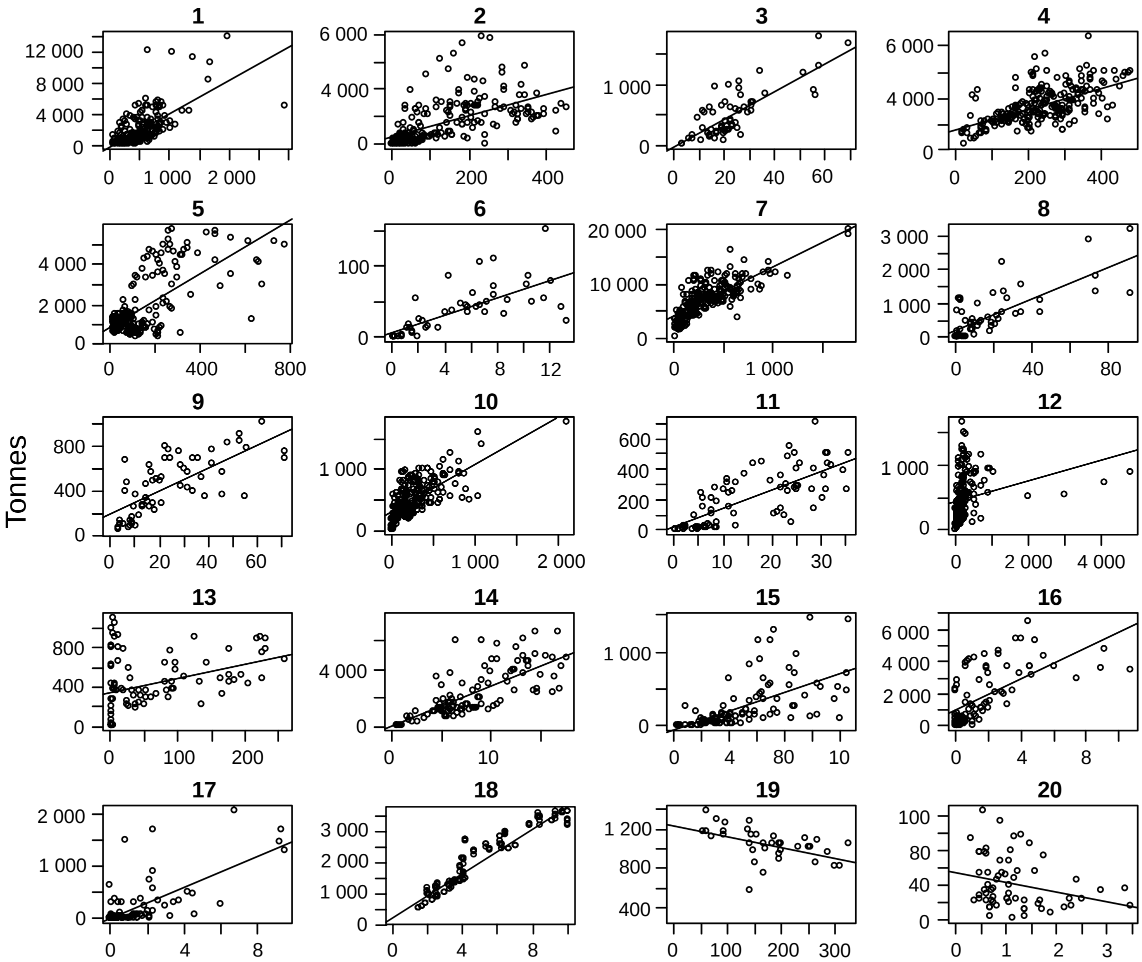
The main conclusions of this exercise were related to both the method itself and the results obtained for the stocks analyzed. Values estimated using the peak-to-peak method were usually greater than those obtained with general additive modeling (GAM). This is not unexpected, as the peak-to-peak method tends to provide values as high as the greatest values obtained, while GAM provides a smooth time series that is later raised to the maximum values observed.

Periods during which the peak-to-peak method estimated overcapacity were apparent for almost all the stocks. A common trend in time was apparent for most stocks too, reaching maximum values during the late 1990s or early 2000s. For most of the stocks analyzed, there was overcapacity during some years. An increase in overcapacity along the time series was due to both an increase in capacity output and a decrease in MSY due to changes in selectivity.

The sensitivity analyses conducted showed the importance of assumptions in the stock assessment, especially those affecting the estimation of MSY. Comparison of the effect of data aggregation appeared to indicate that as the input data are aggregated, overcapacity is estimated to be less than with disaggregated data.

The relationship between effort and capacity output was not clearly evident for most stocks, which limits the ability to determine appropriate effort levels from capacity analyses. The relationship between estimated capacity output and effort for all fisheries in the bigeye tuna stock of the Western and Central Pacific Ocean is shown in Figure 2.

FIGURE 2
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).

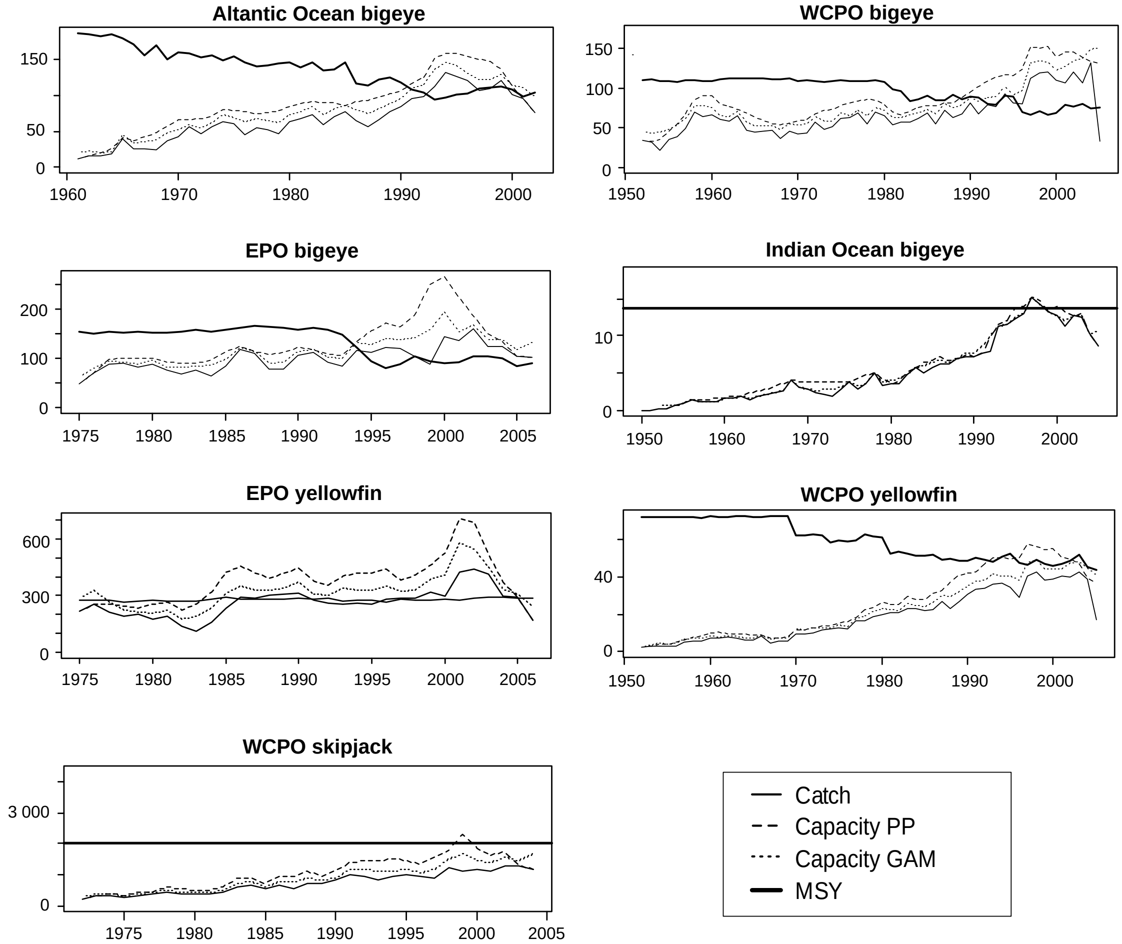
c) General discussion

The difference in the estimates of capacity obtained at the beginning and the end of each time series was noted. The GAM and peak-to-peak methods estimate different values at the start and end of the series, as a GAM is able to interpolate along the whole series, while the implementation of the peak-to-peak method used the observed *F* values as measures of fishing capacity before the first and after the last peak.

The sensitivity analyses carried out appear to indicate that overcapacity estimates are quite sensitive to the way fishing mortality is estimated in the various stock assessment methods, as the inverse relationship between fishing mortality and biomass estimates affects the MSY-related calculations. Assessments carried out using Multifan-CL seem to be especially affected, which could be related to the way fishing mortality is modeled in this model. The coefficient of variation in the fishing mortality estimation is modified, but variability in length frequencies is not, so their relative importance is effectively being altered.

The results for the most recent year obtained for bigeye tuna of the Western and Central Pacific Ocean were negatively affected by having only some of the longline data. A previous comment on the need to account for known changes in the environment modifying the value of MSY was highlighted by the estimates of capacity for Eastern Pacific bigeye. Overcapacity was estimated to be very great

FIGURE 3
Estimates of capacity output, with the Peak to Peak (PP) and general additive model (GAM) methods for all stocks considered in the paper



MSY = maximum sustainable yield; WCPO = western and central Pacific Ocean; EPO = eastern Pacific Ocean.

in 2000, following abnormally strong recruitment. Similarly, the trends in capacity presented for Eastern Pacific yellowfin tuna are not completely consistent with current knowledge of both fishery and stock, which motivated the use of dynamic MSY, as described below.

Variations in the estimated capacity may be caused by variations in fishing mortality due to the imperfect ability of fleets to obtain the same results with their effort.

Estimating dynamic MSY based on FMSY and biomass estimates (Dr Mark Maunder)

An alternative estimation of MSY, taking into consideration yearly changes in stock abundance due to recruitment and environmental factors, was presented for yellowfin tuna in the Eastern Pacific Ocean. MSY is estimated by modeling the population over the historical period, while applying F_{MSY} to recruitment and other parameters taken from the stock assessment. It was suggested that an alternative approach would be to take biomass estimates themselves from the stock assessment for each year and multiply that quantity by F_{MSY}. When MSY is considered to vary according to stock productivity, a different picture of the relationship between catch and capacity emerges.

The estimates of capacity output are shown in Figure 3.

d) Conclusions

- The Workshop recognized the usefulness of this method as a strategic tool to identify problems in estimating capacity and trends in capacity over time, especially in settings in which both fishing mortality and stock abundance fluctuate significantly.
- A useful addition to this method for management purposes would be to simulate the population consequences of application of the estimated fishing capacities to the stock. Increases in capacity following the estimations obtained here would have an impact on the abundance, and thus on the corresponding ability of the fleet to exert its fishing capacity on the stock in the following year.

Methodological

- Calculations should be extended to include MSY variability due to environmental factors, changes in productivity and variability in recruitment, in addition to changes in selectivity.
- Although general methods for calculating capacity such as this one allow for direct comparison of results among stocks and regions, ad hoc methods adapted to the local characteristics of both fishery and stock might provide more practical estimates on which to base management. As the theoretical basis for a method for estimating maximum fishing mortality is not clear, it might prove difficult to justify its adoption.
- One of the methods employed, the peak-to-peak method, appears to underestimate capacity at the start and the end of the series unless peaks are present on the first and last values. The GAM-based method does not suffer from this limitation, as splines are able to interpolate along the whole time series. However, the choice of smoothing splines is mostly arbitrary.
- Fisheries assessment techniques are capable of calculating desired target fleet sizes. For example, with stable gear mixes and average recruitment, FMSY can be estimated and compared to actual F(t), which itself can be related over longer periods of time with levels of fishing effort as measured by days at sea, which, in turn, can be related to fleet size.
- Fishing mortality may be a more appropriate measure of capacity than catch. For example, if the fishery is operating at FMSY and the population size is above the biomass corresponding to MSY (BMSY), the fishery would be designated as at overcapacity, even though the number of vessels may be appropriate to produce the average MSY when the population is at BMSY. The population may be above BMSY because the stock has historically been only lightly exploited or because of increases in productivity (see above).
- Conversely, fishing an overfished stock at FMSY will produce estimated negative overcapacity (using the average MSY).

Interpretation

- Estimates of capacity may be biased upward because the catch may be restricted by the carrying capacity of the fleet and travel time, rather than by the ability of the fleet to find the fish.
- Interpretation of peak values in fishing mortality should include consideration of a range of possible factors. The method assumes that peaks represent instances of full use of the fleet capacity. An alternative view, for example, could explain those peaks as changes in catchability due to environmental or technological factors.
- External information on stock and fishery dynamics that might help explain whether? peaks in fishing mortality should be used. Management measures, changes in fleet dynamics or other biological and technological factors might

be behind some of the observed peaks in fishing mortality, and should not be interpreted only as changes in capacity.

- The difference between potential and practical capacity should be fully explored. Estimates of overcapacity in years during which the catches were extremely high appear to indicate that the method provides an indication of maximum capacity that cannot always be achieved even under the best conditions.
- The methods of estimation of excess capacity reviewed during the meeting all guarantee that the results will indicate excess capacity every year and for every species. Furthermore, if the fishery is managed in what some might consider appropriately by fishing the stock at FMSY (t) the annual catch would match dynamic MSYt, defined as ~Bt*FMSY,t, and thereby guarantee that the estimates will indicate that overcapacity exists. Yellowfin tuna in the Eastern Pacific Ocean is a case in point.
- The quantities "excess capacity" and "overcapacity" (defined as capacity output minus catch and capacity output divided by MSY, respectively) may not represent the estimates desired by fisheries management. Instead fisheries managers may be more interested in obtaining practical levels of fleet size that would allow the fleet to operate under normal conditions year-round without need for further management constraints, except in some circumstances (e.g. the need to reduce the catches of bigeye tuna in sets made on tunas associated with floating objects).

8. PROPOSALS FOR FURTHER APPLICATION AND TESTING OF THE METHOD

It was noted that certain tuna RFMOs may be interested in additional applications of the method, using updated stock assessment data. In this case, the issues summarized in the General Discussion, Conclusions and Recommendations section should be taken into consideration.

Two alternative approaches to the estimation of tuna fishing capacity were recommended for further investigation. The first approach uses F/F_{MSY} as a practical indication of the level of overcapacity, rather than considering it in the context of economic definitions. Regression of F against explanatory factors (*e.g.* total vessel tonnage and stock biomass) could be used to identify appropriate ways to restrict capacity.

The second approach is a method that uses vessel-specific estimates of fishing mortality, rather than estimates aggregated by fishery.

9. PLANS FOR PUBLICATIONS

There was agreement that the work presented by Dr Arrizabalaga and discussions at the Workshop provided insight into the Dr Restrepo's method and into problems associated with estimating fishing capacity in general. Two outlets for publication were suggested. The first was FAO Fisheries Proceedings (Report of the Workshop, plus the paper by Dr Arrizabalaga, with a brief description of the events in the fishery that may have affected the estimates of overcapacity). The second was a primary publication in a peer-reviewed journal, which would outline the problems of determining capacity.

10. GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

The Workshop identified the various difficulties and problems with using the methods considered to estimate fishing mortality. They are probably applicable to the DEA methods, but the lack of expertise at this Workshop did not allow the participants to fully consider them.

The future of the TAC of the FAO Project on the Management of Tuna Fishing Capacity was discussed. In addition to its advisory role for the FAO Project, the Workshop recognized the usefulness of the TAC as a forum for the tuna RFMOs and the tuna fishing industry

- to consider the technical issues involved and
- to consult and coordinate the research related to the management of tuna fishing capacity.

Therefore, the Workshop recommended that before the termination of the FAO Project on the Management of Tuna Fishing Capacity, FAO in consultation with the TAC, consider the transformation of the TAC into a Technical Coordination Committee (TCC) that would continue provide such a forum after the termination of the FAO Project.

The Workshop recommended also that FAO secure funds for meetings of the TCC, for technical work on the management of tuna fishing capacity and for work required to complete the publications described in
Section 9.

11. ANY OTHER MATTERS

No other matters were considered by the participants in the Workshop.

12. ADOPTION OF THE REPORT

The Report of the Workshop was adopted on 16 May 2007.

13. ADJOURNMENT OF THE WORKSHOP

Dr Majkowski, Convenor of the Workshop, thanked:

- the IATTC for hosting the Workshop,
- Dr Allen for chairing the Workshop,
- Dr Arrizabalaga for his presentation,
- the rapporteurs for drafting the report,
- all the participants in the Workshop for their technical input to the Workshop and
- Ms. Mónica Galván and Ms. Cynthia Sacco for secretarial and other assistance.

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APPENDIX 1

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APPENDIX 2

Agenda

Monday 14 May 2007 (9.30 a.m.)

1. Opening
2. Introduction of participants
3. Adoption of the Provisional Agenda
4. Logistic arrangements for the Workshop
5. FAO's activities on the management of tuna fishing capacity: Progress Report
6. Meeting of tuna regional fisheries organizations and their members (Kobe, Japan, 22–26 January 2007): Developments related to the management of tuna fishing capacity
7. Estimation of tuna fishing capacity from stock assessment-related information
   a) Outline of the method
   b) Application and testing of the method
   c) General discussion
   d) Conclusions

Tuesday 15 May 2007 (9.00 a.m.)

7. Estimation of tuna fishing capacity from stock assessment-related information (cont.)
8. Proposals for further application and testing of the method
9. Plans for publications
10. General discussion, conclusions and recommendations
11. Any other matters

Wednesday 16 May 2007 (1.00 p.m.)

12. Adoption of the Report
13. Adjournment of the Workshop

Paper presented at the workshop

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).

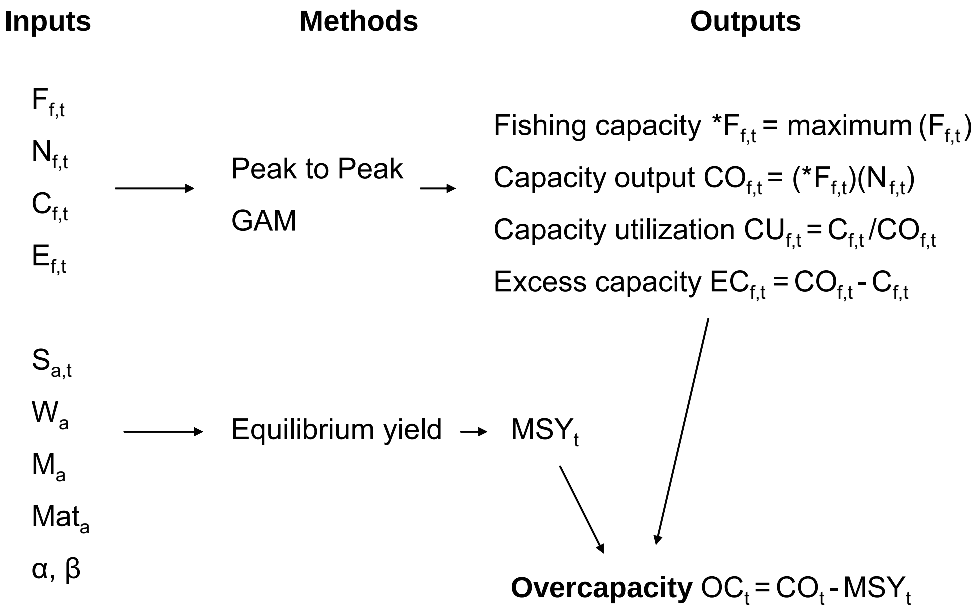
2. MATERIALS AND METHODS

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.

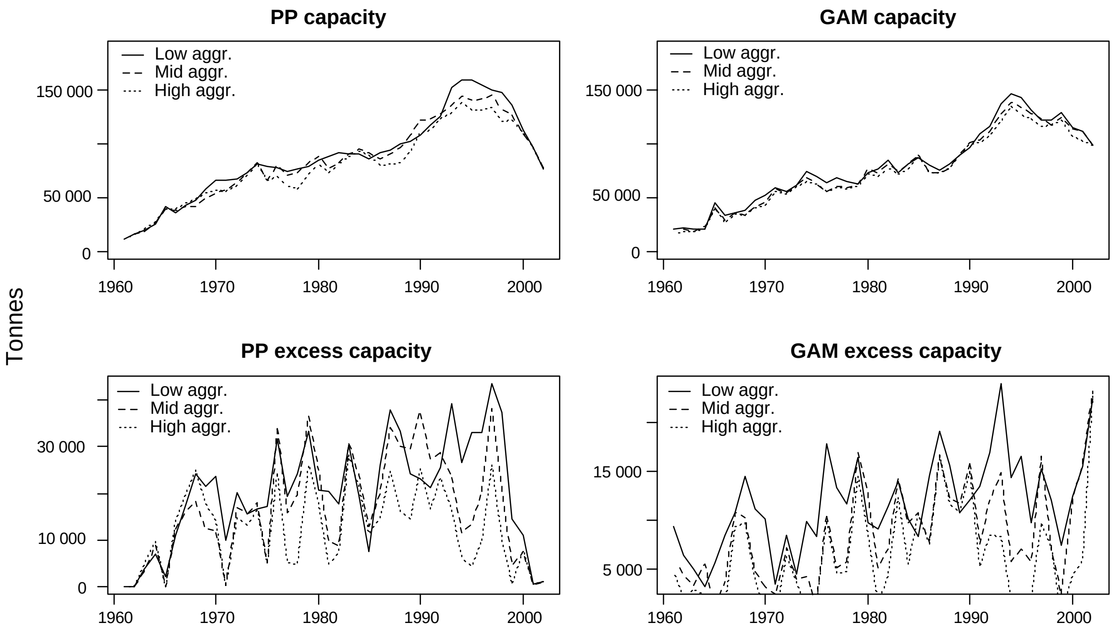
TABLE 2

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

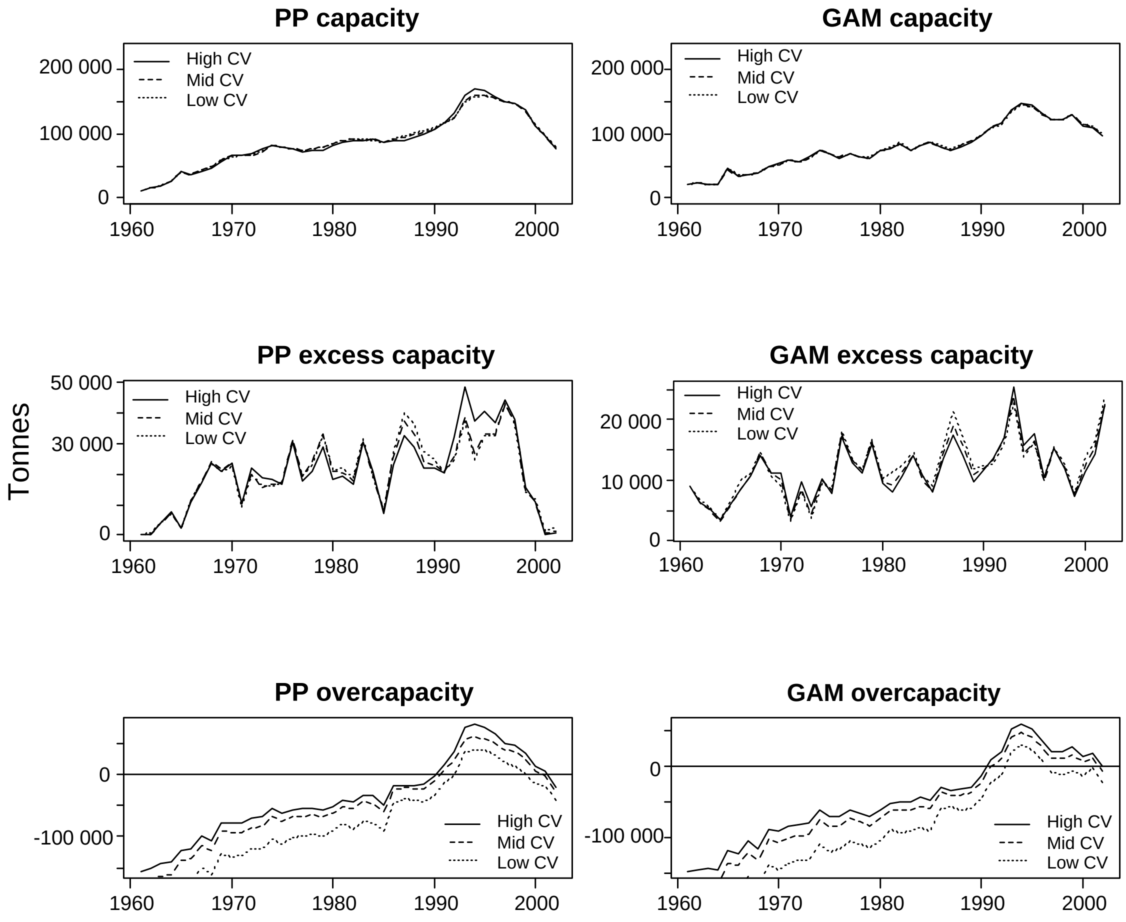


Figure adapted from Arrizabalaga *et al.* (2009).

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

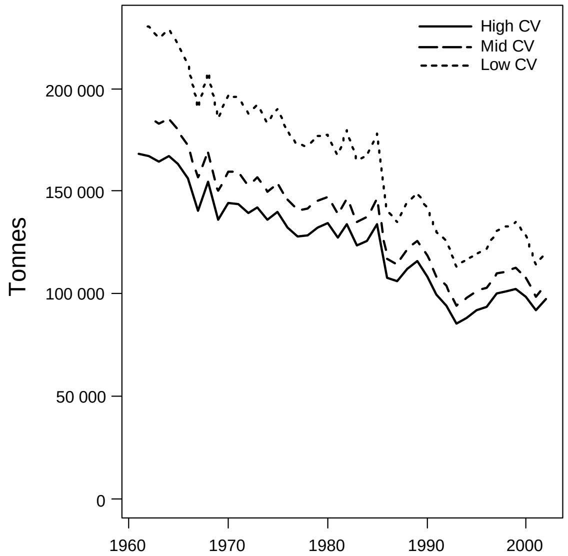


Figure adapted from Arrizabalaga *et al.* (2009).

• 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.

5. ACKNOWLEDGEMENTS

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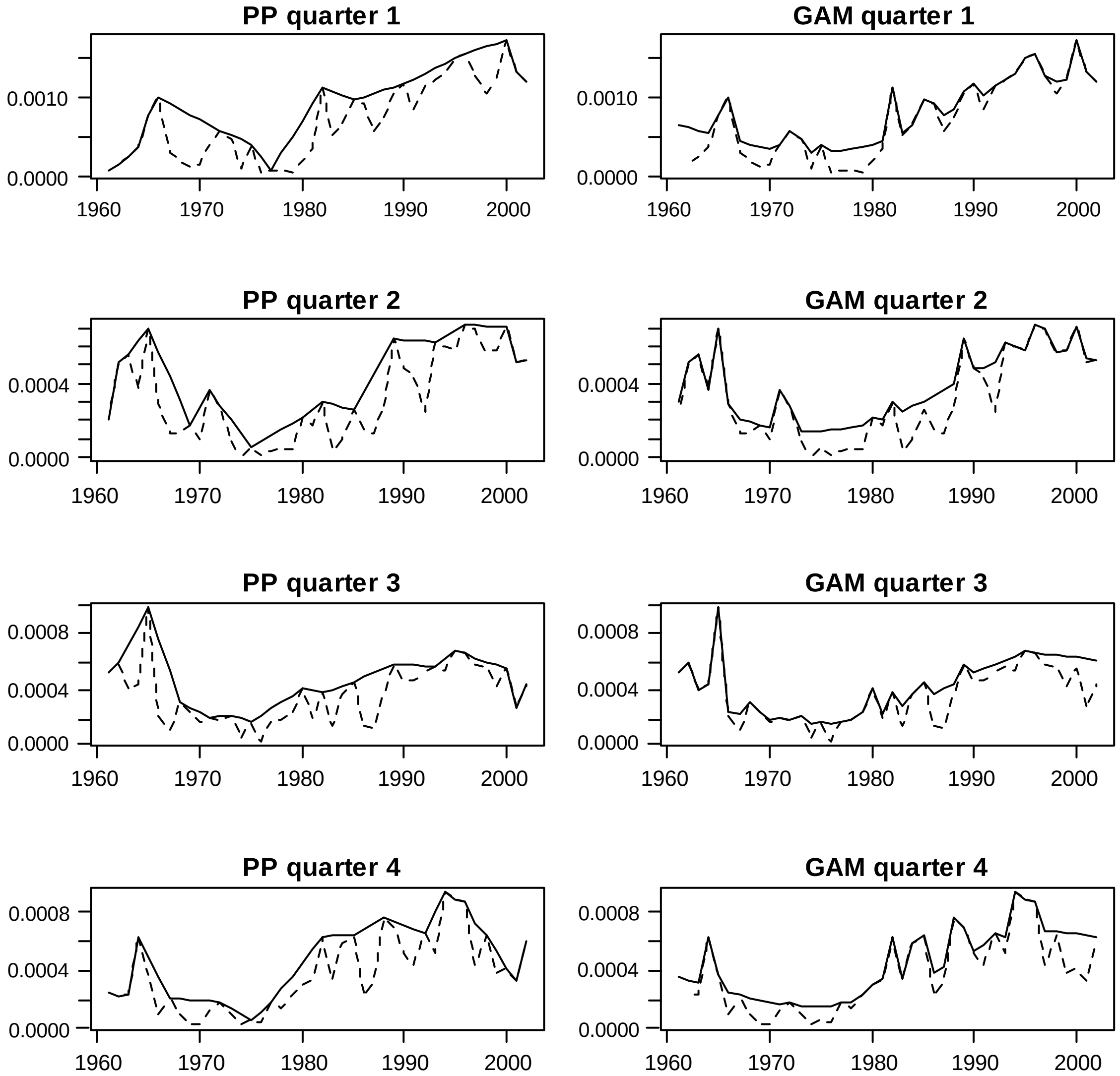
APPENDIX

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

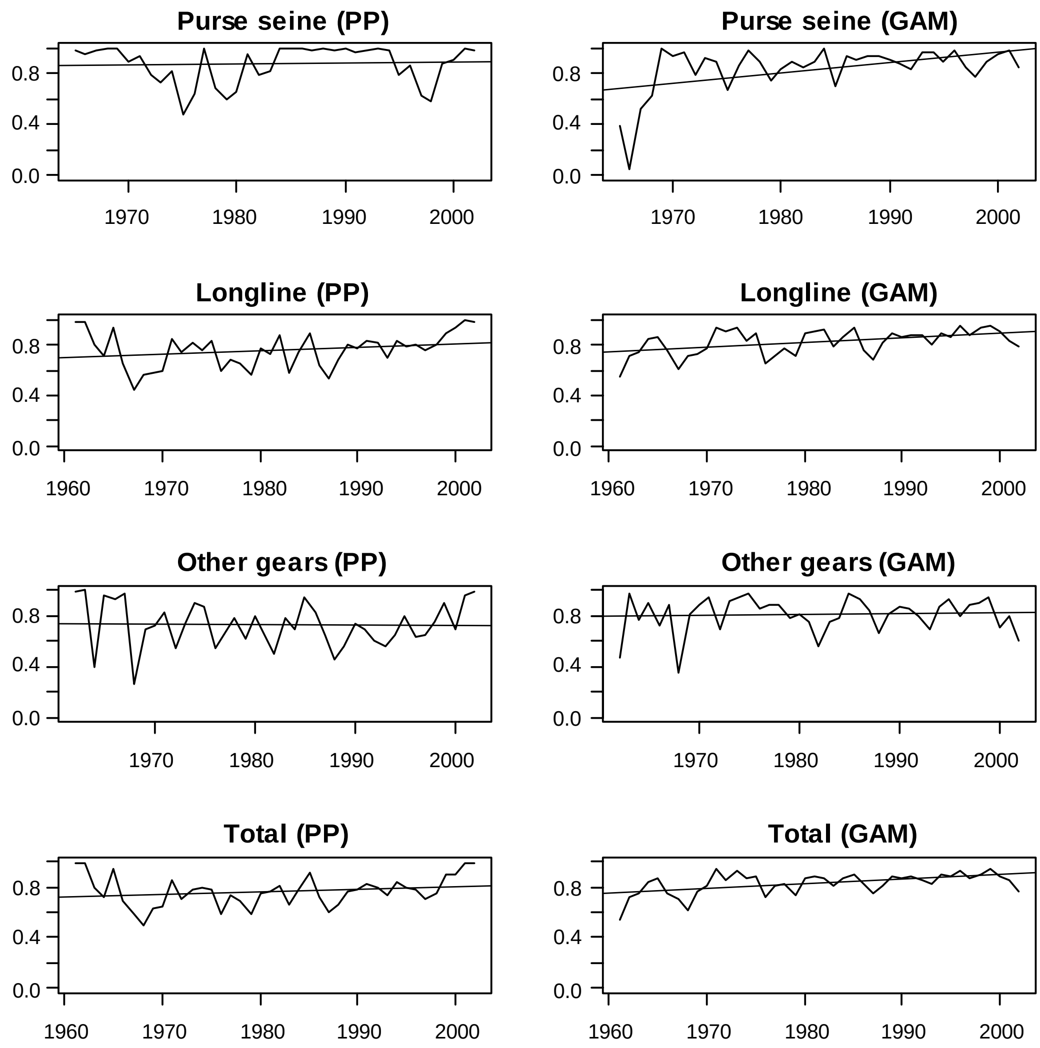


FIGURE 3

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)

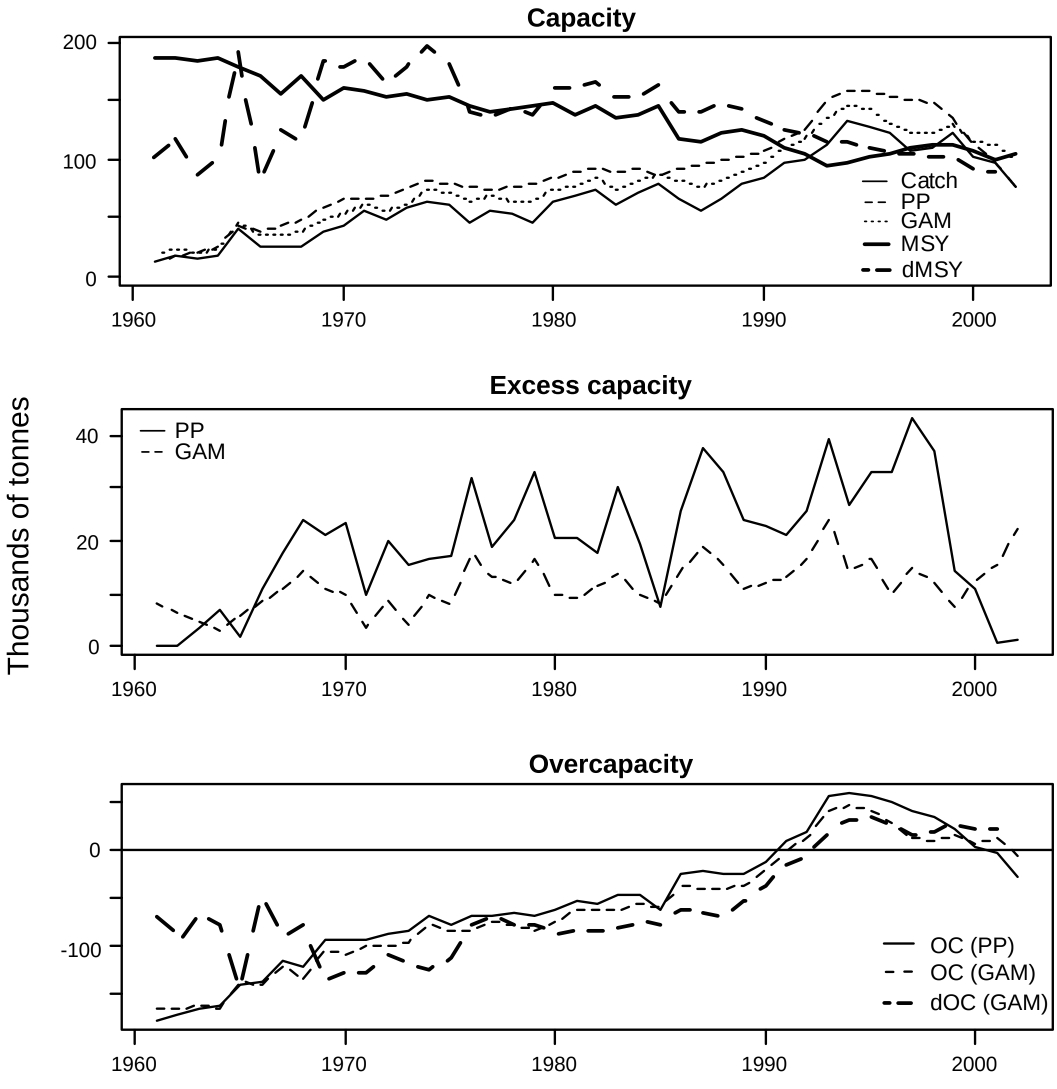


FIGURE 4

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

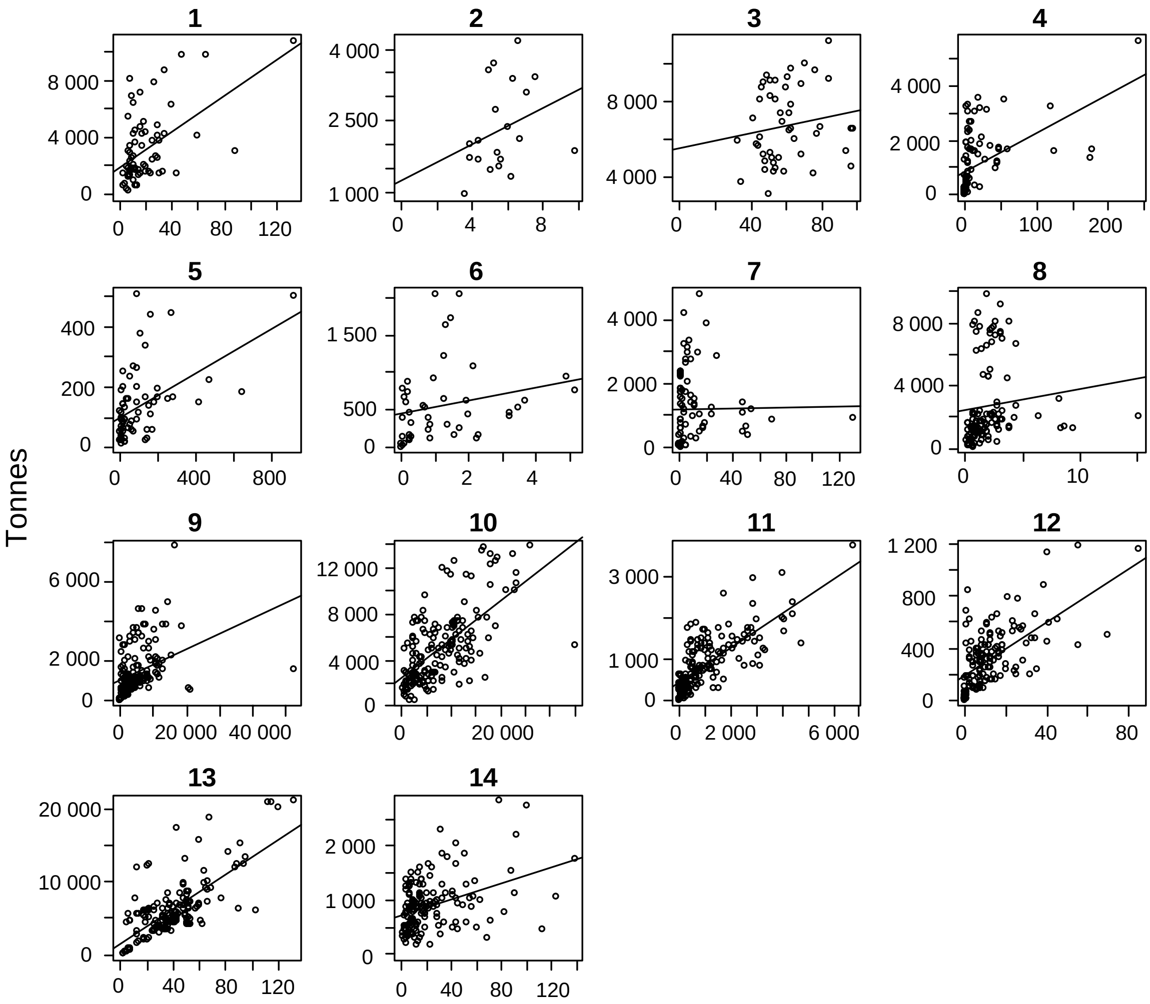
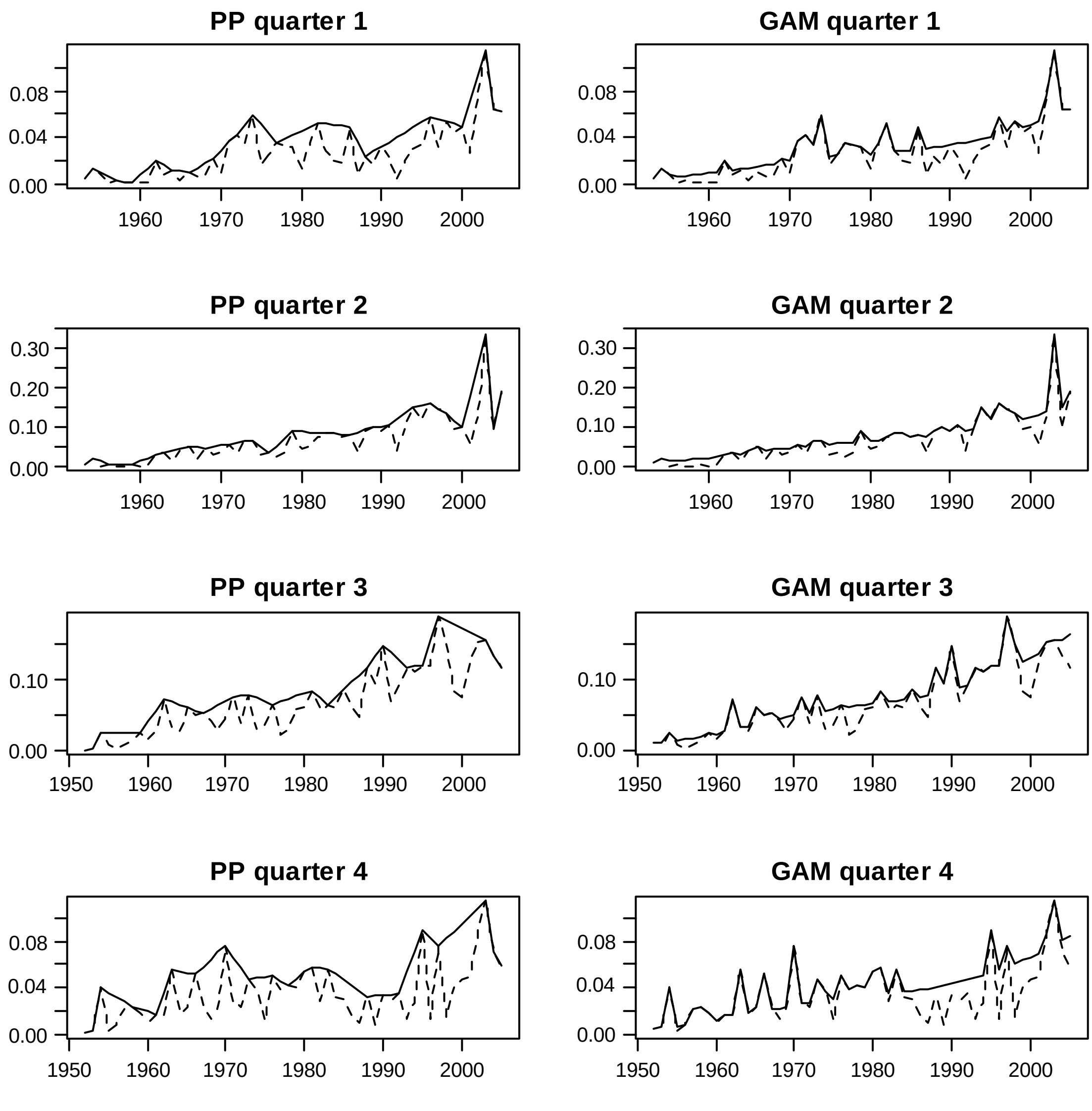


FIGURE 5
Western and Central Pacific bigeye tuna. Example of application of PP and GAM methods to quarterly fishing mortality of Fishery 10 (all longline except that of Australia in Region 5)



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

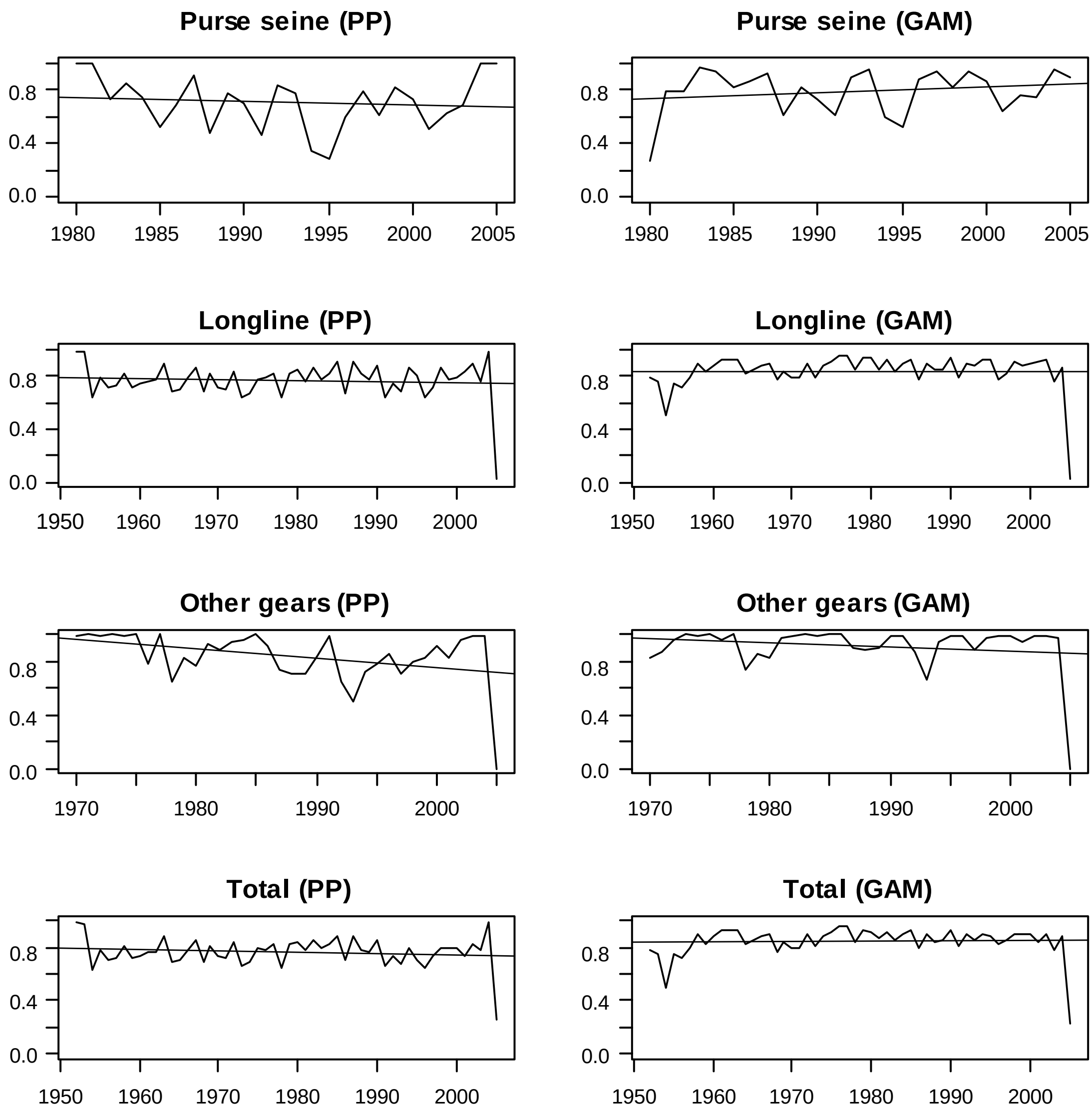


FIGURE 7

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)

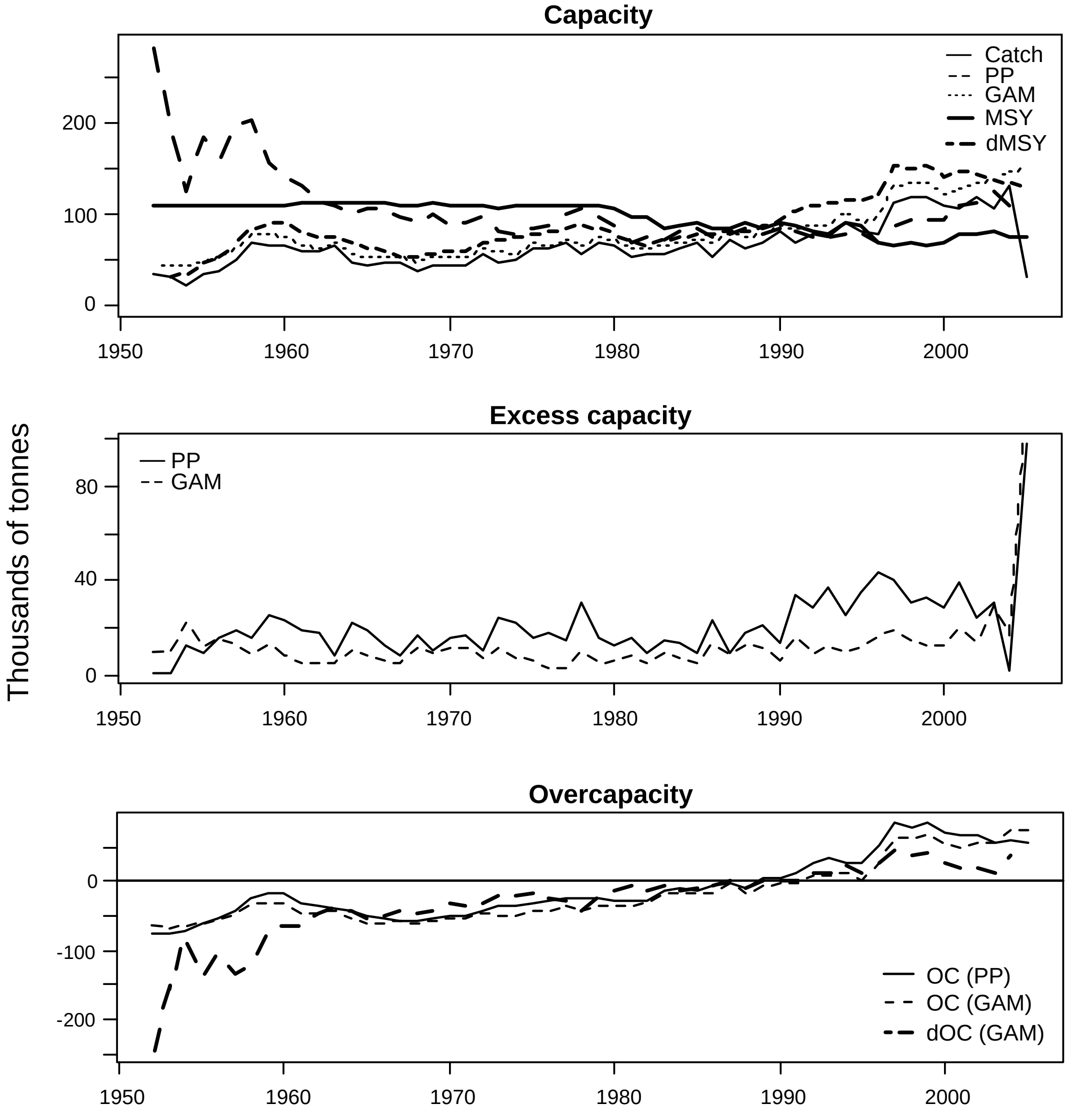


FIGURE 8

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)

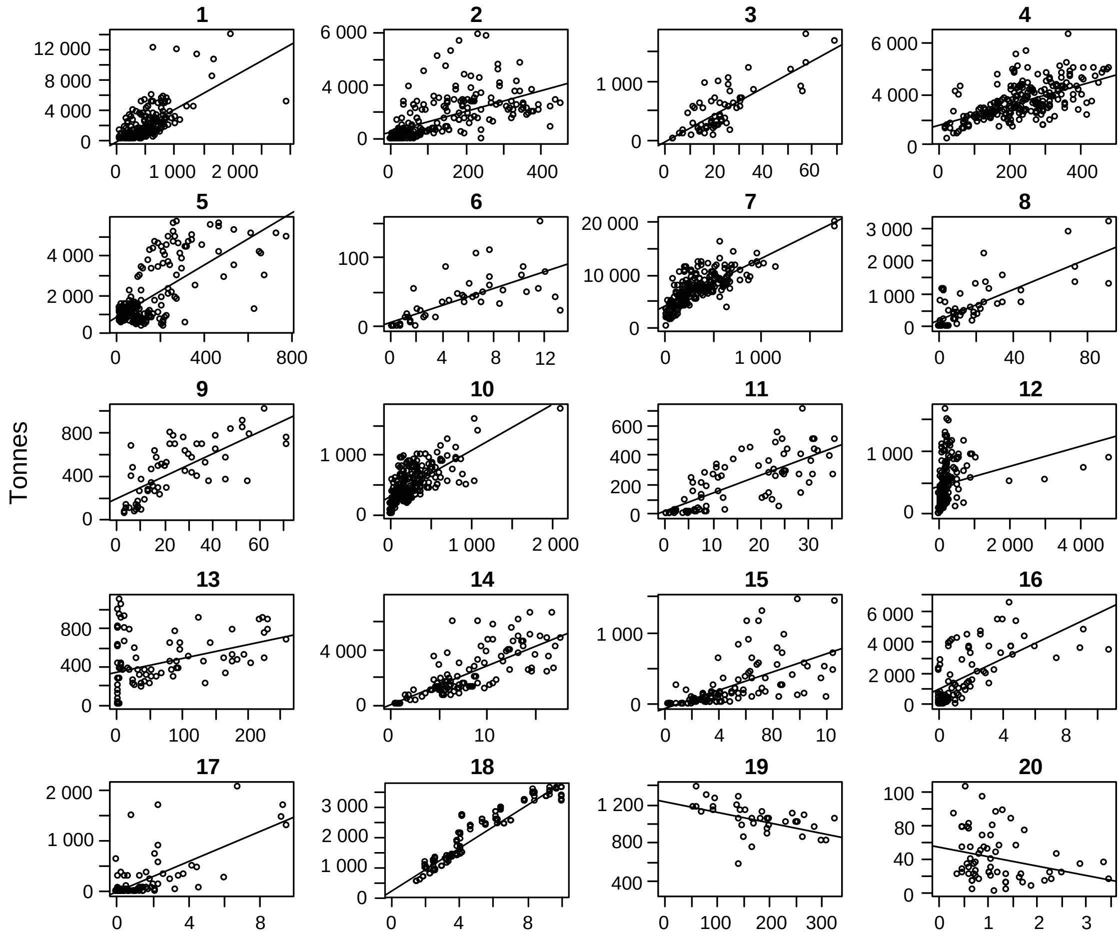
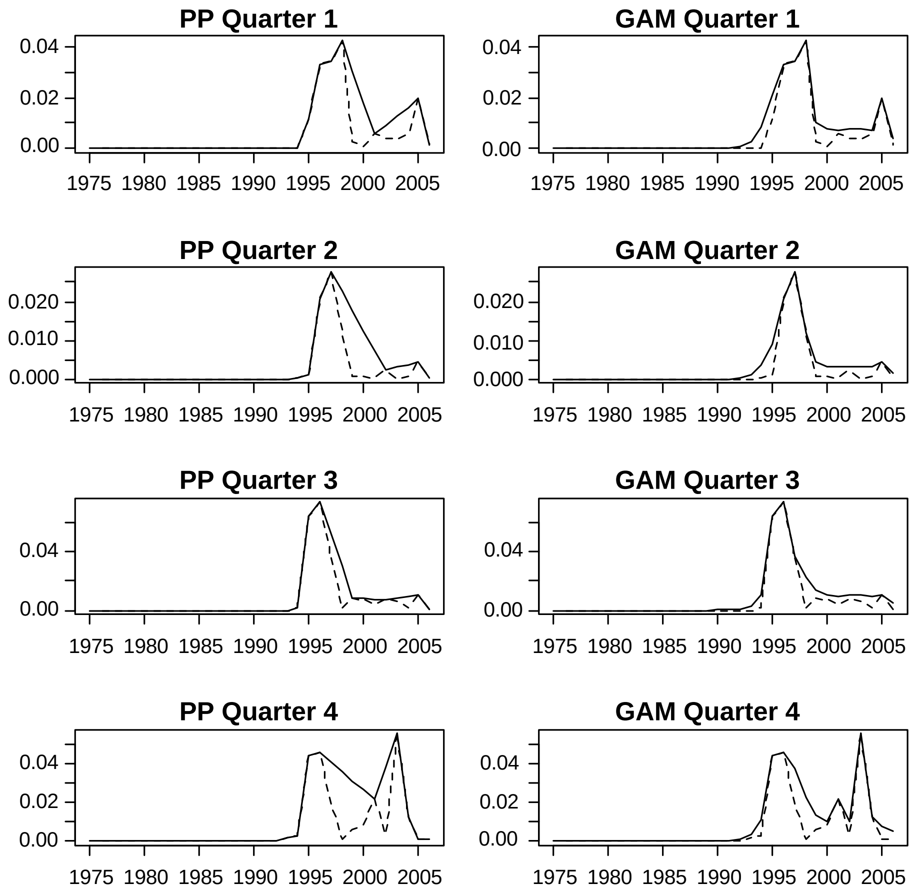


FIGURE 9

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.

FIGURE 10
Eastern Pacific bigeye tuna. Estimated trends in capacity utilization by gear type and for all gears combined

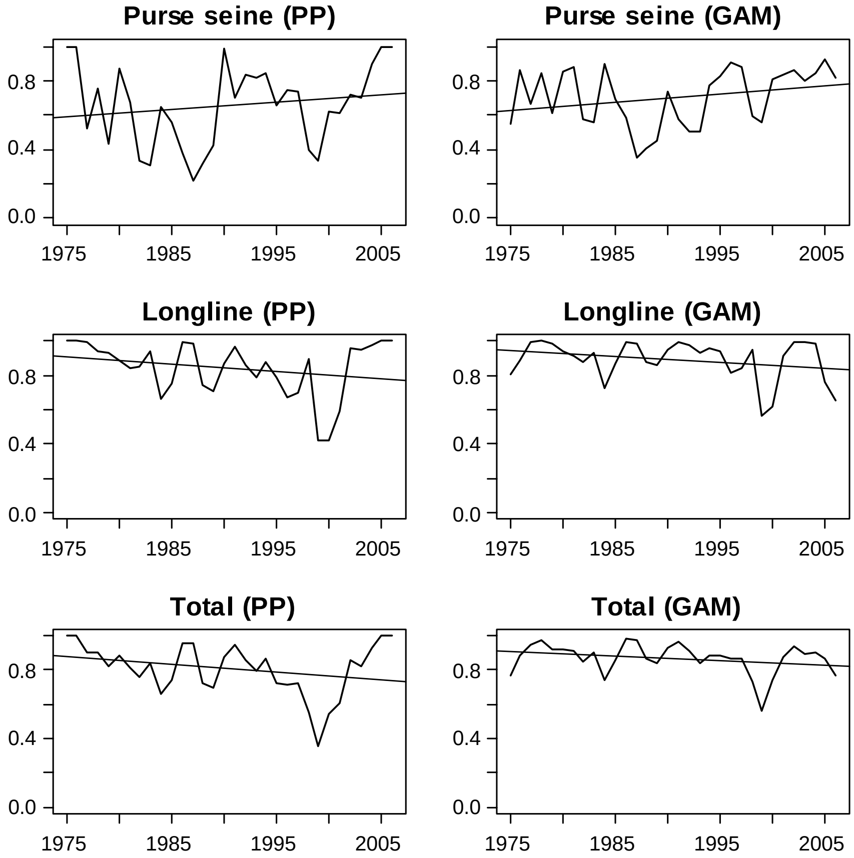


FIGURE 11

Eastern 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)

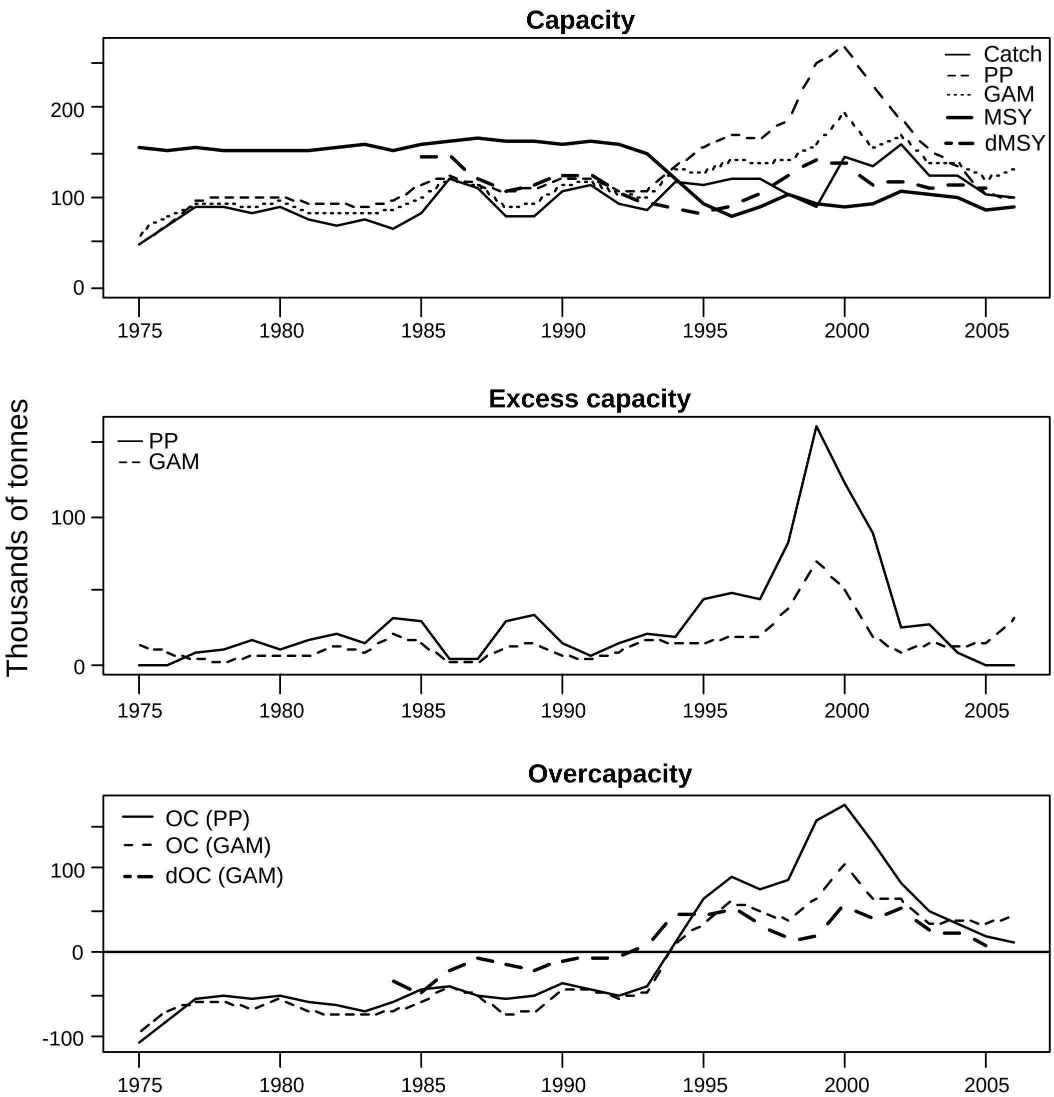


FIGURE 12

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

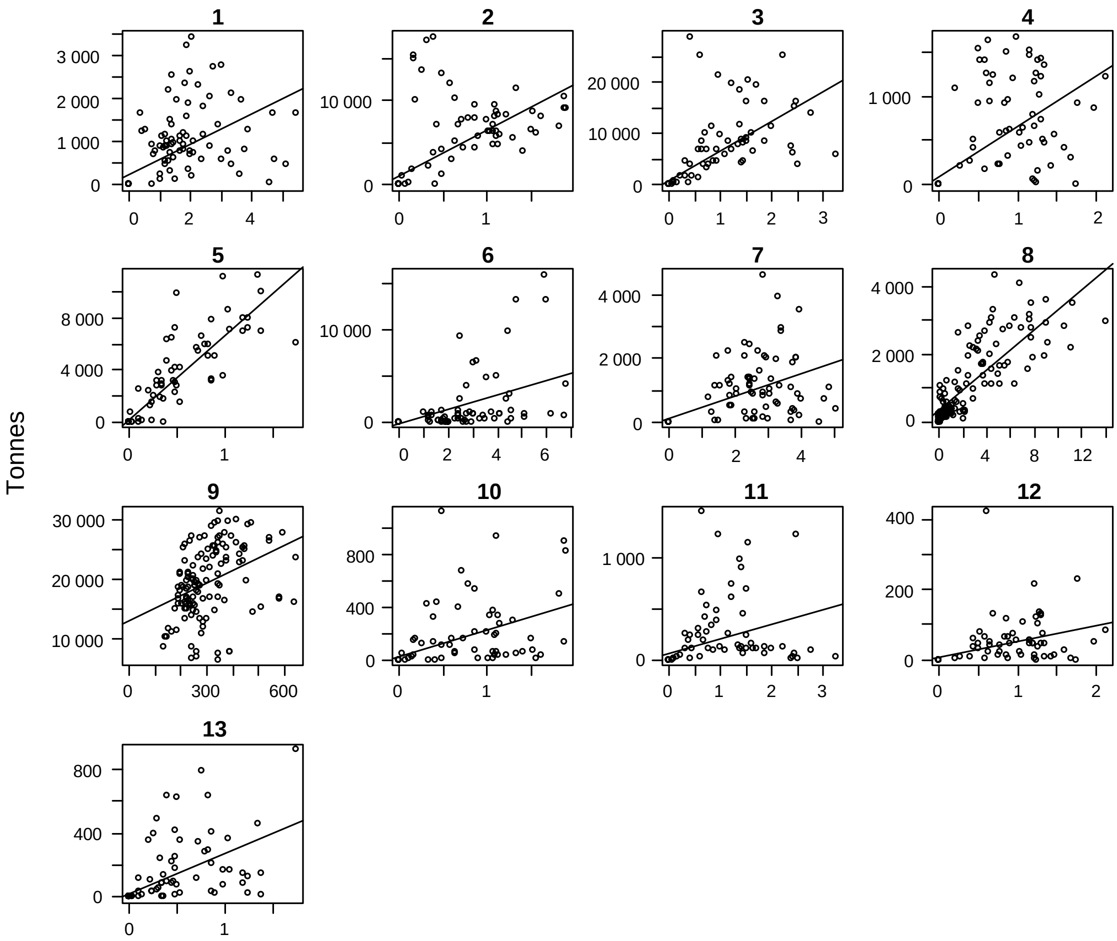
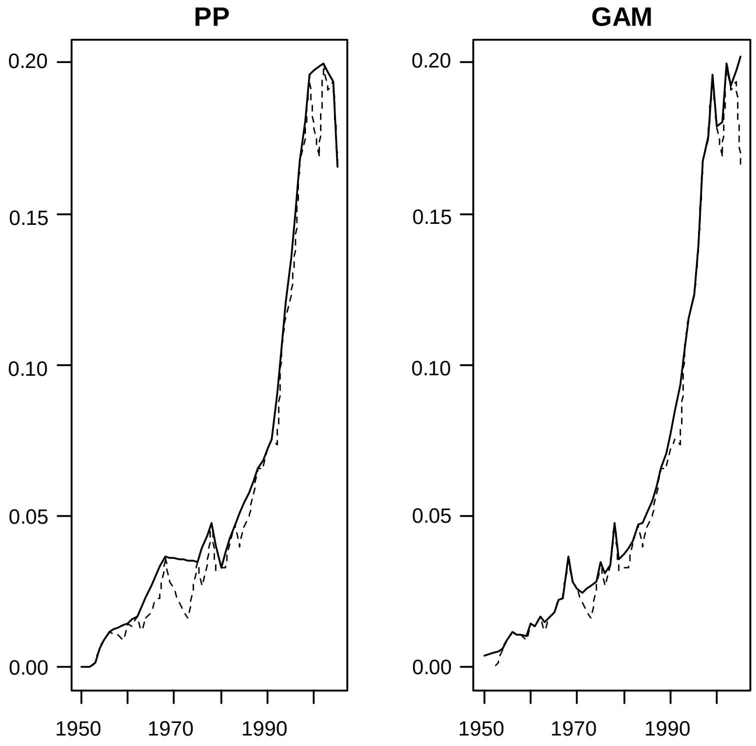


FIGURE 13

Indian Ocean bigeye tuna. Example of application of PP and GAM methods to fishing mortality of the purse-seine fishery



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 14

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

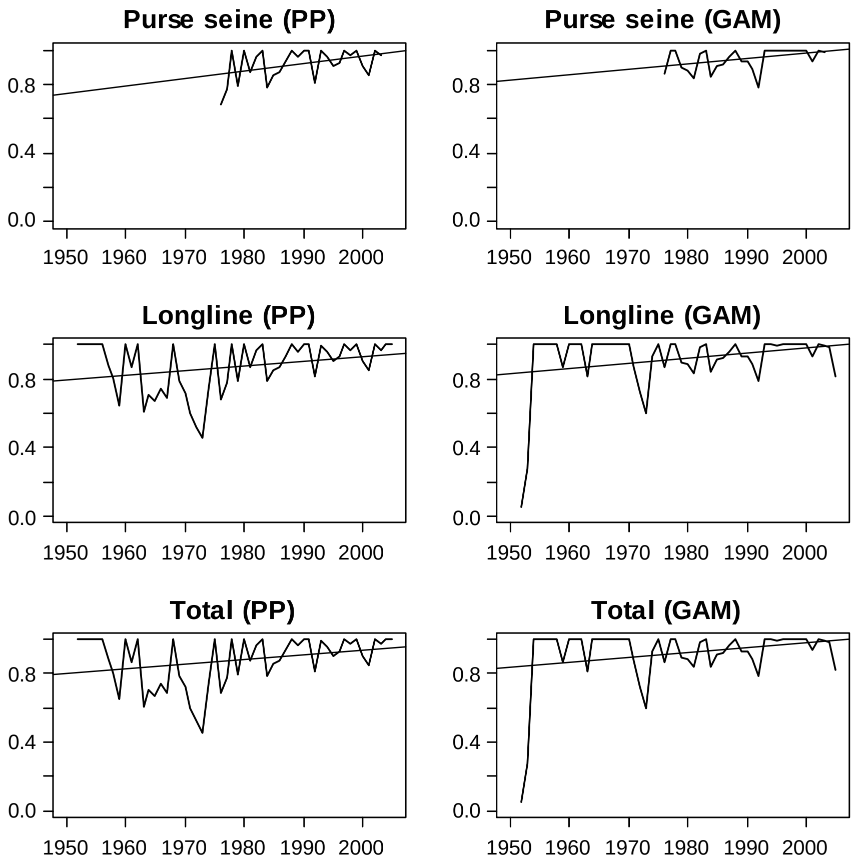


FIGURE 15

Indian Ocean bigeye tuna. Estimated trends of capacity output, excess capacity (EC) and overcapacity (OC), with the PP and GAM methods

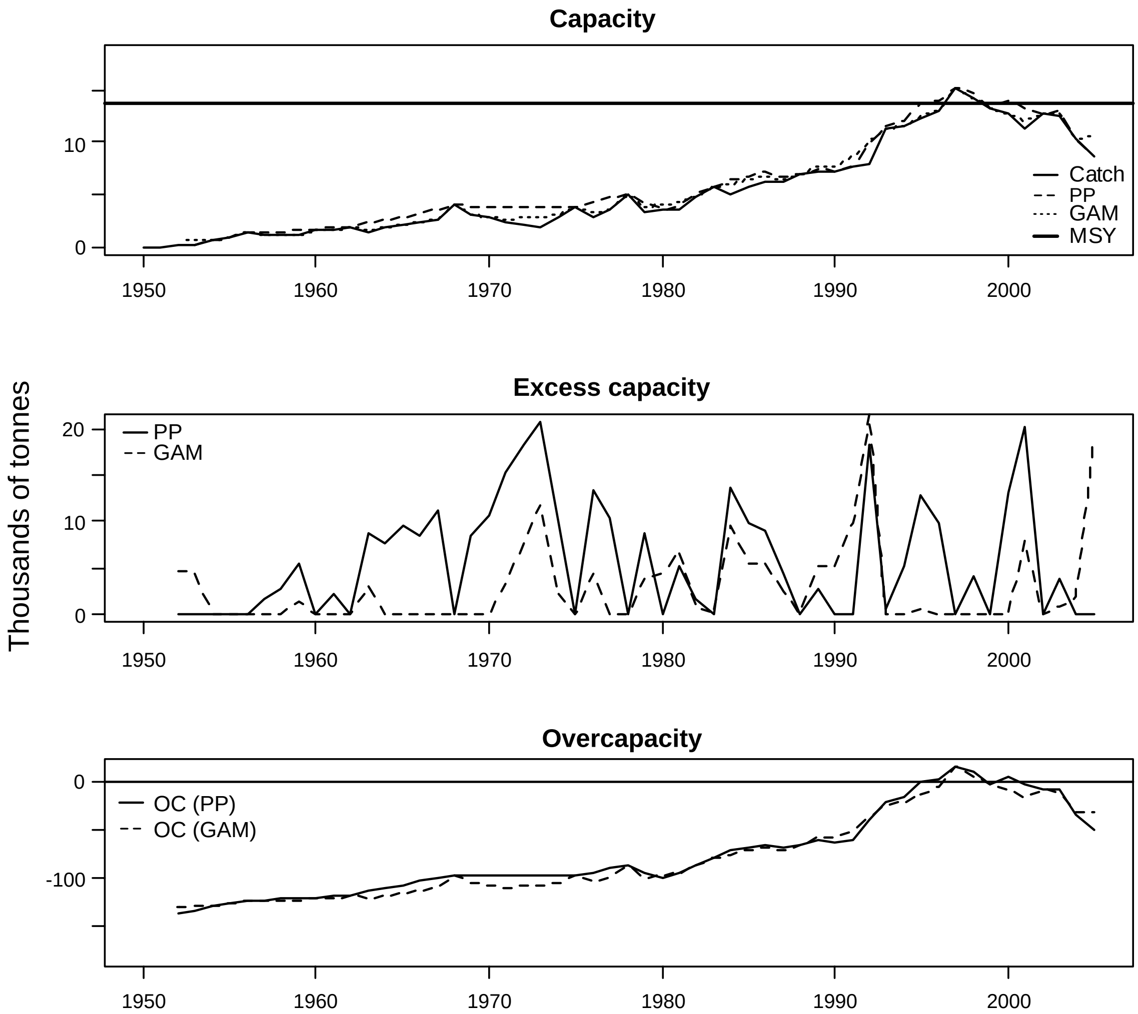


FIGURE 16

Indian Ocean bigeye tuna. Relationship between estimated capacity output (Y axis) and fishing effort (X axis) for the longline fishery

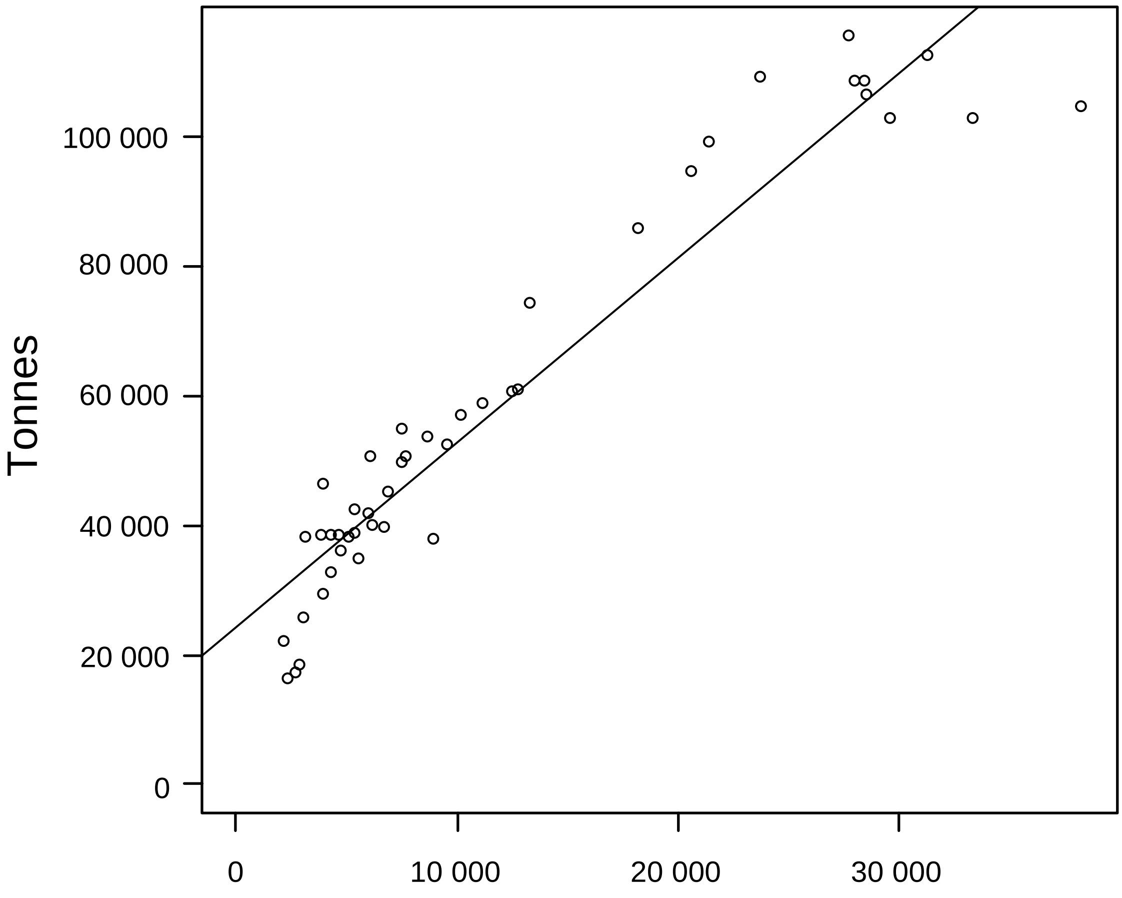
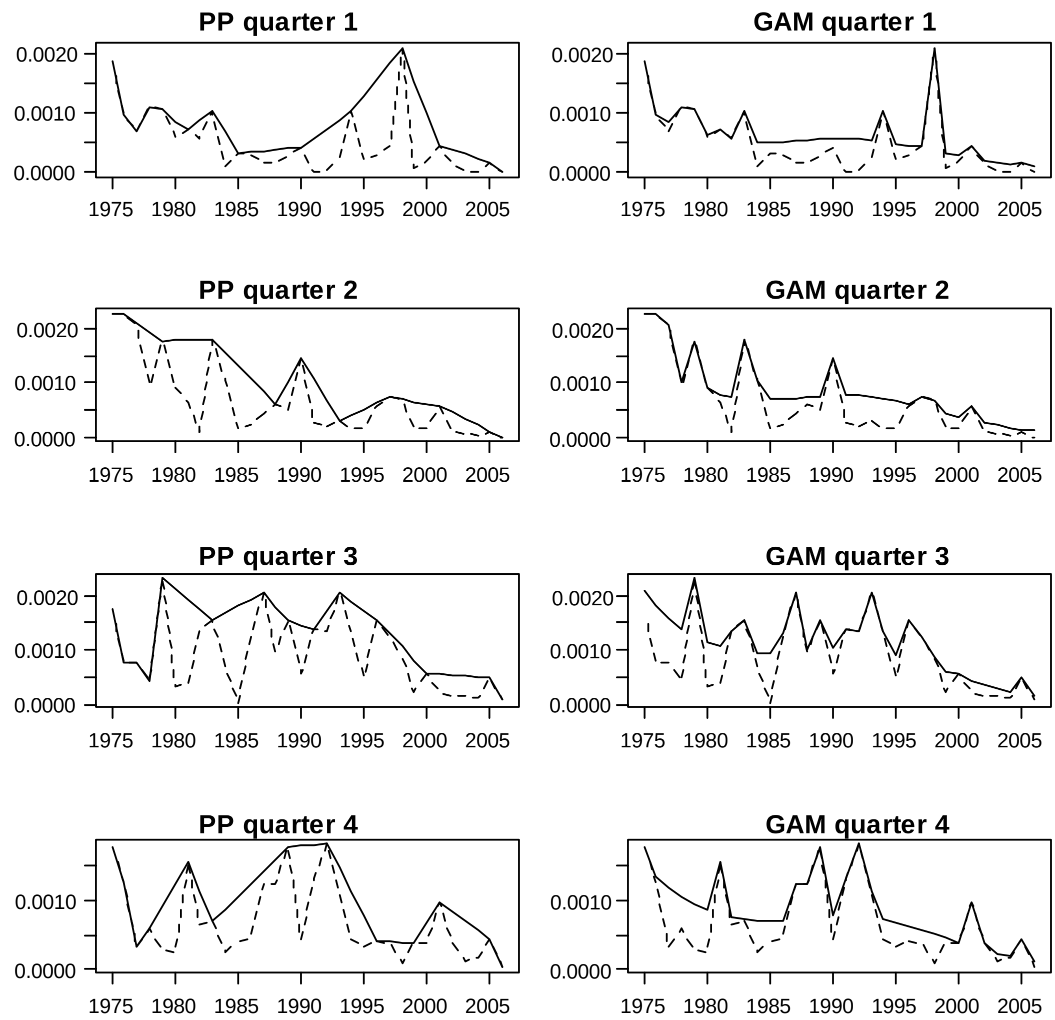


FIGURE 17

Eastern Pacific yellowfin tuna. Example of application of PP and GAM methods to quarterly fishing mortality of Fishery 10 (pole and line in Regions 1-13)



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

FIGURE 18
Eastern Pacific yellowfin tuna. Estimated trends in capacity utilization by gear type and for all gears combined

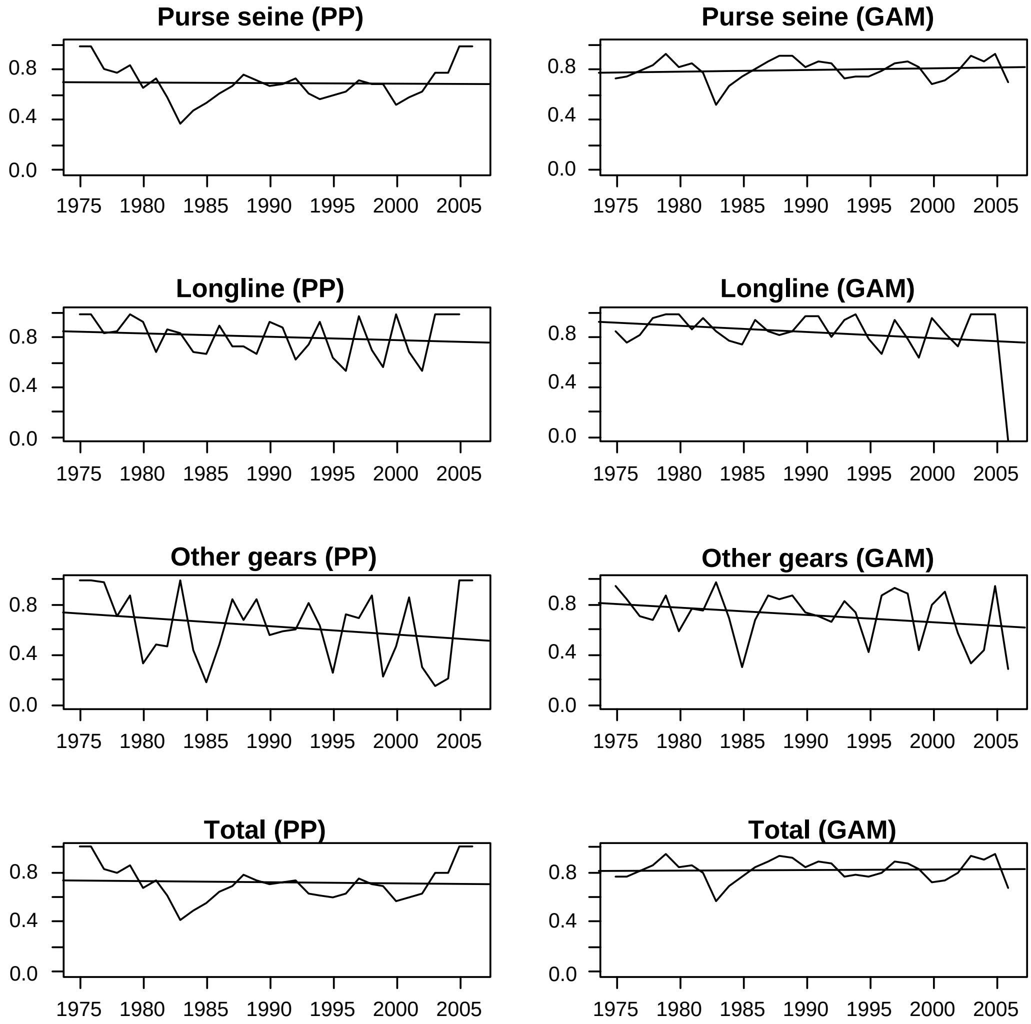


FIGURE 19

Eastern Pacific yellowfin 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)

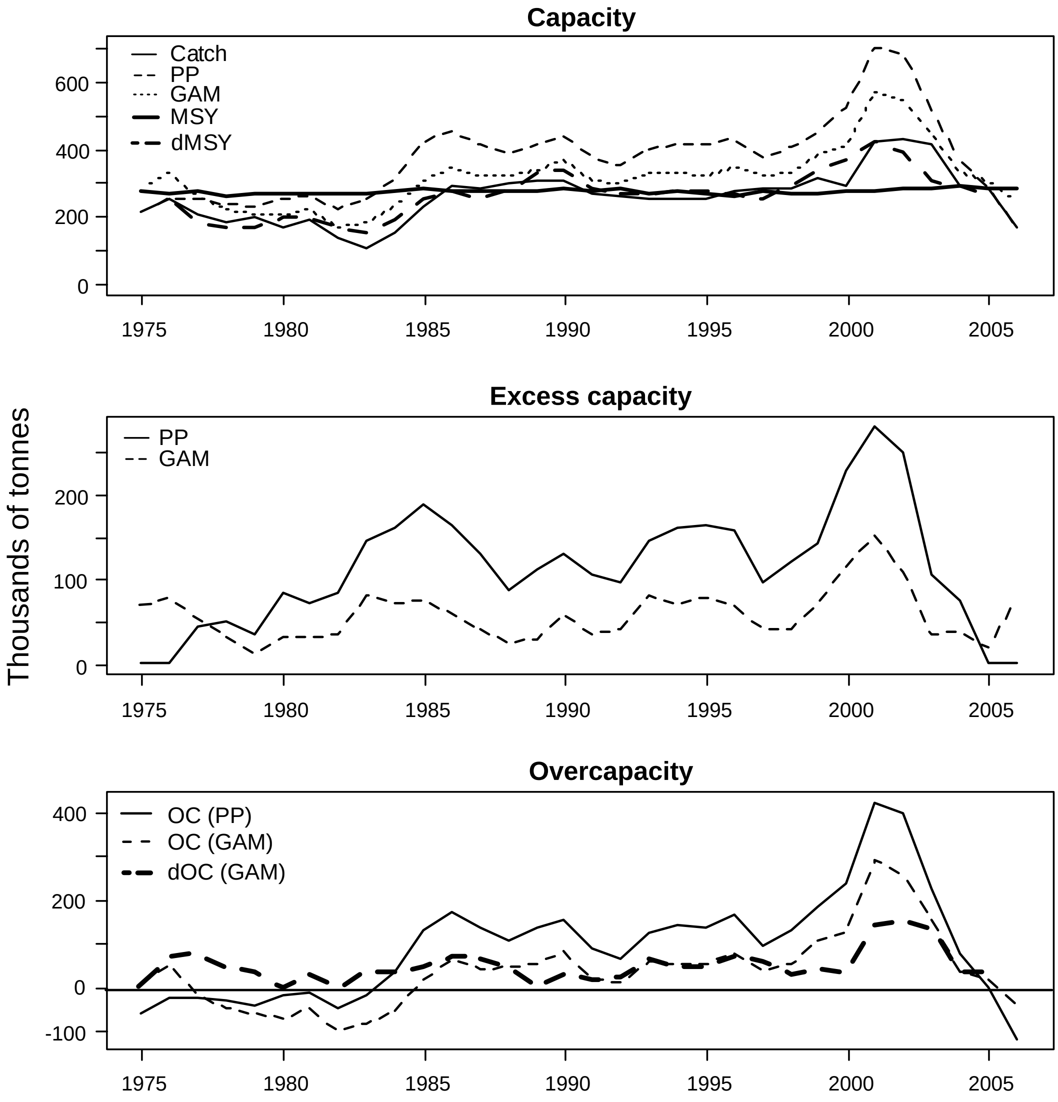


Figure adapted from Arrizabalaga *et al.* (2009).

FIGURE 20

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

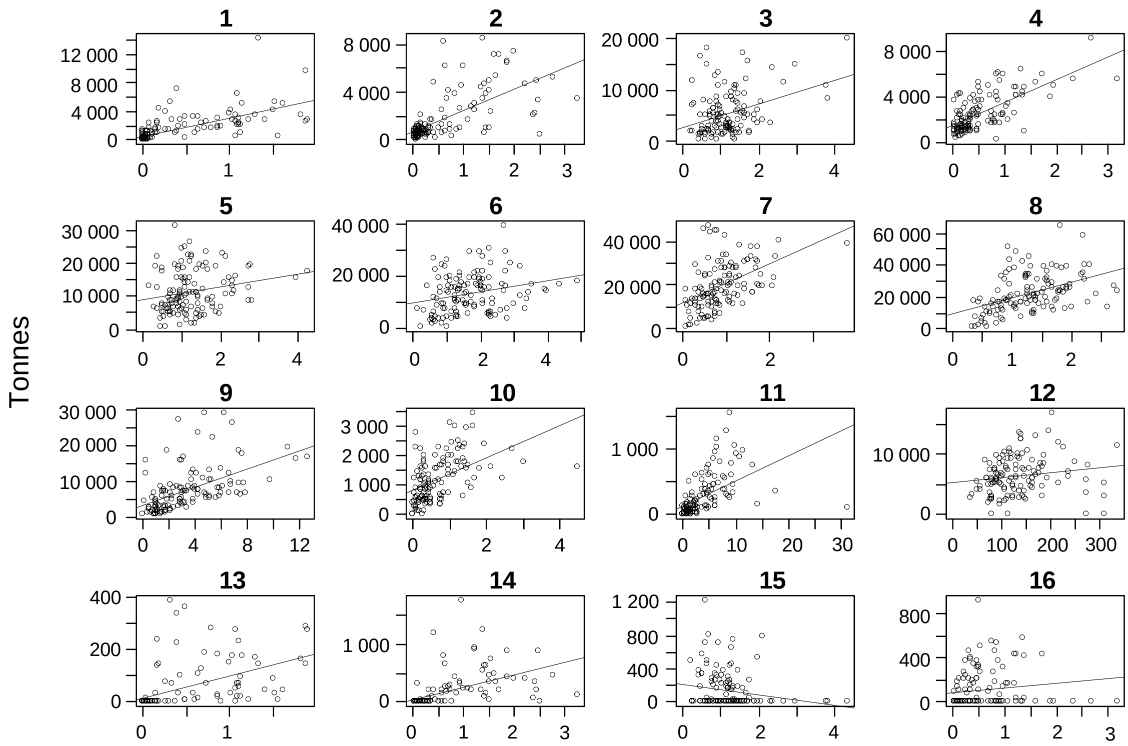
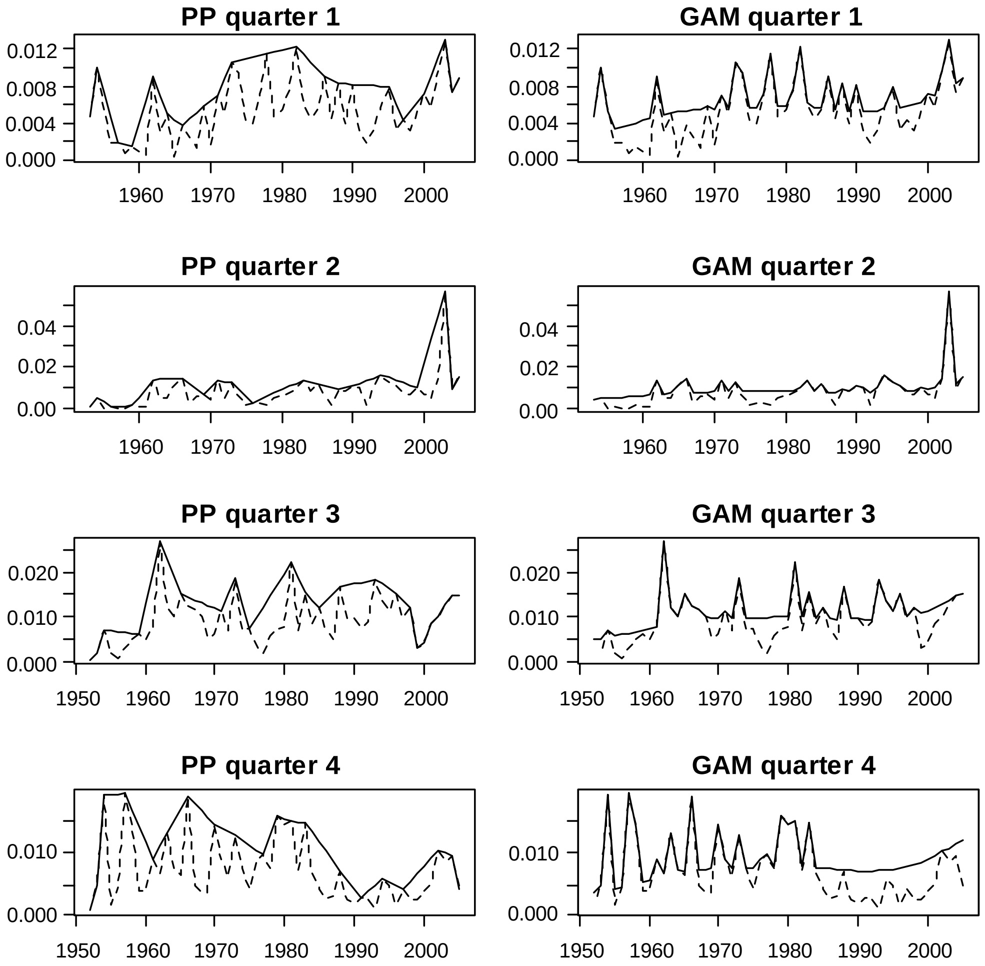


FIGURE 21

Western and Central Pacific yellowfin 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 22

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

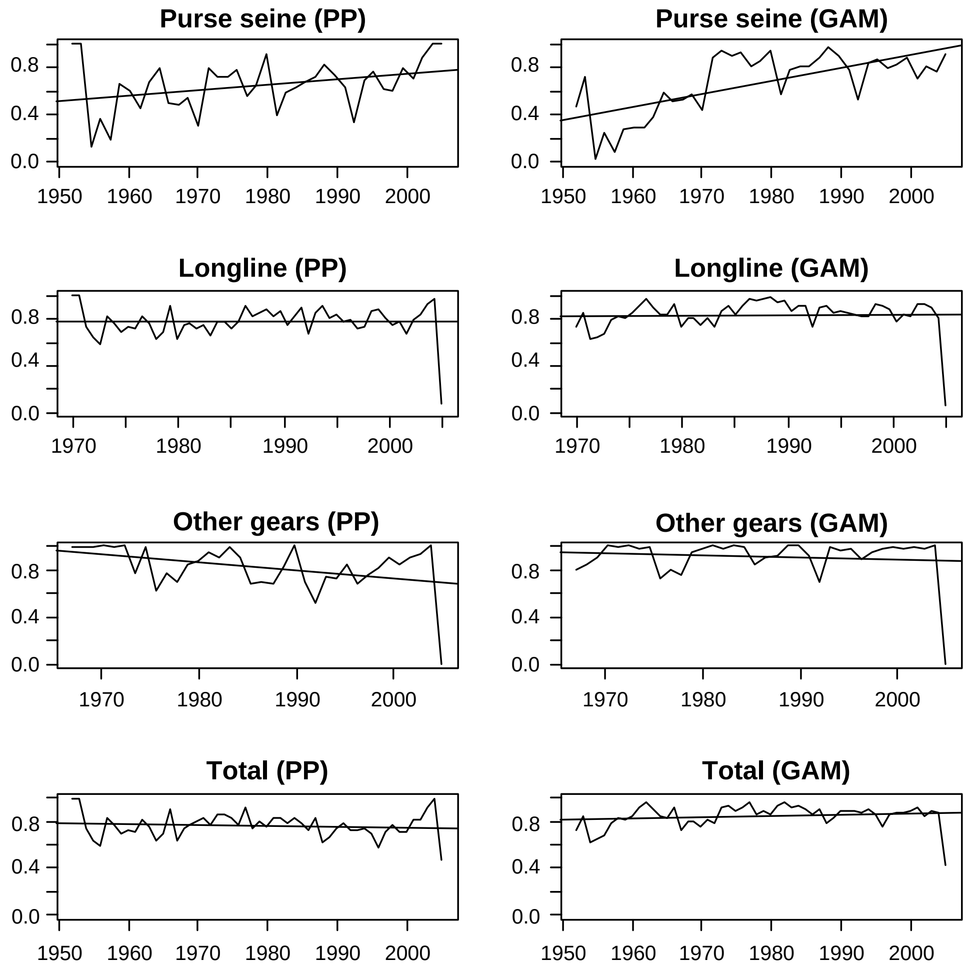


FIGURE 23

Western and Central Pacific yellowfin 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)

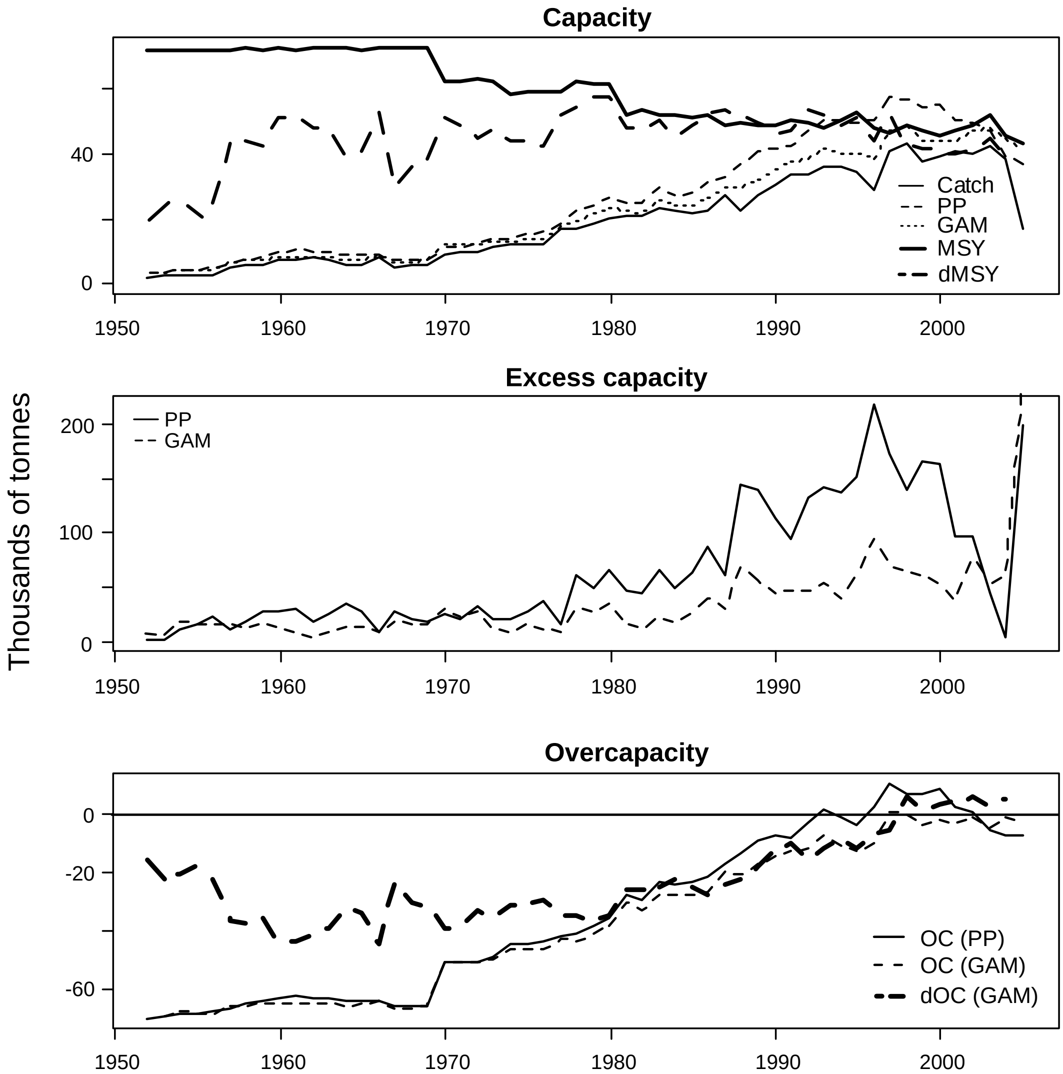


FIGURE 24

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

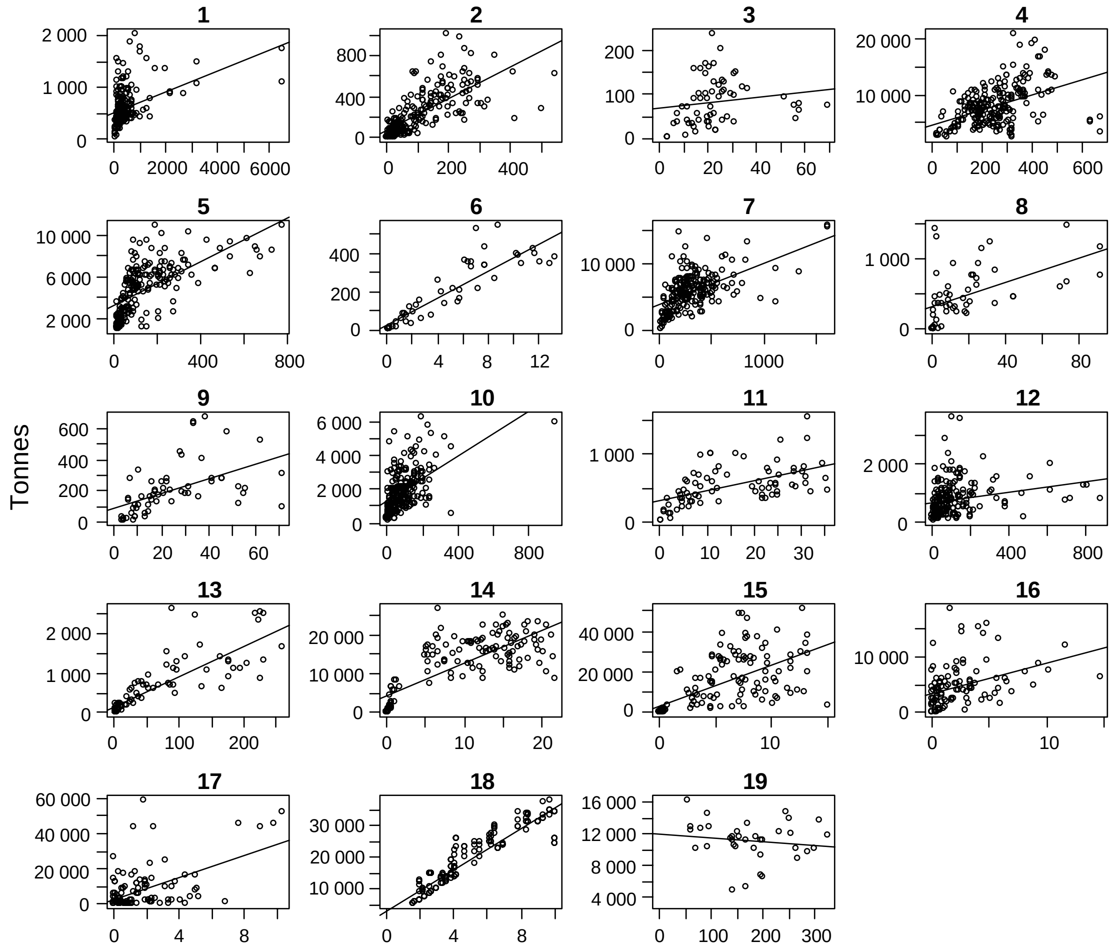
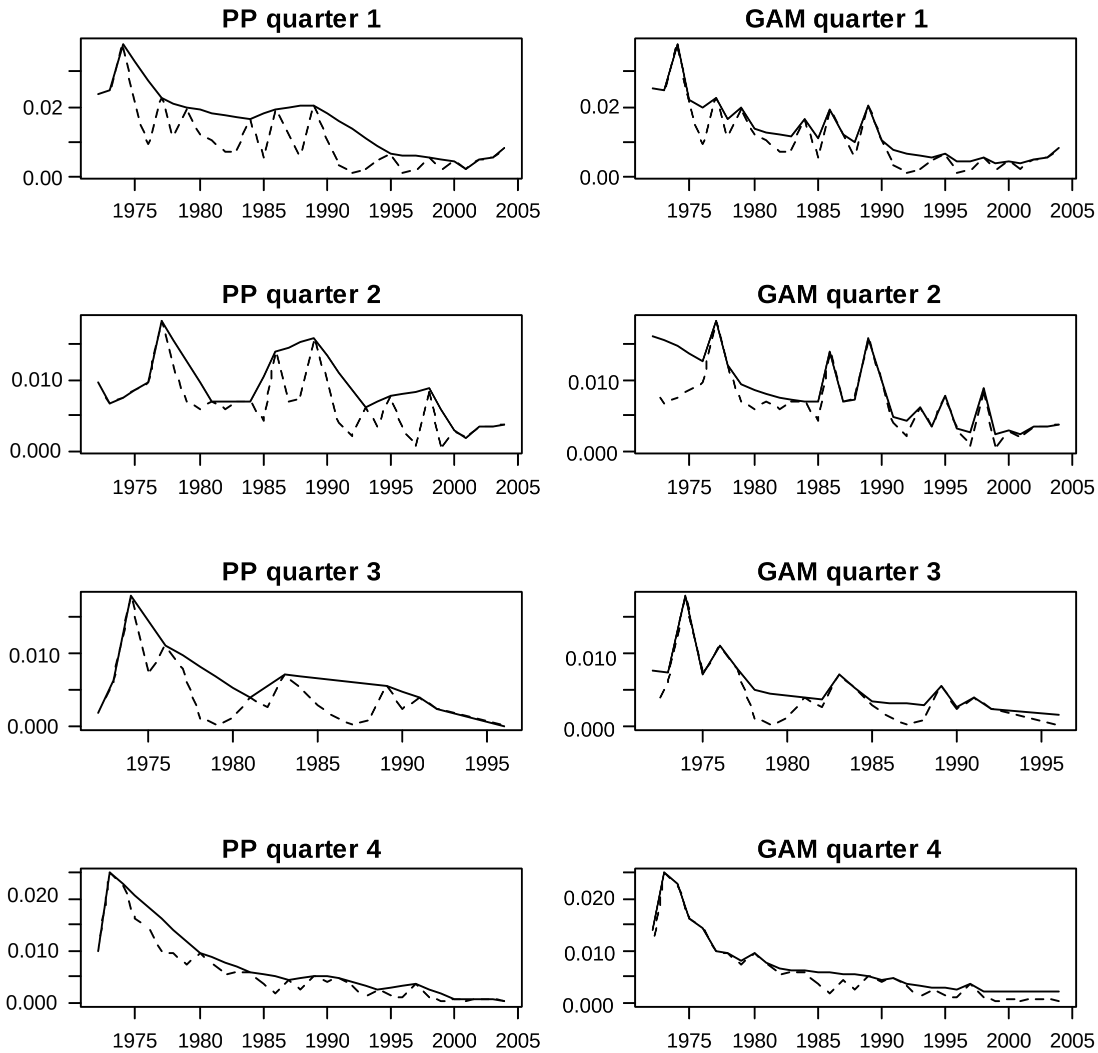


Figure adapted from Arrizabalaga *et al.* (2009).

FIGURE 25
Western and Central Pacific skipjack tuna. Example of application of PP and GAM methods to quarterly fishing mortality of Fishery 10 (Japanese distant-water pole-and-line fishery in Region 5)



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

FIGURE 26

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

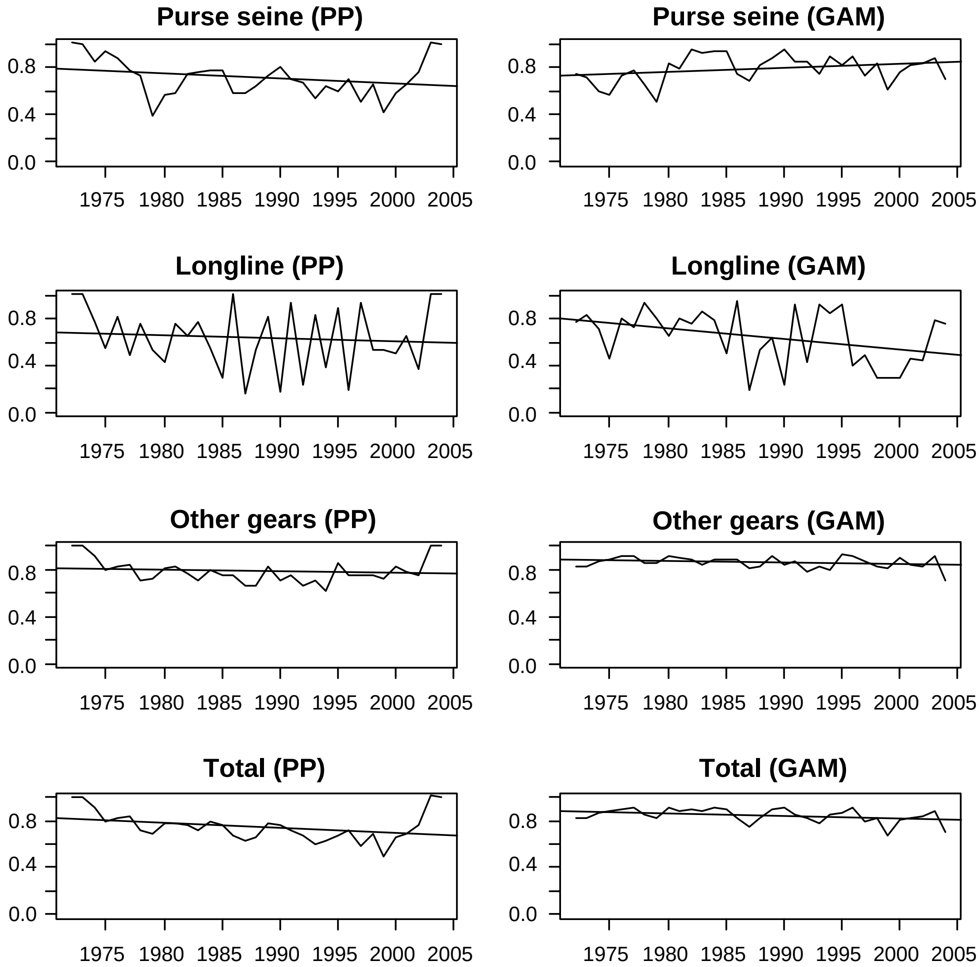


FIGURE 27

Western and Central Pacific skipjack tuna. Estimated trends of capacity output, excess capacity (EC) and overcapacity (OC), with the PP and GAM methods

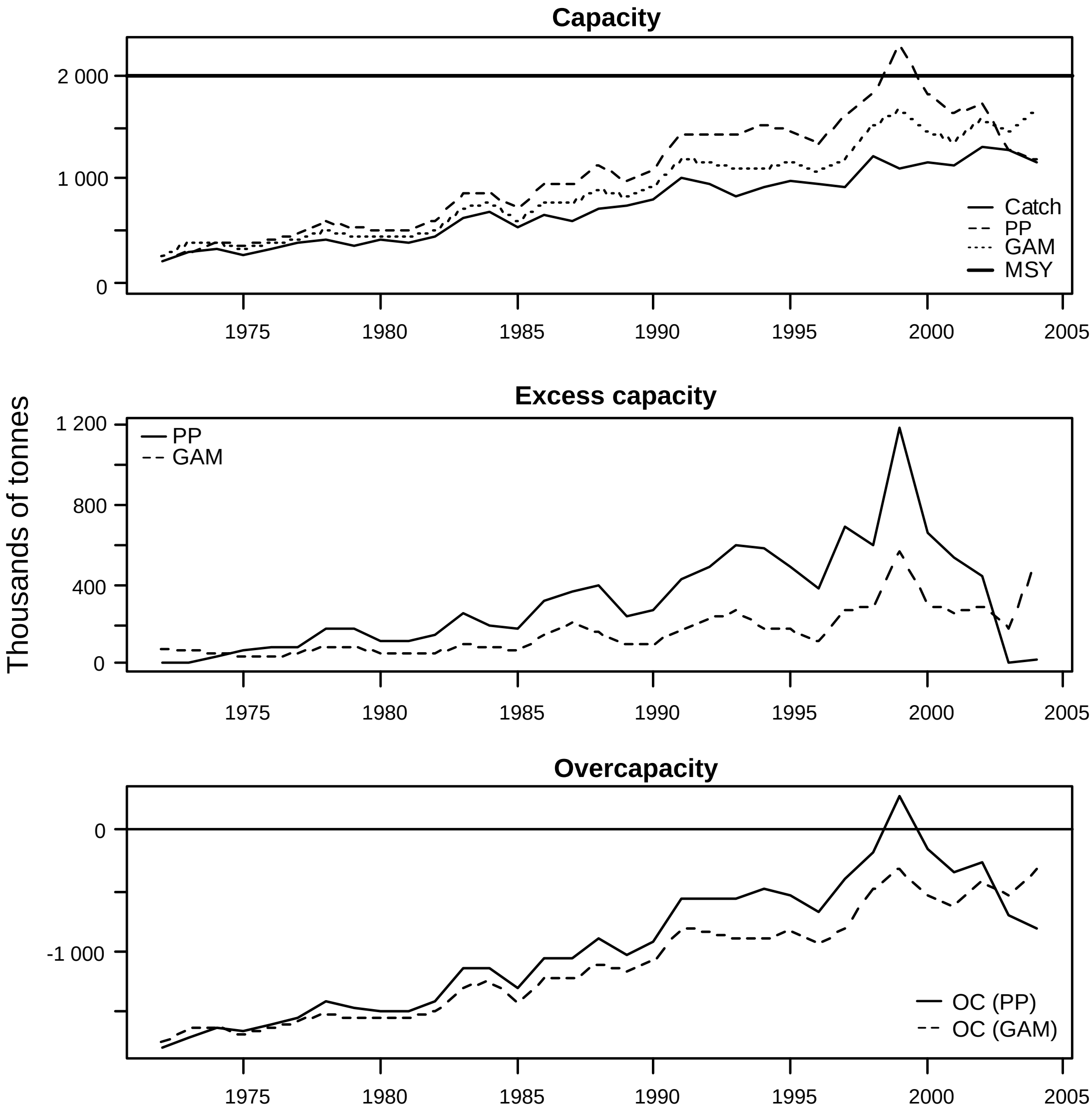
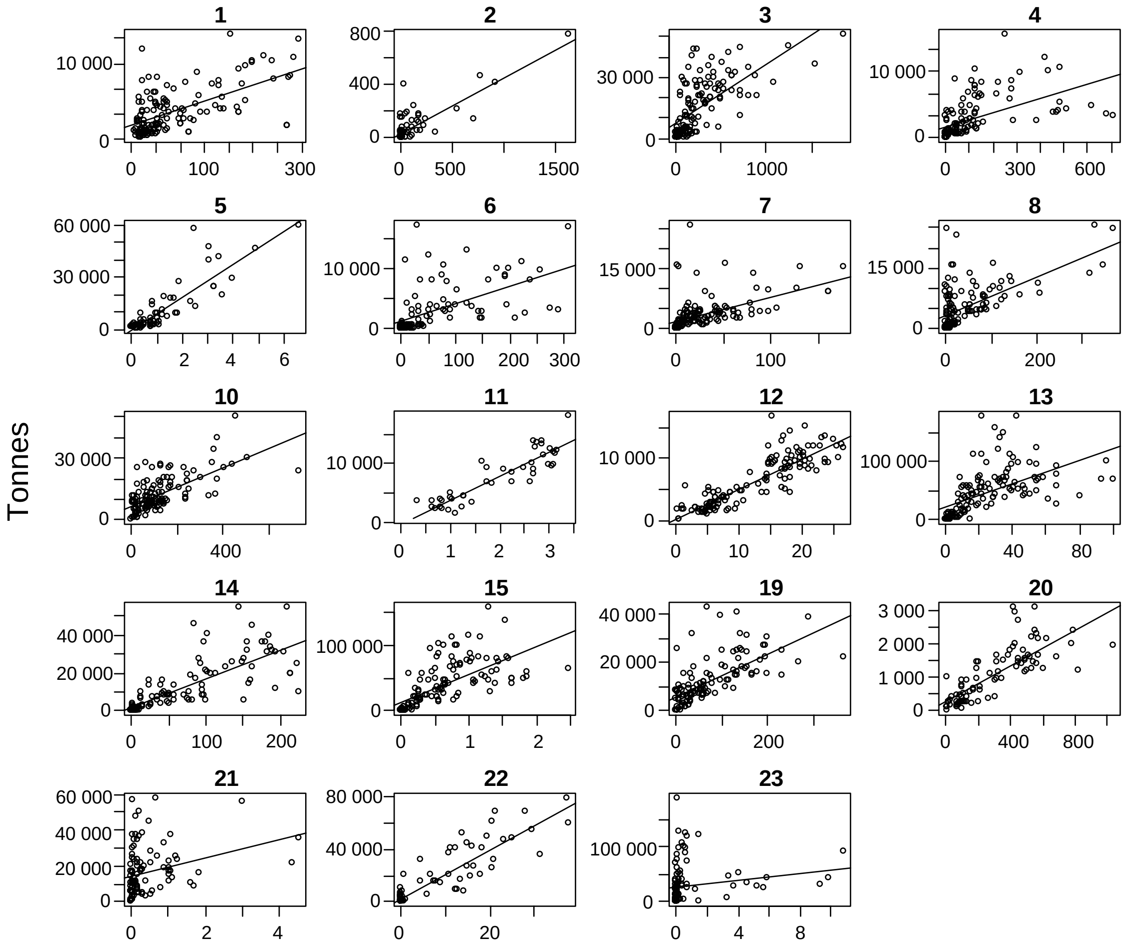


FIGURE 28

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



Estimation of tuna fishing capacity from stock assessment-related information

Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related Information

14–16 May 2007
La Jolla, California, United States of America

These Proceedings include (i) the Report of and (ii) the paper presented at the Workshop to Further Develop, Test and Apply a Method for the Estimation of Tuna Fishing Capacity from Stock Assessment-Related Information. The Workshop was hosted by the Inter-American Tropical Tuna Commission (IATTC) in La Jolla, California, United States of America, from 14 to16 May 2007. It was organized by the Japan-funded Project on the "Management of Tuna Fishing Capacity: Conservation and Socio-Economics" of the Food and Agriculture Organization of the United Nations (FAO) in collaboration with and with in-kind support of several international and national fisheries institutions involved in tuna fisheries research and management. The Report outlines the discussions carried out at the Workshop, some proposals for further work, recommendations and conclusions of the Workshop.

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