ICES Journal of Marine Science Advance Access published June 19, 2009

Using stock assessment information to assess fishing capacity of tuna fisheries

Haritz Arrizabalaga, Victor R. Restrepo, Mark N. Maunder, and Jacek Majkowski

Arrizabalaga, H., Restrepo, V. R., Maunder, M. N., and Majkowski, J. 2009. Using stock assessment information to assess fishing capacity of tuna fisheries. – ICES Journal of Marine Science, 66: 000–000.

In tuna and tuna-like fisheries, there is a need for periodic assessments of fishing capacity to aid management. However, the nature and quantity of data needed to apply conventional methodologies for estimating fishing capacity are not usually available for tuna fisheries. We discuss simple alternative approaches to estimate fishing capacity and related quantities (i.e. capacity utilization, excess capacity, and overcapacity) directly from stock assessment inputs and outputs that are usually available for most tuna (and many other) stocks. Sensitivity analyses are performed to assess the effect of different levels of data aggregation and different assumptions made during the stock assessments on estimates of fishing capacity. Main advantages and disadvantages of the proposed methodologies are also illustrated using stock assessment information from different tuna stocks with different historical developments and trends in fishing mortality.

Keywords: capacity estimation, fishing capacity, stock assessment, tuna fisheries.

Received 18 July 2008; accepted 23 April 2009.

H. Arrizabalaga: AZTI Tecnalia, Marine Research Division, Herrera Kaia Portualdea z/g, 20110 Pasaia (Gipuzkoa), Spain. V. R. Restrepo: International Commission for the Conservation of Atlantic Tunas (ICCAT), Corazón de María 8, 28002 Madrid, Spain. M. N. Maunder: Inter-American Tropical Tuna Commission (IATTC), 8604 La Jolla Shores Drive, La Jolla, CA 92037-1508, USA. J. Majkowski: Fisheries Management and Conservation Service (FIMF), Fisheries and Aquaculture Management Division (FIM), Fisheries and Aquaculture Department (FI), FAO, Via delle Terme di Caracalla, 00153 Rome, Italy. Correspondence to H. Arrizabalaga: tel: +34 943 004800; fax: +34 946 572555; e-mail: harri@azti.es.

Introduction

Fishing capacity refers to the capability to catch fish and can be defined as the maximum amount of fish over a period (year, season) that can be produced by a vessel or fleet of fully utilized vessels, given the biomass and age structure of the fish stock and the present state of the technology (FAO, 1998). Being able to manage fishing capacity is key to successful fisheries management because overcapacity (OC) can lead to stock collapse (Hennessey and Healey, 2000). In principle, having the right capacity should be sufficient to maintain yields while avoiding overexploitation. On the contrary, when there is OC, additional management measures, e.g. TACs (total allowable catches) or time/area closures, are needed. OC leads to problems and fleet behaviour such as the race for fish (Branch *et al.*, 2006). Fishing capacity, frequently reflecting the dependence of users on fish resources, is commonly well above that required for sustainable productivity of the resources, and excess capacity (EC) is believed to be one of the main reasons for the failure of fisheries management (Cochrane, 2000). In fact, fisheries management is not likely to improve unless the levels of fishing capacity are aligned with resource productivity (Mace, 2001).

Although fishing capacity has often been approximated in terms of number of vessels, vessel tonnage, engine power, and days at sea, measuring fishing capacity precisely is not easy because its magnitude depends on the number and the size of the vessels, their technical efficiency, and the time they spend fishing (Smith and Hanna, 1990). The task requires major amounts of data that are not collected routinely in most fisheries (Felthoven *et al.*, 2002), but different methods have been proposed to try to estimate fishing capacity, depending on data availability (Lindebo, 2004). Among them, data envelopment analysis (DEA) has been suggested as the preferred approach to capacity measurement in fisheries (Gréboval, 1999; Kirkley and Squires, 1999; FAO, 2000; Pascoe *et al.*, 2001; Tingley *et al.*, 2003). DEA is a non-parametric approach that allows for the determination of the maximum potential output levels (catch capacity) that can be produced, given existing fixed factors (e.g. the capital stock) and the potential level of variable inputs (e.g. days at sea). In most applications, DEA uses detailed data (e.g. trip-by-trip information on catches, fishing effort, and vessel characteristics) to develop a "production frontier" around the data based on the best-performing vessels of a particular class.

In high sea fisheries in general (Anon., 2005), and for tuna and tuna-like fisheries in particular (Bayliff and Majkowski, 2007), there is a need for periodic assessments of fishing capacity, so as to be able to manage it. This motivated some attempts to estimate fishing capacity of some tuna fisheries using DEA (Reid *et al.*, 2003, 2005), but applying DEA to tuna fisheries is problematic because the nature and quantity of data needed are not usually available (Miyake, 2005; Reid and Squires, 2007). Therefore, alternative approaches are necessary for estimating fishing capacity for tuna fisheries.

The traditional definition of capacity is based on the output of a production system. For fisheries, this would be equivalent to the total catch taken from the stock. However, this may not be a useful concept in terms of fisheries management owing to the fluctuating abundance of the resource and the ability of fisheries to affect its productivity. The catch taken from a system is a function of the fishing effort and the abundance of a stock. For example, $C = qEB$, where C is the catch, E the effort, B the total biomass of the fish stock, and q the catchability coefficient of the fishing method. Therefore, when a virgin stock is fished, the catch for a given level of effort will be higher than when the stock size has been depleted after many years of fishing. From a fisheries management perspective, the maximum potential effort in a fishery might be a more useful indicator of capacity. OC could then be defined when the potential maximum effort in a fishery is larger than that required to produce maximum sustainable yield (MSY). Unfortunately, fisheries are made up of a range of fishing vessels with different physical characteristics, so that the effective effort of individual vessels differs (along with the ages of the fish caught), and it is difficult to determine the potential maximum effort and how it relates to the effort that corresponds to MSY. In addition, the relationship between catch and effort may not be linear. Stock assessment models address this issue by either ignoring fishing effort or modelling the error in the relationship between catch and effort. This is possible because, when the total catch is known and the abundance is estimated, the fishing mortality (F) can be calculated. F can then be compared with its level that corresponds to MSY. It can be used as a measure of fishing capacity that is independent of stock abundance and without the need to know specific details of the effective effort of each vessel.

Here, we present and discuss alternative approaches based on F to estimate fishing capacity and its related quantities [capacity output (CO), capacity utilization (CU), EC, and OC] directly from stock assessment inputs and outputs that are usually available for most tuna (and many other) stocks. Some advantages and disadvantages of the proposed methodology are illustrated using assessment information from different tuna stocks with varying historical developments and trends in F, namely Atlantic bigeye tuna (*Thunnus obesus*), Indian Ocean bigeye tuna, eastern Pacific yellowfin tuna (*Thunnus albacares*), and western and central Pacific yellowfin tuna.

Material and methods

Time-series of F are generally available from stock assessments, and for some tuna stocks, estimates of F by year, season, and fishery are available. The maximum fishing mortality that a fishery could have exerted in a given period, if utilized fully, can be regarded as a proxy for fishing capacity. Here, we considered two ways to estimate such F frontiers as indicators of fishing capacity.

The first method, peak-to-peak (PP), or piecewise regression between peaks (following Kirkley and Squires, 1999; Restrepo, 2007), consisted of connecting peaks of F for each fishery and quarter (tuna fisheries can be very seasonal). Peaks were defined as values greater than those immediately preceding and following them in the time-series. Between two consecutive peaks, the capacity trend is calculated by linear regression between peaks:

$$F'_y = \frac{F'_{y1} + (F'_{y1} - F'_{y2})}{n}, \qquad (1)$$

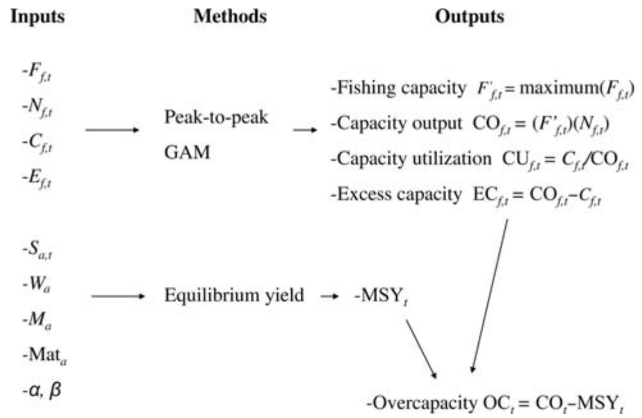

Figure 1. Flowchart describing the general procedure followed to obtain fishing capacity and related quantities. *F*, fishing mortality; *N*, exploitable biomass; *C*, catch; *E*, effort; *S*, selectivity; *W*, weights-at-age; *M*, natural mortality; Mat, maturity; α and β, parameters of the Beverton and Holt stock–recruitment relationship. The subscripts *f*, *t*, and *a* stand for fishery, time, and age, respectively.

where F'_y is the fishing capacity estimate at year y, F'_{y1} and F'_{y2} the fishing mortality values at two consecutive peaks at times $y1$ and $y2$, and n the number of years between them. The F values before the first and after the last peak in the time-series were not modified.

The second method consisted of applying a non-parametric regression model to the estimates of F. The regressions used were fishery-specific generalized additive models (GAMs) for which F was modelled as a spline function of year (y) and as a factor for quarter (q):

$$\hat{F}_{y,q} = s(y) + \beta q + \varepsilon, \qquad (2)$$

where ε is a normally distributed error term with zero mean and σ variance.

The degrees of freedom specified for the splines were equal to the number of years in each series, divided by 5. Fishing capacity for each quarter and year was estimated as the maximum between the F estimated in the stock assessment and the F predicted by the GAM (following Restrepo, 2007):

$$F'_{y,q} = \max(F_{y,q}, \hat{F}_{y,q}). \qquad (3)$$

Estimates of fishing capacity (as maximum potential F) were then applied to stock sizes available from the stock assessments to compute CO, which is defined as the potential catch that would have resulted from the estimated fishing capacity, given the exploitable stock size, for each fishery. CU was estimated as the ratio of observed catch to CO, EC as the difference between CO and the catch, and OC by subtracting the estimates of MSY from the overall (all gears combined) CO (Figure 1).

MSY varies in time in response to variations in the total selectivity vector, as the relative contributions of the various fisheries vary in time. Time-varying MSY was estimated combining stock–recruitment relationships and equilibrium computations of spawning-biomass- and yield-per-recruit (Restrepo *et al.*, 1994). Additionally, an alternative calculation of MSY was considered, taking into consideration annual changes in stock abundance attributable to recruitment and environmental factors. "Dynamic MSY" (dMSY) was calculated as the yield obtained when modelling the population over the historical period while applying *F* at MSY to recruitment.

Both PP and GAM methods assume that whenever a high value of *F* is estimated for a given period (a peak), some unutilized fishing capacity may have existed in previous and subsequent periods. Moreover, the methods do not consider peak *F* values as outliers, but as values that could have been achieved by the fishery in neighbouring periods. Issues such as the level of aggregation of the data in the stock assessment or analyst choices made during the stock assessment with respect to the variability in *F* estimates could affect estimated peaks of *F*, and therefore, on fishing capacity. To assess the impact of both issues on capacity estimates, two sensitivity analyses were conducted, using data from the Atlantic bigeye tuna stock assessment (ICCAT, 2005).

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

In 2004, the Atlantic bigeye tuna stock was assessed using MULTIFAN-CL software (Fournier *et al*., 1998), and the input data were structured considering the existence of 14 fisheries and quarterly time-steps (ICCAT, 2005). In our sensitivity analysis, two alternative aggregation levels were considered. In the first case, the 14 fisheries were aggregated into three main gear categories (purse-seine, longline, and others), and quarters were aggregated into semesters. In the second case, all fisheries were combined into a single one, and quarters were aggregated into years. 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 then applied to estimate fishing capacity time-series and related quantities.

Sensitivity analysis with respect to the variability in *F* allowed in the assessment model

In MULTIFAN-CL, the variability in *F* can be increased by allowing a higher coefficient of variation (*CV*) in the effort-deviation estimates (Kleiber *et al*., 2008). In the original MULTIFAN-CL run for the Atlantic bigeye assessment (ICCAT, 2005), parameter values of $p = 5$, 10, and 20 were used for different fisheries, corresponding to approximate *CV*s for effort deviations of 0.32, 0.22, and 0.158, respectively, as $p{\sim}1/(2\ CV^2)$. In our sensitivity analysis, we considered a "high *F* variability" scenario with *p*-values of 1, 2, and 3 to allow approximately twice the *CV*s in the original run. In addition, the "low *F* variability" scenario considered values of *p* of 20, 40, and 80 to allow for approximately half the *CV*s in the original run. MULTIFAN-CL was re-run with these new specifications, and the inputs and outputs were used to obtain fishing capacity and its related variables following the PP and GAM approaches.

Results

Fishing capacity estimates using the PP method were usually greater than those obtained with GAM. This was not unexpected, because the former method connects peaks with straight lines and the latter provides a smooth time-series where the lowest estimates of *F* are raised, but the highest ones are not altered. In other words, the PP method estimates that fishing capacity was higher than the exerted fishing mortality in all but peak points, whereas the GAM method estimates that fishing capacity was utilized fully in a larger proportion of points along the time-series. First and last points of the time-series are exceptions, because the PP method, as implemented here, used the observed *F* values as a measure of fishing capacity before the first and after the last peak, which were generally lower than the estimates provided by the GAM method. An alternative could be to assume constant capacity before the first and after the last *F* peak, perhaps a reasonable choice for time-series where peaks are not too far from the start or end of the time-series.

The differences between PP and GAM are greatest when the *F* time-series has many consecutive high peaks and deep valleys, as for Atlantic bigeye tuna, in contrast to Indian Ocean bigeye tuna, for which the *F* time-series is more monotonic (Figure 2), resulting in higher estimates of CU and less marked differences between PP and GAM estimates of fishing capacity.

Results of the first sensitivity analysis showed that for most of the years in the time-series, the greatest estimates of CO and EC were obtained with the most disaggregated data (Figure 3), regardless of the method used (PP or GAM). The maximum relative differences between the estimates of CO in the most disaggregated (base case) and the most aggregated case were 24.9 and 22.1% for the PP and GAM methods, respectively, and the mean relative differences were, respectively, 6.9 and 7.8%.

On the other hand, the estimates of CO and EC for the scenarios with high and low variability in effort deviations were similar to those in the base case (Figure 4), and EC estimates were not systematically greater in the "high *CV*" scenario, as would be expected intuitively. However, the sensitivity analyses carried out appear to indicate that OC estimates are sensitive to the way *F* is estimated in the stock assessment, because the inverse relationship between *F* and biomass affects the MSY-related calculations. The "high *CV*" scenario estimated higher *F* values and lower biomass values, giving lower MSY estimates and higher estimates of OC (Figure 5).

Application of PP and GAM methods to different tuna stocks revealed that for some stocks, OC estimates based on MSY differed substantially from those based on dMSY. For instance, trends in

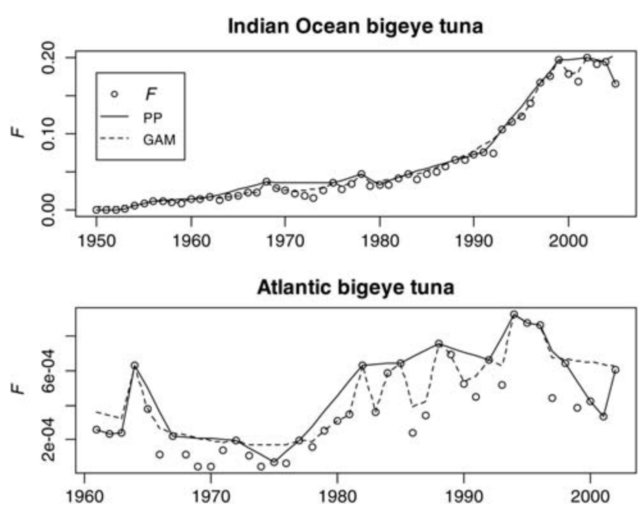

Figure 2. Example of application of PP and GAM methods to estimate quarterly fishing mortality (*F*). The upper panel corresponds to the purse-seine fishery catching Indian Ocean bigeye tuna, and the lower panel to the Japanese longline fishery catching Atlantic bigeye tuna in region 2 (as defined in ICCAT, 2005) in quarter 4.

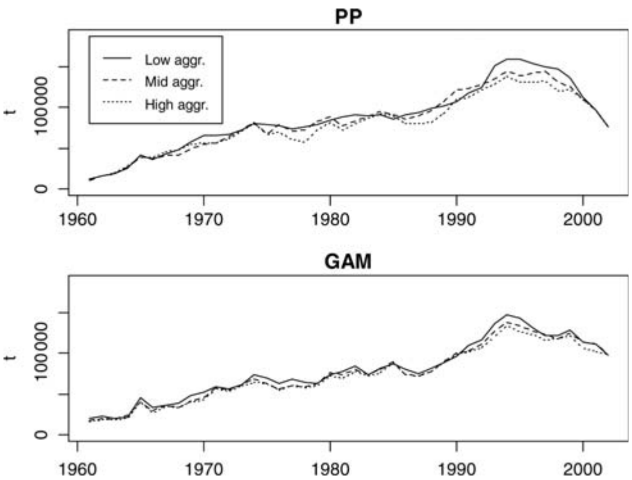

Figure 3. Atlantic bigeye tuna CO estimated in the sensitivity analysis with respect to the level of aggregation in the data. "Low aggr." represents the scenario with lowest level of aggregation in the data, corresponding to the original Atlantic bigeye analysis with 14 fisheries and quarterly time-steps; "Mid aggr." the mid-aggregation scenario with three main gears (purse-seine, longline, and others) and semi-annual time-steps; and "High aggr." the scenario with the highest level of aggregation with a single fishery and annual time-steps.

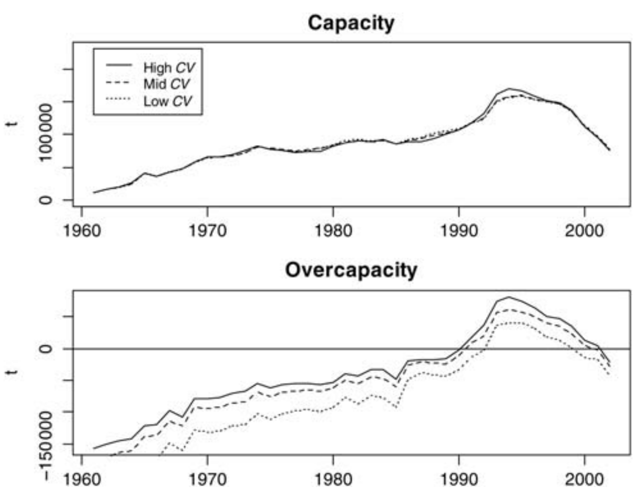

Figure 4. Sensitivity analysis for Atlantic bigeye tuna with respect to the variability in effort deviations allowed in the assessment model: CO (upper panel) and OC (lower panel) estimated by the PP method under high, medium, and low levels of variability in effort deviations.

the CO estimates for eastern Pacific yellowfin tuna are not entirely consistent with current knowledge of both fishery and stock. Strong cohorts entered the fishery during the years 1998–2001, and these cohorts increased the biomass from 1999 to 2001 (Maunder, 2006). This coincided with the start of a 3-year period with high catch rates and catches, where the fleet is believed to have operated at its maximum capacity, whereas the estimated MSY remained fairly stable during the time-series. This led to maximum OC estimates for that period (based on MSY; Figure 6). The estimates of EC were relatively high for the stock owing to the great variability in *F*, especially during the years with the greatest catches (2001–2003). However, OC estimates were highly correlated with EC estimates throughout the period ($r^2 = 59.8$ and 85.6% for GAM and PP methods, respectively; $p < 0.05$), suggesting either that the estimated OC was not utilized or that the fleet operated at maximum capacity. Conversely, maximum dMSY estimates were also computed for the period of maximum catches and capacity. Hence, OC estimates based on dMSY were slightly positive for the entire time-series, but much less variable and of lesser magnitude in the later years relative to the estimates of OC based on MSY.

Discussion

Our methods have some advantages in relation to others more commonly used to estimate fishing capacity and related quantities. They are conceptually simple, do not require vessel-specific disaggregated data, and use information that is readily available for most tuna stocks. Being based on stock assessment information makes the methodology familiar to fishery scientists, allows for temporal trends in stock abundance to be taken into account, and permits the modelling of multiple fisheries simultaneously or of changes in efficiency and species targeting over time. Although other more data-demanding methods may need to constrain the analysis to a certain period when sufficient data are available, our methods can provide a historical perspective of the evolution of fishing capacity, which can be helpful for management.

Other methods for estimating fishing capacity require slightly different assumptions. For instance, the conventional application of PP to catch-and-effort (number of vessels) data needs one to assume that high catch rates observed in 1 year remain available in neighbouring years (Kirkley and Squires, 1999). Moreover, DEA assumes constant capacity per unit effort between boats for a constant return to scale (Pascoe *et al.*, 2001), and even constant catch rates in time by individual boats can be assumed to estimate fishing capacity (Felthoven *et al.*, 2002). The main assumption in our approach is that a high level of *F* in a given period was probably available in neighbouring periods, which is probably more reasonable than, or at least as reasonable as, the assumptions noted above.

The PP and GAM methods presented require some subjective decisions, such as how to define peaks or the number of degrees of freedom for smoothing splines. A certain subjectivity also exists in other capacity-estimation techniques, for instance when applying PP to catch and data on the number of vessels (Kirkley and Squires, 1999), or when considering alternative shapes for frontiers in DEA (Pascoe *et al.*, 2001; Tingley *et al.*, 2003), but this does not lead one to discard (although it probably limits) the utility of these techniques in assessing fishing capacity.

As the methods are based on stock assessment data, it is important to consider the assumptions and choices made during the assessment process, as well as the level of data aggregation, that may affect the quality of MSY and *F* estimates, given that peak values of *F* are not considered outliers but rather periods of full capacity use. Conceptually similar limitations apply to other technical–economic approaches that define a deterministic frontier of maximum output. For instance, deterministic DEA assigns catch outliers to CU or technological efficiency (Reid *et al.*, 2003), and most disaggregated datasets are likely to end up in higher estimates of capacity.

Estimates of OC in years during which catches were extremely high, and positive EC estimated for every species and every year,

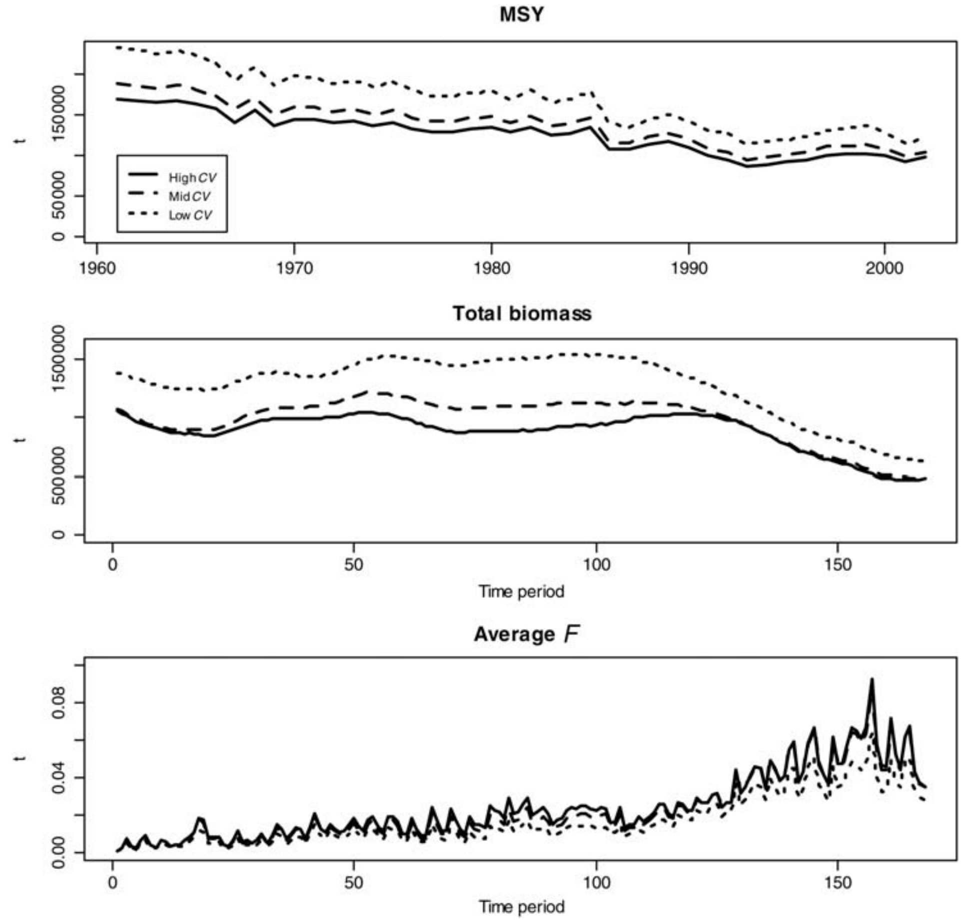

Figure 5. Sensitivity analysis for Atlantic bigeye tuna with respect to the variability in *F* allowed in the assessment model: estimates of MSY, exploitable biomass, and average quarterly fishing mortality under high, medium, and low variability in effort deviations.

suggest that the method provides an indication of maximum capacity that cannot always be achieved under even the best of conditions. Estimates of fishing capacity may be biased upwards because the catch may be restricted by the carrying capacity of the fleet and the travel time, rather than by the ability of the fleet to find the fish. Moreover, even if a fishery is managed as some might consider appropriately by fishing the stock at the *F* corresponding to MSY (F_{MSY}), the results might indicate that CO is higher than MSY and hence there is OC. Yellowfin tuna in the eastern Pacific Ocean are a case in point. Whereas MSY considers only changes in selectivity through time, it may be necessary to incorporate changes in the ecosystem, such as regime shifts observed in the past in the eastern Pacific, that would switch the system to a different level of MSY. For that reason, using dMSY instead of MSY may be more appropriate when estimating OC.

On the other hand, interpretation of peak values of *F* should include consideration of a range of possible factors. The method assumes that peaks represent instances of full use of fleet capacity. An alternative view, for example, could explain those peaks as changes in catchability attributable to the environment or technology. External information on stock and fishery dynamics that might help explain peaks in *F* should be used. Management measures, changes in fleet dynamics, or other biological and technological factors might be behind some of the observed peaks in *F*, which should not, therefore, be interpreted only as changes in capacity.

Management measures such as time/area closures can also impact trends in *F* and need to be considered carefully because the methods presented here will likely detect a decrease in capacity. If in fact there has been no reduction in capacity, then a possible solution is to adjust the values of *F* for the effect of management regulations, for the appropriate period, before estimating capacity.

Some regulations allow fleets to switch between stocks, which may impact estimates of capacity based on *F*. For example, fleets moving between the western and central Pacific and the eastern Pacific areas would decrease fishing pressure on one of the stocks, and the switch would be reflected in estimates of *F* and fishing capacity. However, the effective fishing capacity may remain at the previous level because those fleets may be permitted to return to the initial stock. Additional problems for assessing and managing tuna fishing capacity arise when dealing with multispecies (e.g. purse-seine) fisheries because the optimum capacity for yellowfin tuna may differ from the optimum capacity for skipjack (*Katsuwonus pelamis*), or when different gears operate on the same stock (the optimum capacity for purse-seine depends on the capacity of the longline; Arenas, 2007). Multispecies and multigear issues, however, are not specific to tuna fisheries; they have also been identified when estimating capacity in other non-tuna fisheries (Smit, 1996; Tingley *et al.*, 2003).

Being able to estimate tuna fishing capacity would be most valuable, obviously, if estimates could be used to manage fishing

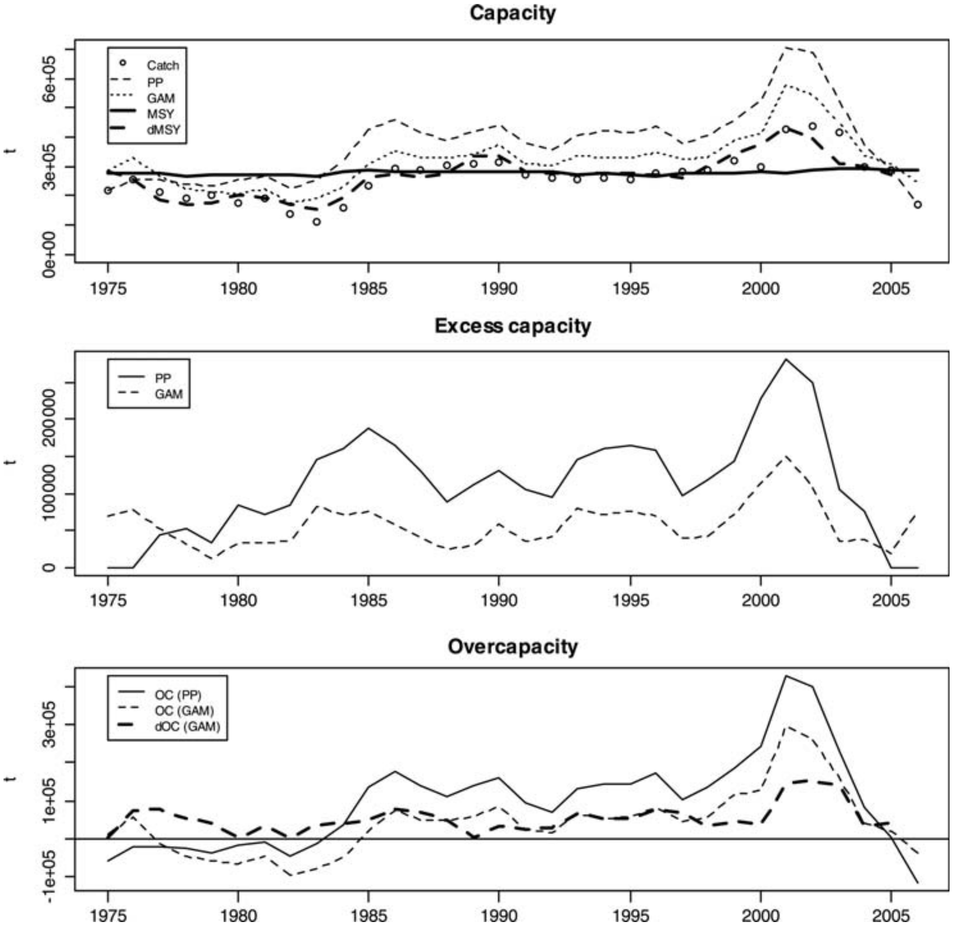

Figure 6. Eastern Pacific yellowfin tuna trends of CO, EC, and OC estimated with the PP and GAM methods. dOC, OC estimated as the difference between CO and "dMSY".

capacity. EC and OC, as defined here (CO minus catch and CO divided by MSY, respectively), may not represent the estimates that are most intuitively useful to 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 the need for further management constraints. Or perhaps it might be useful for managers to know the level of effort reduction required to avoid overexploitation. In the analyses performed for different tuna stocks, the relationship between fishing effort and CO was not linear for many fisheries (Figure 7), limiting the ability to determine appropriate effort levels from capacity analyses.

One of the reasons for this lack of linear relationship between CO and fishing effort is that the assessment models allow for changes in catchability over time, both seasonally and annually. Therefore, the underlying relationship between fishing effort and *F* would not necessarily be expected to be linear. Another reason is that estimates of CO in each period are conditioned by the size of the resource then. This suggests that maximum potential *F* may be a more useful metric for management than CO, because *F* is more directly related to fishing effort than catch and is independent of (i.e. less dependent on) resource abundance. For example, if the fishery is operating at F_{MSY} and the population size is above the biomass corresponding to MSY, the fishery would be designated as at OC, although the number of vessels may be appropriate to produce the average MSY when the population is at B_{MSY} (the biomass at MSY). The population may be above B_{MSY} because the stock has historically been only lightly exploited or because of increases in productivity. Conversely, fishing an overfished stock at F_{MSY} will produce an estimated negative OC (using the average MSY). This suggests that the *F* to F_{MSY} ratio, often used to assess the status of stocks, may be a good proxy to assess OC.

Other authors suggest that although more complex physical and economic data are required to understand fishing capacity theory better, limited data and carefully interpreted simple indicators of capacity may still be useful for making conservative management decisions (Clark *et al*., 1985; Hsu, 2003). Here, we have presented simple methods that could be applied broadly to stocks assessed routinely, have identified their merits and disadvantages, and have contrasted them with other available approaches to estimating fishing capacity. CO, as we define it, is the concept more intuitively comparable with the conventional definition of capacity. However, capacity estimates from different methods are not directly comparable because they are based on slightly different definitions of capacity (Kirkley *et al*., 2004). Although estimating the capacity of tuna fisheries was beyond the scope of this work, the point estimates of capacity obtained from these (and other) approaches should be considered with caution. The approach did, however, allow us to analyse the various issues that arise when trying to estimate capacity and

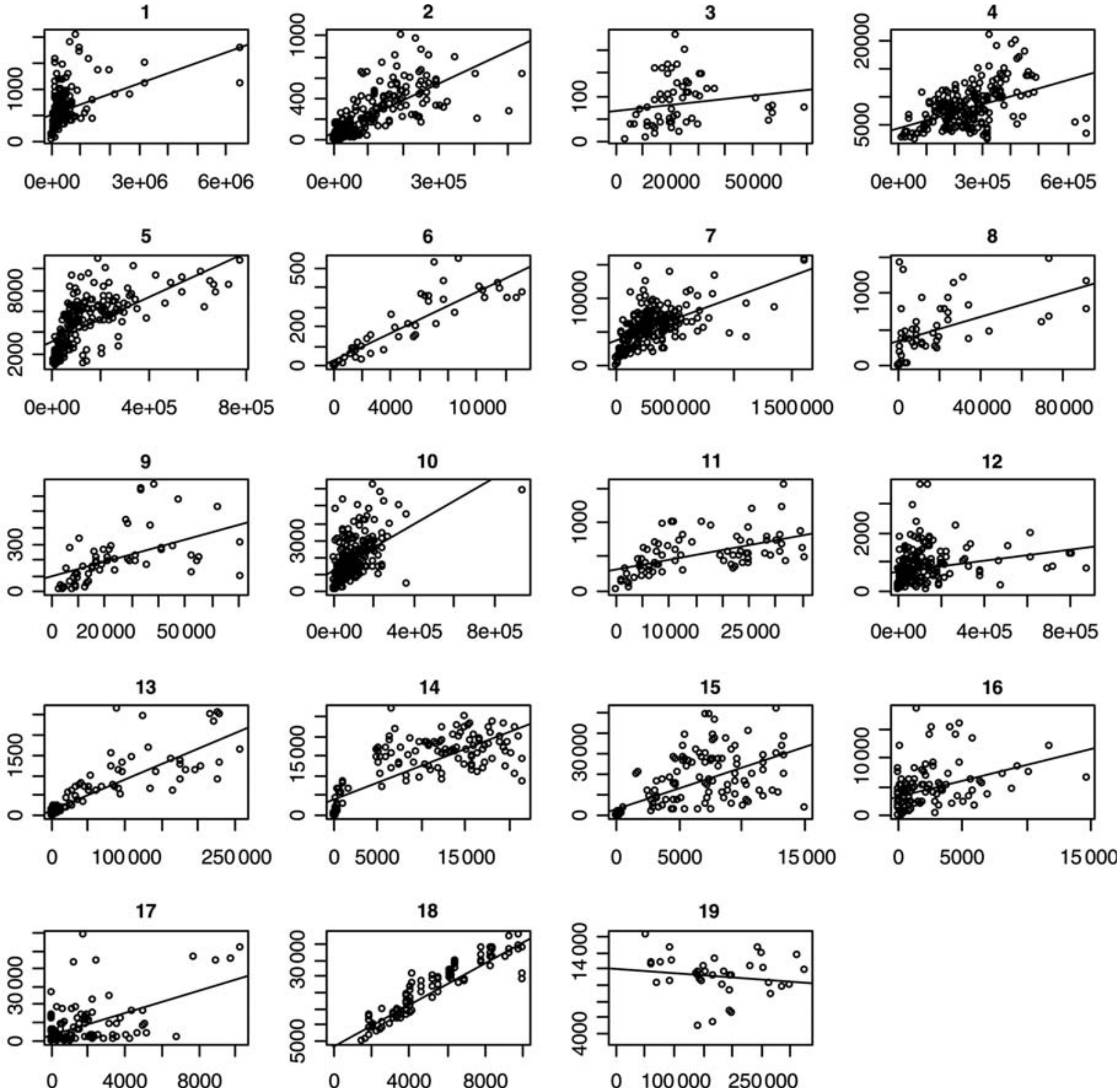

Figure 7. Relationship between estimated CO (*y*-axis) and fishing effort (*x*-axis) by fishery (number at the top of each panel) for western and central Pacific yellowfin tuna. Fishery definitions are given in Hampton *et al.* (2006).

trends in capacity over time, based on commonly available stock assessment data.

Acknowledgements

The work was conducted with funds provided by the FAO. ICCAT, WCPFC, SPC, IATTC, and IOTC provided stock assessment data, and Pierre Kleiber, Yukio Takeuchi, and Richard Hillary provided technical advice. Dale Squires and two anonymous referees made valuable comments on an earlier draft. This paper is contribution number 463 from AZTI-Tecnalia (Marine Research).

References

Anon. 2005. Conference on the governance of high seas fisheries and the UN fish agreement: moving from words to action. International Journal of Marine and Coastal Law, 20: 605–629.

Arenas, P. 2007. Estimated target fleet capacity for the tuna fleet in the eastern Pacific Ocean, based on stock assessments of target species. *In* Methodological Workshop on the Management of Tuna Fishing Capacity—Stock Status, Data Envelopment Analysis, Industry Surveys and Management Options, La Jolla, California, USA, 8–12 May 2006, pp. 39–50. Ed. by B. H. Bayliff, and J. Majkowski. FAO Fisheries Proceedings, 8. 218 pp.

Bayliff, W. H., and Majkowski, J. 2007. Methodological Workshop on the Management of Tuna Fishing Capacity—stock status, data envelopment analysis, industry surveys and management options, La Jolla, California, USA, 8–12 May 2006. FAO Fisheries Proceedings, 8. 218 pp.

Branch, T., Hilborn, R., Haynie, A., Fay, G., Flynn, L., Griffiths, J., Marshall, K., *et al.* 2006. Fleet dynamics and fishermen behavior: lessons for fisheries managers. Canadian Journal of Fisheries and Aquatic Sciences, 63: 1647–1668.

Clark, C. W., Charles, A. T., Beddington, J. R., and Mangel, M. 1985. Optimal capacity decisions in a developing fishery. Marine Resource Economics, 2: 25–54.

Cochrane, K. L. 2000. Reconciling sustainability, economic efficiency and equity in fisheries: the one that got away? Fish and Fisheries, 1: 3–21.

FAO. 1998. Report of the Technical Working Group on the Management of Fishing Capacity, La Jolla, California, USA, 15–18 April 1998. FAO Fisheries Report, 586. 57 pp.

FAO. 2000. Report of the Technical Consultation on the Measurement of Fishing Capacity, Mexico City, 29 November–3 December 1999. FAO Fisheries Report, 165. 51 pp.

Felthoven, R. G., Hiatt, T., and Terry, J. M. 2002. Measuring fishing capacity and utilization with commonly available data: an application to Alaska fisheries. Marine Fisheries Review, 64: 29–39.

Fournier, D. A., Hampton, J., and Sibert, J. R. 1998. MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. Canadian Journal of Fisheries and Aquatic Sciences, 55: 2105–2116.

Gréboval, D. 1999. Managing fishing capacity: selected papers on underlying concepts and issues. FAO Fisheries Technical Paper, 386. 206 pp.

Hampton, J., Langley, A., and Kleiber, P. 2006. Stock assessment of yellowfin tuna in the western and central Pacific Ocean, including an analysis of management options. Second Meeting of the WCPFC-Scientific Committee, 7–18 August 2006, Manila, Philippines, WCPFC-SC2-2006/SA WP-1. 103 pp.

Hennessey, T., and Healey, M. 2000. Ludwig's ratchet and the collapse of New England groundfish stocks. Coastal Management, 28: 187–213.

Hsu, T. C. T. 2003. Simple capacity indicators for peak-to-peak and data envelopment analyses of fishing capacity. A preliminary assessment. *In* Measuring Capacity in Fisheries, pp. 233–259. Ed. by S. Pascoe, and D. Gréboval. FAO Fisheries Technical Paper, 445. 314 pp.

ICCAT. 2005. Report of the 2004 ICCAT Bigeye Tuna Stock Assessment Session, Madrid, 28 June–3 July 2004. Collective Volume of Scientific Papers ICCAT, 58: 1–100.

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

Kirkley, J. E., and Squires, D. 1999. Measuring capacity and capacity utilization in fisheries. *In* Managing Fishing Capacity: Selected Papers on Understanding Concepts and Issues, pp. 75–199. Ed. by D. Gréboval. FAO Fisheries Technical Paper, 386. 206 pp.

Kleiber, P., Hampton, J., and Fournier, D. A. 2008. MULTIFAN-CL User's Guide. 126 pp. http://www.multifan-cl.org/Downloads/MFCLdoc-1.pdf.

Lindebo, E. 2004. Measuring capacity in fisheries: analytical tools and data aggregation. *In* Measuring and Appraising Capacity in Fisheries: Framework, Analytical Tools and Data Aggregation, pp. 7–39. Ed. by S. Pascoe, D. Gréboval, J. Kirkley, and E. Lindebo. FAO Fisheries Circular, 994. 48 pp.

Mace, P. M. 2001. A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. Fish and Fisheries, 2: 2–32.

Maunder, M. N. 2006. Status of yellowfin tuna in the eastern Pacific Ocean. *In* Report of the 8th Meeting of the Working Group to Review Stock Assessments, La Jolla, California, USA, 7–11 May 2007, SAR-8-08a. 76 pp.

Miyake, P. M. 2005. A review of the fishing capacity of the longline fleets of the world. *In* Second Meeting of the Technical Advisory Committee of the FAO Project "Management of Tuna Fishing Capacity: Conservation and Socio-economics", pp. 157–170. Ed. by W. H. Bayliff, J. K. de Leiva Moreno, and J. Majkowski. FAO Fisheries Proceedings, 2. 336 pp.

Pascoe, S., Coglan, L., and Mardle, S. 2001. Physical versus harvest-based measures of capacity: the case of the United Kingdom vessel capacity unit system. ICES Journal of Marine Science, 58: 1243–1252.

Reid, C., Kirkley, J. E., Squires, D., and Ye, J. 2005. An analysis of the fishing capacity of the global tuna purse-seine fleet. *In* Second Meeting of the Technical Advisory Committee of the FAO Project "Management of Tuna Fishing Capacity: Conservation and Socio-economics", pp. 117–156. Ed. by W. H. Bayliff, J. K. de Leiva Moreno, and J. Majkowski. FAO Fisheries Proceedings, 2. 336 pp.

Reid, C., and Squires, D. 2007. Measuring fishing capacity in tuna fisheries: data envelopment analysis, industry surveys and data collection. *In* Methodological Workshop on the Management of Tuna Fishing Capacity—Stock Status, Data Envelopment Analysis, Industry Surveys and Management Options, La Jolla, California, USA, 8–12 May 2006. Ed. by W. H. Bayliff, and J. Majkowski. FAO Fisheries Proceedings, 8. 218 pp.

Reid, C., Squires, D., Jeon, Y., Rodwell, L., and Clarke, R. 2003. An analysis of fishing capacity in the western and central Pacific Ocean tuna fishery and management implications. Marine Policy, 27: 449–469.

Restrepo, V. R. 2007. Estimates of large-scale purse-seine, baitboat and longline fishing capacity in the Atlantic Ocean: an analysis based on stock assessment of bigeye tuna. *In* Methodological Workshop on the Management of Tuna Fishing Capacity—Stock Status, Data Envelopment Analysis, Industry Surveys and Management Options, pp. 51–62. Ed. by W. H. Bayliff, and J. Majkowski. FAO Fisheries Proceedings, 8. 218 pp.

Restrepo, V. R., Porch, C. E., Turner, S. C., Scott, G. P., and Rosenberg, A. A. 1994. Combination of spawner-recruit, spawning biomass-per-recruit and yield-per-recruit computations for the estimation of the long term potential for west Atlantic bluefin tuna. Collective Volume of Scientific Papers ICCAT, 42: 214–222.

Smit, W. 1996. An economic approach to measuring fishing effort: application to a Dutch cutter fleet. Marine Resource Economics, 11: 305–311.

Smith, C. L., and Hanna, S. S. 1990. Measuring fleet capacity and capacity utilization. Canadian Journal of Fisheries and Aquatic Sciences, 47: 2085–2091.

Tingley, D., Pascoe, S., and Mardle, S. 2003. Estimating capacity utilisation in multi-purpose, multi-metier fisheries. Fisheries Research, 63: 121–134.

doi:10.1093/icesjms/fsp165