Campbell, R.A., J.D. Prince, C.R. Davies, N.A. Dowling, and D.S. Kolody. 2017. An Empirical Decision Tree–Based Harvest Strategy for in-Country Management of a Shared Pelagic Resource. In: T.J. Quinn II, J.L. Armstrong, M.R. Baker, J. Heifetz, and D. Witherell (eds.), Assessing and Managing Data-Limited Fish Stocks. Alaska Sea Grant, University of Alaska Fairbanks. https://doi.org/10.4027/amdlfs.2016.10

An Empirical Decision Tree–Based Harvest Strategy for in-Country Management of a Shared Pelagic Resource

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Abstract

Quota management systems often increase the burden for reliable stock assessments that are beyond the capacity of most fisheries. There is therefore a need to re-assess the utility to fishery assessment of simpler procedures that make greater use of indicators collected directly from the fishery. This is especially the case for data-poor fisheries. This study describes the rationale behind the development of an empirical indicator based harvest strategy for management of the Eastern Tuna and Billfish Fishery off eastern Australia. While Australian legislation requires management of this fishery against given reference points, in practice management is hampered by the distribution of the fished resources beyond the Australian jurisdiction and the shared nature of the total catch with other fishing nations. The harvest strategy is based on the use of empirical indicators (size-based catch rates and catch proportions) and the use of a multilayered decision-tree process. Implementation of the harvest strategy to one of the principal target species, broadbill swordfish, is described. The main strengths of the strategy are that it is broadly applicable to data-poor fisheries where

only catch rate and size information are available, is readily understood and acceptable to stakeholder groups, and relatively easy to implement.

Introduction

There is a growing realization that most of the world's fisheries are fully if not overexploited (Mullon et al. 2005, FAO 2011). However, conventional stock assessment techniques cannot be applied to many fisheries due to data limitations (Prince 2010, Costello et al. 2012). Likewise, preferred or mandated management systems, like quota management systems, often increase the burden for reliable stock assessments and determination of harvest levels which is beyond the capacity of most fisheries (Walters and Pearse 1996, Cochrane 1999). Given this situation the challenge becomes devising alternative assessment methods that require limited data but are capable of revealing stock status and fulfilling fishery management requirements (Bentley and Stokes 2009, Cope and Punt 2009).

There has therefore been interest in recent years in re-evaluating the reliance on complex stock assessment models and on re-assessing the utility of simpler methods to estimate appropriate catch limits (Rochet and Trenkel 2003, Honey et al. 2010, Carruthers et al. 2014). For example, Beddington and Kirkwood (2005) proposed a method to estimate potential yield and stock status using life-history parameters, while Zhou et al. (2012) have linked fishing mortality reference points to life history parameters. There has also been an interest in developing harvest strategies that make greater use of empirical indicators collected directly from the fishery (Schroeter et al. 2009, Geromont and Butterworth 2015a).

A distinction between "data-poor" and "low information" fisheries has been made by Bentley and Stokes (2009) who argue that many fisheries may be rich in data yet remain low in information. In this regard, spatial complexity can be a contributing factor causing a fishery to remain low in information. Long time series of data may exist giving the appearance of data-richness but not at the scale required to meaningfully index local patterns of abundance (Wilson 2006). Oresanz et al. (2005) term these spatially complex data-poor fisheries "S-fisheries" for being small-scale, composed of spatially structured meta-populations, exhibiting spatial heterogeneity of population dynamics, and experiencing localized effects of fishing. With the focus being on the larger scale, higher value fisheries there has been a tendency to leave these fisheries effectively unmanaged.

A similar situation occurs for stocks with an extensive spatial distribution, for example highly migratory pelagic species such as tunas and billfish, and for which there is usually a range of fisheries operating within or across a number of limited jurisdictions. While there may be an overarching management agency (e.g., a Regional Fisheries Management Organisation, Cullis-Suzuki and Pauly 2010) managing the stock there is often also a need for localized assessment and management within separate jurisdictions. Such a situation exists within the western and central Pacific Ocean (WCPO) where the regional tuna and billfish resources are managed by the Western and Central Pacific Fisheries Commission (WCPFC). Many of the tuna species are assumed (in the absence of evidence to the contrary) to constitute a single stock, but are fished by numerous fisheries, both domestic (e.g., Australia, New Caledonia, Fiji) and distant-water (e.g., Japan, Korea, Chinese Taipei), which use a range of fishing methods (e.g., longline, purse-seine, pole-and-line) both within and across the large number of exclusive economic zones of the member nations and territories within the region (Parris 2010, Williams and Terawasi 2013).

Within Australia, which is a member of the WCPFC, the pelagic resources distributed across the WCPO are targeted by the Eastern Tuna and Billfish Fishery (ETBF) which is managed by the Australian Government. In December 2005, the Australian Government launched a new fisheries policy, "Securing our Fishing Future," which aimed to cease overfishing and rebuild overfished stocks (DAFF 2005, Rayns 2007, Smith et al. 2014). Coincident with this policy launch was a requirement to develop and implement formal harvest strategies for all Australian Commonwealth fisheries (McDonald 2005). These harvest strategies were to be developed in a manner consistent with a set of Harvest Strategy Guidelines (DAFF 2007). For the ETBF the adopted harvest strategy is based on the use of several empirical indicators derived from data collected from this fishery. After a brief description of the ETBF, the main features of, and the rationale behind, the adopted harvest strategy are outlined. The approach is then illustrated by applying it to broadbill swordfish, one of the principal target species in this fishery.

The Eastern Tuna and Billfish Fishery

The ETBF operates off eastern Australia within the Coral and Tasman Seas in an area roughly defined as south of 10°S and between the east coast of Australia and 170°E (Fig. 1). The ETBF is a multispecies, multi-method commercial fishery that operates year-round and is dominated by the longline sector. Forty-five longline vessels operated in the fishery during 2012 deploying around 6.8 million hooks, a decrease from the 136 vessels which set around 12.7 million hooks in 2003 before the restructure announced as part of the above policy (Campbell 2013a). The principal target species are yellowfin tuna (YFT, *Thunnus albacares*), bigeye tuna (BET, *Thunnus obesus*), albacore tuna (ALB, *Thunnus alalunga*), broadbill swordfish (SWO, *Xiphias gladius*), and striped marlin (STM, *Tetrapturus audax*) with the total catch of these five species

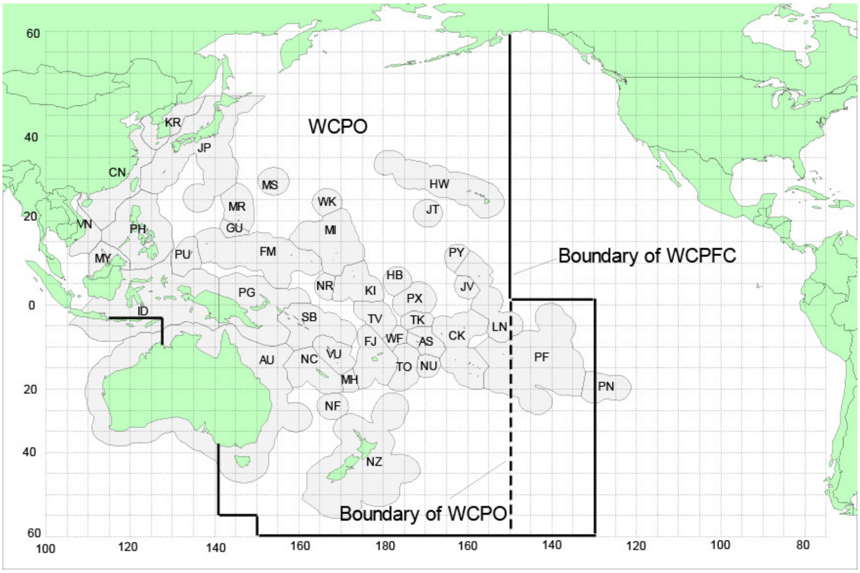

Figure 1. Map showing exclusive economic zones (EEZs) across the western-central Pacific Ocean. Also shown is the region managed by the Western Central Pacific Fisheries Commission (WCPFC, bounded by the dark line) and the region known as the Western Central Pacific Ocean (WCPO, limited by the dashed line). The Eastern Tuna and Billfish Fishery is limited to the Australian EEZ (AU and NF) and adjacent international waters.

in 2012 being around 4,100 metric tons (Campbell 2013a). A number of byproduct species have also increased in economic importance in recent years.

As the fish caught in the ETBF are part of stocks distributed throughout the wider WCPO the status of resources within the ETBF cannot be assessed in isolation. With the exception of the two billfish species, the catch taken by the ETBF also represents a very small portion of the total catch taken by all fisheries across the WCPO. For example, the catch of YFT and BET in the ETBF in 2012 was less than 0.4% of the total catch of these two species taken in the WCPO (about 655,000 t and 162,000 t respectively, OFP 2013). For SWO and STM, each assumed to be separate stocks within the southwest Pacific, the ETBF catch in 2012 was 12 and 15% respectively of the total catches taken within the WCPO south of the equator.

The impact of one fishery within the WCPO on another remains uncertain as the localized residency of fish within any single region and movement rates between regions remains highly uncertain. Tagging studies undertaken over the past decade nevertheless indicate that the interchange of fish in the ETBF with other regions of the WCPO may be small (Gunn et al. 2006, Evans 2010, Evans et al. 2011, Wilcox 2014) supporting previous studies indicating only moderate levels of interchange between different regions of the WCPO (Sibert and Hampton 2002). As such, localized depletions within a single jurisdictional area are possible, and would explain the localized trends in SWO catch rates observed within the ETBF (Campbell and Hobday, 2003). These observations lend themselves to the working hypothesis that the fish resources available to the ETBF have, to some extent, a relative degree of separation from the much larger resources found within the broader WCPO, especially those in equatorial regions. On this basis, between 2008 and 2013 the annual catches in the ETBF as a percentage of the total in this southwest Pacific region (10-50°S, 140-170°E) represented 9% YFT tuna, 22% BET tuna, 5% ALB tuna, 68% SWO, and 48% STM.

Rationale of approach

The Commonwealth Harvest Strategy Policy (hereafter referred to as the Policy, DAFF 2007) states that any harvest strategy must contain:

- *A process for monitoring and conducting assessments of the biological and economic conditions of the fishery; and*
- *Rules that control the intensity of fishing activity according to the biological and economic conditions of the fishery (as defined by the assessment).*

For control rules to be clear and effective, the above policy further states that "*the objectives need to be expressed in the form of quantifiable reference points*" and that "*management decisions should be pre-agreed actions linked directly to the biological and economic status of the fishery relative to these reference points.*" In this regard, the Policy includes two operational objectives:

- *Maintain fish stocks, on average, at a target biomass point (B_{TARG} or proxy) equal to or greater than the stock size required to produce maximum economic yield (B_{MEY})*
- *Ensure fish stocks will remain above a biomass level where the risk to the stock is regarded as too high, that is B_{LIM} (or proxy).*

While these statements outlined the broad components of any harvest strategy to be developed for the ETBF, a number of features pertinent to the ETBF raised a number of issues in relation to incorporation of the two operational components of the Policy. These issues generally relate to the highly migratory nature of the target species, the shared nature of these fisheries, and the use of indicators based on estimation of current biomass and/or fishing mortality.

Issues relating to straddling fish stocks

The Policy states that the harvest strategy should apply "*to fish stocks throughout their range and mortality resulting from all types of fishing*." Given the shared international nature of the ETBF resources this implies that the development of a harvest strategy for this fishery would need to take into account the status of stocks throughout the WCPO and account for catches and fishing mortality taken by all fleets exploiting these stocks. This would have direct implications for the development and implementation of a harvest strategy for the ETBF. For example, in the absence of an international agreement on catch levels the Policy could potentially result in Australia unilaterally reducing the catches of certain species in the ETBF in response to WCPO wide assessments that indicate depletion below identified reference points, but largely resulting from catches by other nations, even though the regional components of these populations within the ETBF are being harvested at a sustainable level.

Issues relating to MSY or MEY as reference points

The use of maximum economic yield (MEY) based reference points in the Policy also presents a number of conceptual and technical difficulties in the case of straddling and highly migratory stocks as there is an interaction between the technical validity of the use of the reference points and the geographic/stock scale at which they are applied. In brief, MSY and MEY are "whole stock" concepts that have little meaning at a scale of less than an entire reproductive population. If harvest strategies are developed for a regional scale, such as YFT in the Coral Sea, it would be of questionable validity to use reference points based on estimates of B_{MEY} or F_{MEY} from a global assessment. It was therefore considered best to develop harvest strategies for Australia's tropical tuna and billfish fisheries that are based on local indicators of stock status. That is, indicators derived from activities of the Australian fleet in the area of relevance to current Australian operations.

Model versus empirical performance indicators

The performance indicators and reference points used in the assessment and management of many fisheries are often based on complex bioeconomic models of the fishery. Furthermore, these reference points have generally focused on fishing mortality (F) or biomass (B) and the associated management actions are usually aimed at maintaining these at levels that prevent biologically or economically undesirable events from happening.

Estimation of reference points with stock assessment models is, however, a technically challenging problem (Punt et al. 2013). Experience has shown that even for fisheries with long time-series and significant investments in research these quantities remain poorly resolved (Walters and Maguire 1996). These models are also generally sensitive to arbitrary constraining assumptions that are required to make tractable estimators (Schnute and Richards 2001). As a result, multiple model specifications might be plausibly consistent with the same data, but indicative of vastly different reference points and management implications. Recognition of this problem has been part of the impetus for the development of harvest strategies that are robust to alternative possibilities to the extent possible.

Experience has shown that once the full-level of stock assessment uncertainty is admitted, relatively simple models or data-based indicators can often provide the basis for effective feedback decision rules that are equivalent to decision rules based on complex assessment models (Anon. 2005, Geromont and Butterworth 2015b). While complex models are useful for identifying the alternative possible states of nature that are consistent with the data, a single model is unlikely to adequately reflect the true levels of uncertainty inherent in the system under consideration and, as such, may not provide an appreciably better basis for a feedback decision rule than a data-based decision rule relying on essentially the same data. Provided that the data-based decision rules are able to extract key signals from the data, they can often be "tuned" to perform very effectively. Given that multiple alternative states of nature can be plausibly consistent with the data, the best tuning usually represents a trade-off, yielding reasonable performance most of the time. The performance is rarely optimal (Schnute and Haigh 2006), but hopefully the rules are robust in that they can respond appropriately to prevent irreversible damage if pessimistic scenarios turn out to be the closest to reality.

Ideally, empirical or data-based indicators and reference points should be based on variables that are themselves related to, or are influenced by, the basic reference variables F and B (Caddy 1998). Examples include:

(i) CPUE based Indicators

The use of commercial catch-per-unit-effort (CPUE) as a low-cost index for monitoring resource abundance is based on the assumption that catch rates are related in some quantifiable manner to fish abundance. However, there are many potential problems with using CPUE in this manner, as it is the objective of the industry to maximize fishing efficiency, and thus economic returns, rather than to provide standard measures of relative abundance (Paloheimo and Dickie 1964, Harley et al. 2001). Fishing power usually changes over time as the fleet learns when, where, and how to fish more effectively (commonly called effort creep). The spatial and temporal distribution of effort can also change over time, and if the coverage is not comprehensive assumptions must be made about abundance in times and areas that are not fished (Campbell 1998, Walters 2003). Nevertheless, standardization of catch rates against the factors that influence targeting practices and effort creep can help to overcome these problems.

(ii) Size composition of the catch

Changes in the size-composition of the catch are often used to infer various changes in the underlying population (Beverton and Holt 1957). For example, use of mean size as a reference point may be based on a yield-per-recruit analysis, or an exploitation rate where the mean size of fish caught is equal to, or greater than, the average size at maturity (so that at least 50% of individuals have an opportunity to reproduce) could be used. Variations of this approach may consider the percentage of catch within various size classes (Froese 2004, Cope and Punt 2010). Furthermore, estimates of total mortality based on size composition data have also been developed (e.g., Sparre et al. 1989, Clay 1991), but these methods inevitably involve assumptions about fishery selectivity and natural mortality, which are generally poorly known (Klaer et al. 2012), and also assume equilibrium conditions.

(iii) Spatial distribution

Changes in the spatial distribution of fishing effort and the distribution of the stock are sometimes noted as a fishery develops and can be identified by the use of simple spatial indices of aggregation such as that proposed by Gulland (1955). If this is the case, simple indices of concentration could be used to formulate limit reference points designed to detect unfavorable changes. Alternatively, it may be possible to specify situations where CPUE becomes low and uniform or where the area fished contracts in size with overexploitation, as observed in the fishery for southern bluefin tuna (Campbell 2016).

While the empirical approaches to identifying performance measures and related reference points may lack the theoretical rigor usually associated with the more familiar model-based reference points, initial results indicate the utility of this approach (Hilborn 2002). Such approaches also have the advantage of simplicity as the decision rule inputs are readily available and calculated with minimal technical expertise and as such may be more readily understood and accepted. In other words, a highly technical reference point or control law may be difficult to explain but will still need to accumulate practical hands-on experience, while a less precise empirical based reference point may be more effective if it is understood and receives consensus from the industry and still leads to effective results.

The primary control rule

The management framework for the ETBF is presently predicated on setting an annual total allowable catch (TAC) for each of the five principal target species. In determining each TAC managers are guided by the recommended biological catch (RBC) identified by the harvest strategy. In the absence of a model-based stock assessment for each species from which performance indicators of exploitation and biomass levels can be inferred and used for updating the TAC, the harvest strategy developed for the ETBF uses an empirical approach where the TAC is updated in response to changes in some measurable statistic. In principle this statistic should be some measure of the exploitable biomass or the fishing mortality, and standardized CPUE was chosen to represent the former. Given a TAC in year T the primary control rule for determination of the RBC in the following year, $T+1$, then involves using the formula:

$$RBC_{T+1} = M^*TAC_T \qquad (1)$$

where M is a multiplier given by:

$$M = (1+ \beta.S_{CPUE}) \qquad (2)$$

and S_{CPUE} is the slope of a linear regression of the standardized CPUE over the last N_{TREND} years and β is a control parameter referred to as the feedback gain factor (Magnusson and Stefansson 1989, Magnusson 1992). The TAC in the first year can be determined by various means, such as a previous stock assessment or the average of the catch over some appropriate period in the history of the fishery.

Logic indicates that the above control rule will tend to recommend a decrease in the TAC following years of declining CPUE (indicating a decrease in resource availability) and increase the TAC after years of increasing CPUE (indicating an increase in resource availability). However, application of this harvest strategy over the long term will tend to stabilize the TAC around the value it had in the year the rule is first applied, i.e., it will not allow the stock to rebuild if it is overfished nor allow a long-term increase in fishing mortality if the stock is presently only lightly fished. The problem stems from the fact that the change in the TAC is premised on the slope of the CPUE which takes as its reference the horizontal slope corresponding to the situation where the TAC remains unchanged. For example, when there has been some rebuilding of the stock (increasing CPUE) then the above rule results in the TAC being increased which results in fishing the stock down again. The opposite occurs when there has been a decrease in the stock. Thus even though the TAC may increase and decrease in any year, over the long term the TAC remains, on average, similar to the TAC in the year that the strategy was first applied.

A solution to this problem is one that allows the fishery to exploit the resource at some identified long-term optimum and sustainable level. This is achieved by setting $S_{CPUE} = S_{TARG}$ where S_{TARG} is the slope based on the angle subtended by the CPUE trend line and the line joining the present CPUE value and a target CPUE value a specified number of years, N_{TARGET}, in the future. Such a situation is shown in Fig. 2 where it is assumed $N_{TARGET} = 5$ years. If $A = \tan(\alpha)$ is the slope of the linear regression of CPUE over the past 5 years, and $B = \tan(\theta)$ is the slope to the target CPUE, then $S_{CPUE} = \tan(\alpha + \theta)$ and after accounting for the different configurations of A and B it can be shown that:

$$S_{TARG} = \begin{cases} \tan[tan^{-1}(A) - tan^{-1}(B)] & A > 0, B \geq 0, A \geq B \\ -\tan[tan^{-1}(B) - tan^{-1}(A)] & A > 0, B \geq 0, A < B \\ \tan[tan^{-1}(A) + tan^{-1}(-B)] & A > 0, B < 0 \\ -\tan[tan^{-1}(-A) + tan^{-1}(B)] & A < 0, B \geq 0 \\ \tan[tan^{-1}(-B) - tan^{-1}(-A)] & A \leq 0, B < 0, -A < -B \\ -\tan[tan^{-1}(-A) - tan^{-1}(-B)] & A \leq 0, B < 0, -A \geq -B \end{cases} \quad (3)$$

A simple example highlights the above two rules. We used a simple biomass production model to simulate a hypothetical stock and fishery and for a period of 15 years. The time series of effort, catch, and relative biomass are shown in Fig. 3. After 15 years the biomass has been driven down to less than 0.4 *Bo* where *Bo* represents the initial unfished biomass. If B_{TARG} is set equal to 0.5 *Bo* then the stock is considered to be overexploited. A harvest strategy was then applied at the start of the 16th year. The following two alternative primary control rules (PCRs) were examined:

PCR-1: Slope to Horizontal: This is the default control rule based on equation (1) with the simple slope of the CPUE indicator taken over the previous five years (i.e., $N_{TREND} = 5$).

PCR-2: Slope to Target: We take 50% of the initial CPUE as the target reference point for rebuilding CPUE (and biomass). Again, $N_{TREND} = 5$ and we set $N_{TARGET} = 5$ years. Having calculated the slope-to-target, S_{TARG}, the TAC is then adjusted in a similar manner as before.

The hypothetical fishery was then projected forward another 15 years under annual catch levels determined by application of each of the above primary control rules at the end of each year. The future time-series of effort, catch, and biomass are shown in Fig. 3. As expected, PCR-1 stabilizes effort and biomass around the values they had at the end of the historical period while PCR-2 allows rebuilding of the stock to the defined target reference point. Given that the biomass under PCR-1 remains at around 35% *Bo*, and in what for this example is considered

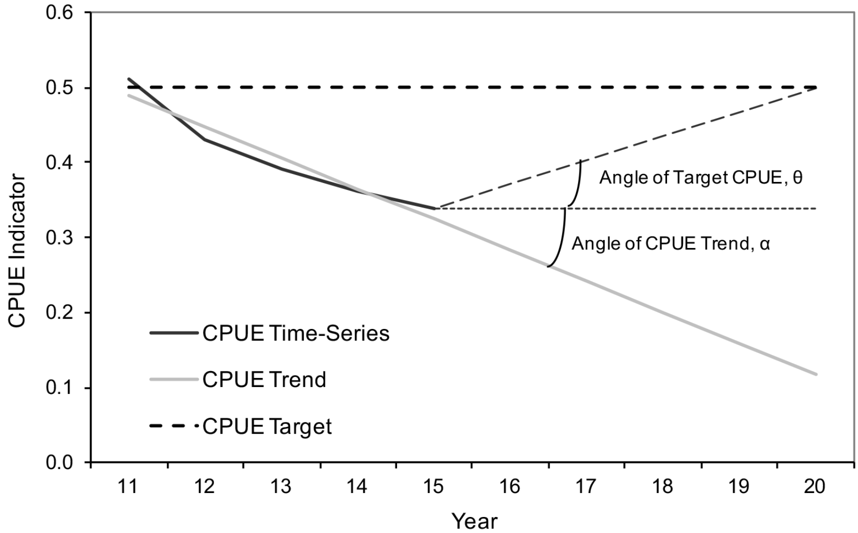

Figure 2. Conceptual example of how the slope-to-target parameter is derived.

to be an overfished state, this harvest strategy has limited utility in recovering the stock to a more sustainable level. Indeed, at best it will only just keep the biomass from declining further.

Several other benefits of PCR-2 are also apparent. Over the 15 year projection period, the average effort level under PCR-2 is around 18% less than under PCR-1. On the other hand, the average catch over that period is very similar, and indeed remains higher into the future under PCR-2, while the CPUE is, on average, 20% higher under PCR-2 compared to PCR-1. Such an increase in efficiency underpins a much more profitable fishery.

Application of a decision tree–based control rule

While the primary control rule provides a simple decision rule for identifying a preliminary RBC, additional information collected from the fishery can also be used to help assess the status of the resource and refine the above rule. In particular it was considered important to incorporate indicators on the size structure of the catch into the assessment process as these can be indicative of underlying changes in the resource under differing levels of exploitation (Hilborn and Walters 1992, Haedrich and Barnes 1997).

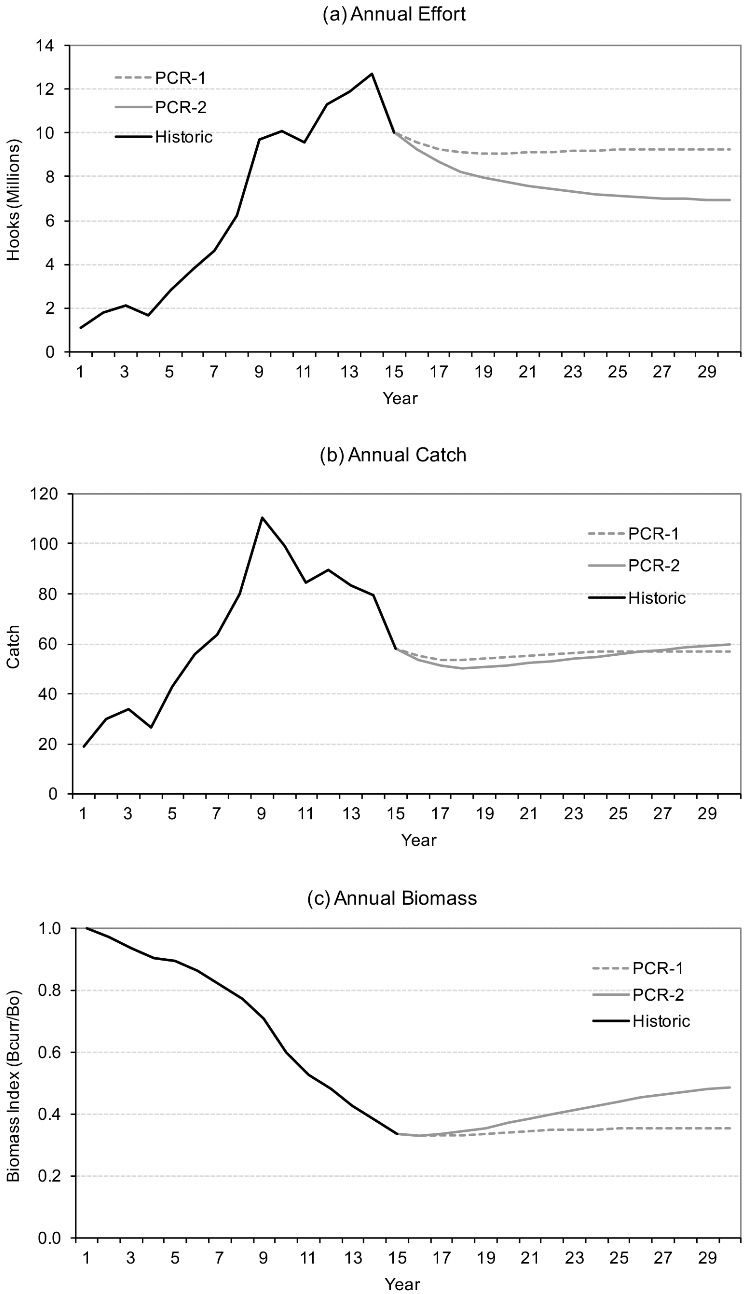

Figure 3. The time-series of annual (a) effort, (b) catch, and (c) CPUE (together with their corresponding historical values) for the hypothetical fishery described in the text under the application of various primary control rules (PCR) for years 16-30.

Froese (2004) has conjectured that fisheries assessment and management can be kept simple by monitoring three size-based indicators of stock status: (1) the percent of mature fish in the catch, (2) the percent of fish in the catch of optimum length, and (3) the percent of "mega-spawners" in the catch. The indicators chosen and the Decision Tree developed for the ETBF applies a like-minded approach to qualify the decisions of the primary CPUE-based decision rule and so guard against situations that might otherwise prevent this decision rule being precautionary. For example, the maintenance or an increase in catch rates due to effort creep may mask an underlying decline in resource status. While the primary CPUE-based decision rule by itself would reward this observation by maintaining or possibly increasing catch levels, the Decision Tree could override this result if the proportion and/or catch rate of the largest fish was found to be declining.

The size data collected from the fishery were divided into small, medium, and large fish (respectively termed *Recruits*, *Prime* and *Old*) and used to derive a number of size-based indicators, most notably the proportion of the total catch within each size class and corresponding catch rates. The exact definition of the *Prime* sized category varies by species, but is intended to include the majority of the preferred market-size fish in the catch. *Recruits* here refers to the part of the size distribution of the catch encompassing small or suboptimal sized fish, while the *Old* size class refers to large fish which may include those fish which contribute greatly to the spawning potential of the resource (i.e., the "mega-spawners," Birkeland and Dayton 2005) and which for certain species may also be suboptimal from a marketing perspective. Instead of attempting to combine these additional size-based indicators into a single primary control rule the adopted approach was to monitor a selected set of indicators and then adjust the RBC resulting from application of the primary control rule by following an explicit set of rules laid out as a multilayered decision tree. This builds on approaches developed previously for the ETBF (Campbell 2004) and the Australian abalone fisheries (Prince et al. 2008).

In following the above logic, the Decision Tree combines a range of empirical size- and CPUE-based performance indicators to infer biomass levels for different size classes in the exploited fish populations. Each of these indicators can then be compared to pre-agreed target values to ascertain the levels of exploitation for each size class (conditional on assumptions about fishery selectivity and natural mortality) and with accompanying decision rules can be used to adjust the RBC. Given that trends can have quite different interpretations, it is helpful to consider indicators of both size and abundance (as measured by CPUE) together. For example, a decrease in mean proportion of *Old* fish may be interpreted as heavy exploitation of large fish or as good recruitment of small ones. Examination of the CPUE of each component of the resource helps suggest which interpretation is most likely correct.

For the Decision Tree developed for the ETBF, four types of information were included in the decision process: the standardized CPUE of each of the three size classes and the proportion of *Old* fish. The size data used are the individual weight of fish rather than length as this is the type of data most commonly collected in the ETBF (Campbell et al. 2013). The overall "assessment" combines these individual assessments and associated decision rules in a staged decision tree process in order to determine a final RBC (Fig. 4). This decision tree–based assessment is undertaken independently for each species.

Outline of the Decision Tree

The Decision Tree has four levels and at each level questions are asked about either the size or catch rate trends being observed in the fishery. The answer to the questions asked at each level determines which branch of the Decision Tree is followed at the next level with the final branch corresponding to a separate state of the resource.

Level 1: Primary control rule

As described previously, the primary control rule assesses the standardized CPUE of the prime size classes (CPUE-*Prime*) in relation to a pre-agreed target CPUE level and determine the change in catch required to move the present CPUE levels to the target over a given time period. This preliminary RBC will then be modified or affirmed by application of the Decision Tree. The application of the Decision Tree identifies and resolves situations such as stock declines masked by effort creep, recruitment failure, and/or pulses which would remain undetected, or ambiguous, if only CPUE-*Prime* were used.

Level 2: CPUE-Prime

It is assessed whether CPUE-*Prime* is rising, stable or falling and uses the result to determine which of the three main limbs of the Decision Tree shown in Fig. 4 will be subsequently followed. Stability is assessed on whether or not the annual rate-of-change in CPUE-*Prime* is within a given limit (in this case 5% of the average CPUE-*Prime* over the previous five years).

Level 3: CPUE-Old and Proportion-Old

Here it is assessed whether each of the two indicators CPUE-*Old* and Proportion-*Old* are above or below their respective target levels. The four possible outcomes have different interpretations depending on how CPUE-*Prime* was categorized at Level 2 and accordingly the assess-

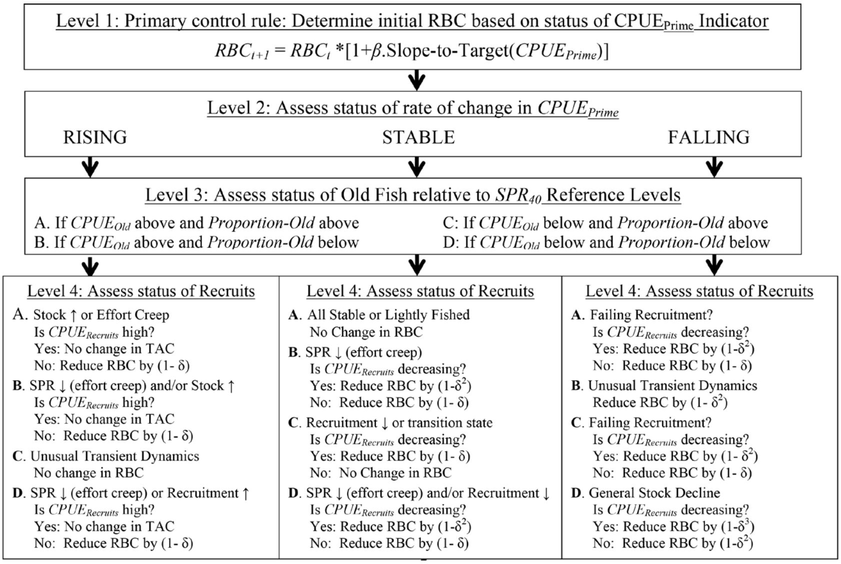

Figure 4. Outline of the Decision Tree adopted for calculating the annual recommended biological catch in the Eastern Tuna and Billfish Fishery.

ment proceeds down to the matching category (A, B, C, or D) in the fourth level. Both the CPUE-*Old* and Proportion-*Old* are used because they provide somewhat different information and should increase the discriminatory power of the assessment process.

Level 4: CPUE-Recruits

At this final level the primary RBC level is either affirmed or an additional question is asked about CPUE-*Recruits*. The idea is that this smallest class of fish are suboptimal for the market, and biologically speaking best kept out of the fishery. However, trends in their rate of bycatch can provide information about recruitment trends to the fishery. In some cases changes in the Proportion-*Old* may be produced by a change in rates of recruitment rather than a change in the actual absolute amount of *Old* fish. In this way CPUE-*Recruits* provides a final test for distinguishing between some otherwise potentially ambiguous possibilities. In those situations where CPUE-*Recruits* is assessed the RBC initially identified at Level 1 may be reduced, with the level of adjustment dependent upon the assessed condition of the stock as indicated by the answers at this and the previous two levels of the Decision Tree.

Table 1. Parameters, and adopted values, used in the Decision Tree.

Decision level	Parameter	Adopted value
Level 1	Number of years over which the past trend of CPUE-*Prime* is calculated, N_{TREND}	5 years
	Number of years over which the slope to CPUE-*Target* is calculated, N_{TARGET}	5 years
	Feedback gain factor, β	1
	Target value for CPUE-*Prime*	48%Bo
Level 2	Bound on the percentage annual change in CPUE-*Prime* to define stability in this indicator (Note: change is relative to the mean value of CPUE-*Prime* over the previous N_P years)	5% per year
	Number of years mean CPUE-*Prime* is calculated over, N_P	5 years
Level 3	$SPR_{40\%}$ reference value for CPUE-*Old*	60% V_o
	$SPR_{40\%}$ reference value for Proportion-*Old*	20% V_o
Level 4	Value of CPUE-*Recruits* to define high recruitment	>70% V_o
	Decrease in the percentage annual change in CPUE-*Recruits* to define declining recruitment (Note: change is relative to the mean value of CPUE-*Recruits* over the previous N_R years)	>10% per year
	Number of years mean CPUE-*Recruits* is calculated over, N_R	5 years
	Multiplier for reducing TAC, δ	0.95

*Vo = Virgin level, taken as the mean of the related indicator over the years 1997-2001.

Summary of key parameters

Application of each of the decision rules used in the above Decision Tree is contingent on target values against which the corresponding indicators can be assessed and other parameters in the rules to adjust the RBC. A listing of all the parameters used in each level of the Decision Tree, together with the associated value used in its implementation, is given in Table 1. These values are based on initial simulation studies (Davies et al. 2007, Prince et al. 2011) and a data-conditioned evaluation of the harvest strategy across all five target species using age-structured, spatially disaggregated (two regions) operating models iterated on a quarterly time-step (Kolody et al. 2010). Most of the biological parameters required for the operational models were generally derived from those used in the most recent WCPFC stock assessments, while the evaluations of the harvest strategy were made across an extensive range of the key parameter values and future effort scenarios, for both the ETBF and non-ETBF fisheries, projected over the period from 2009 to 2030.

Application of a CPUE smoother

Initial testing and application of the primary control rule indicated that the TAC multiplier *M* can be sensitive to the time period N_{TREND} chosen for the CPUE slope analysis (Campbell 2012a). An example is shown in Fig. 5, where the primary control rule is applied to the data used in the 2011 assessment for yellowfin tuna with N_{TREND} set to either (a) 5 years or (b) 7 years. The sensitivity is, to a large extent, due to the degree of interannual variation in the CPUE time series. However, whether the degree of variability in this index truly reflects annual changes in the abundance or is due to uncertainties inherent in calculating the abundance index remains uncertain. The issue is basically a signal-to-noise ratio problem, with the trend in the abundance of a species being obscured to some extent by shorter-term trends due to the imprecision in which the CPUE is measured and standardized and its natural variability. A method is required to dampen the "noise" so that the "signal" is more dominant.

To assist in this endeavor several approaches for smoothing the CPUE index were investigated:

(1) Moving average (MA):
$$MA_t = \frac{w_t C_t + w_{t-1} C_{t-1} + w_{t-2} C_{t-2}}{w_t + w_{t-1} + w_{t-2}} \quad (4)$$

where C_t is the CPUE in year *t* and for the example shown the following weights were adopted $(w_t, w_{t-1}, w_{t-2}) = (5, 3, 1)$ to preference catches is more recent years.

(2) Exponential moving average (*EMA*): This smoother is structured around a single weight parameter and is defined by the recursive series:

$$EMA_1 = (C_1 + C_2)/2 \quad for\ t = 1 \quad (5a)$$

$$EMA_t = \beta . C_t + (1-\beta) . EMA_{t-1} \quad for\ t > 1 \quad (5b)$$

The values of β adopted for each species were YFT = 0.384, BET = 0.433, ALB = 0.429, SWO = 0.640, STM = 0.562 (Campbell 2012b).

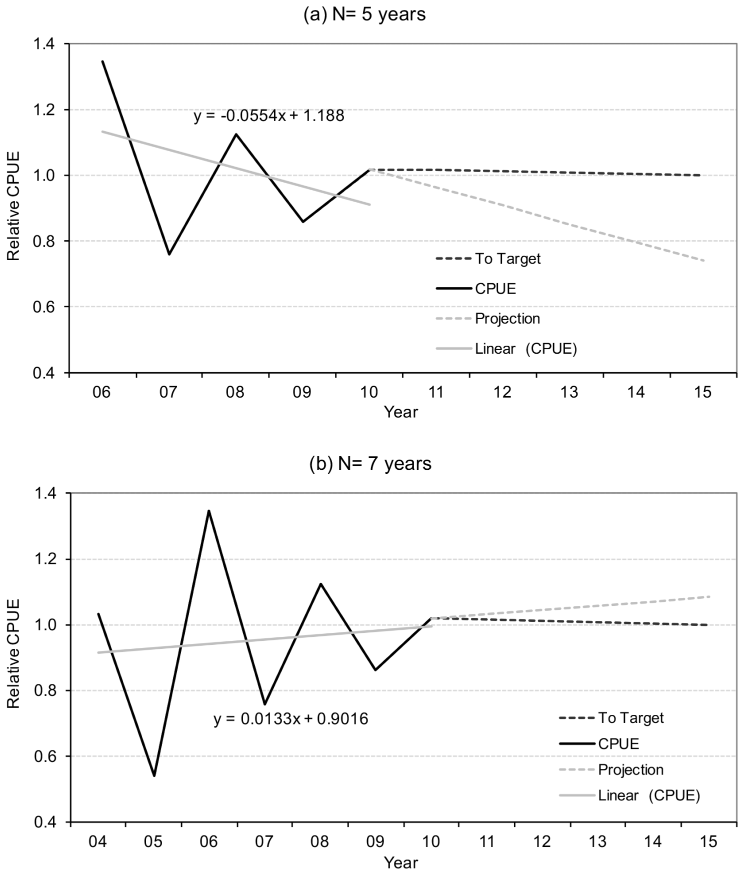

Figure 5. Application of the primary control rule to yellowfin tuna with data used in the 2011 assessment with N_{TREND} set to either (a) 5 years or (b) 7 years.

(3) State-space filter (SSF): It was assumed that the CPUE in any year is a function of the CPUE in the previous year and the catches removed from the population during that year, i.e., if y_t is the "true" log-scale prime CPUE then:

$$y_{t+1} = y_t + f(y_t, logCatch_t, \theta) \tag{6}$$

where θ are filter parameters (Hillary et at. 2012).

(4) LOESS: This well-known smoother fits simple weighted polynomial regressions to localized subsets of the data to build up a function that describes the deterministic part of the variation in the data, point by point. The algorithm described by Peltier (2009) was used with the number of points for the moving regression taken to be 6.

For YFT and SWO, chosen for their different life histories, a comparison of the four smoothed CPUE series with the original standardized CPUE series is shown in Fig. 6a while a comparison of the corresponding TAC multiplier *M* based on a retrospective analysis for all assessment years between 2002 and 2011 is shown in Fig. 6b. For YFT each smoother is found to greatly reduce the high level of inter-annual variability in the standardized CPUE and consequently in the corresponding values of the *M*. For SWO the differences are smaller due to the already smooth nature of the standardized CPUE. The values of *M* based on the SSF smoother for SWO, however, display a distinct difference suggesting that the process equation used may be overly simplistic resulting in too much of the signal being removed.

In order to provide some quantitative measure of the performance of each smoother the following two measures of utility were used:

$$U1 = \sum_{t=1}^{N} abs(S_t - C_t) \tag{7a}$$

$$U2 = \sum_{t=3}^{N} abs(S_t - 2.S_{t-1} + S_{t-2}) \tag{7b}$$

where S_t is the smoothed CPUE in year *t*, *U1* is a measure of difference from the original standardized CPUE index C_t, and *U2* is a measure of "smoothness" between years. The values of both measures for each smoother over the years 1997-2010 for all five target species is shown in Fig. 7. The utility of each smoother compared to the original standardized CPUE is clearly seen. Summed over all species, the value of *U1* is similar (approximately 10) for the MA and EMA smoothers and slightly higher for the SSF (14.5) compared to the LOESS (13.5). On the other hand, the summed value of *U2* for the MA and EMA smoothers (13.1 and 10.5 respectively) are appreciably higher than the SSF and LOESS smoothers (2.70 and 2.67 respectively). Finally, to ascertain the performance of each smoother in relation to the resulting TAC multiplier the

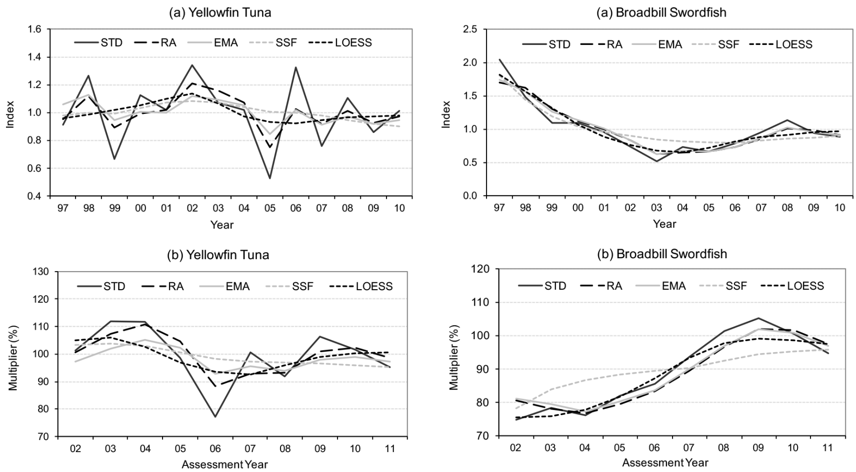

Figure 6. (a) Comparison of the four smoothed CPUE series with the original standardized CPUE series, and (b) resulting TAC multiplier resulting from using the alternative smoothed CPUE series in the primary control rule of the harvest strategy. Results are shown for both yellowfin tuna and broadbill swordfish.

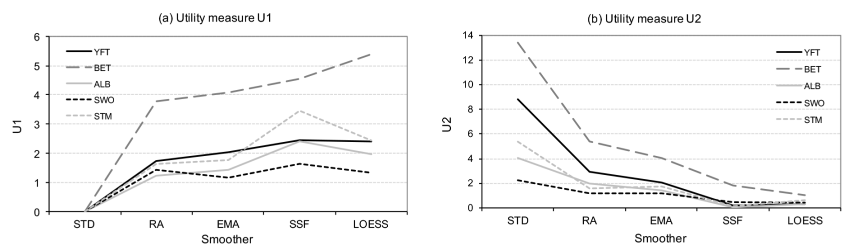

Figure 7. Two measures of utility applied to the standardized CPUE series (STD) and each of the four smoothed CPUE time-series for each of the five target species in the Eastern Tuna and Billfish Fishery.

range and mean of the absolute annual change in *M* between adjacent years and the range and mean "smoothness" were determined and are shown for YFT and SWO in Fig. 8. Compared to the value of *M* based on the original standardized CPUE the utility of each smoother is clearly seen for YFT, though for SWO, as noted previously, the utility is smaller. Ignoring the SSF smoother, the utility in decreasing the absolute change in *M* between adjacent years is greatest for the LOESS smoother and this approach was adopted.

Application to the ETBF

To illustrate the Decision Tree–based harvest strategy for adjusting the annual TAC we applied the methodology to SWO in the ETBF. The time series of effort, catch, and performance indicators (CPUE-*Prime* and catch-proportions by size) for SWO from 1997 to 2012 are shown in Fig. 9 and Table 2.

CPUE standardization

Catch rates were standardized using a general linear model which was fitted to the data for each longline set. To obtain catch rates pertaining to each size class the SWO catch rate for each set was first multiplied by the proportion of SWO retained within each size class using the processed weight data recorded by processors receiving the fish at the end of each trip. To identify appropriate cutoff weights for the three size classes the histogram of the 342,634 SWO weights collected from the fishery between July 1997 and December 2012 (representing about 80% of all SWO landed during this period) was used. *Recruits* and *Old* fish were defined to be those within the lower 25th and upper 25th percentile of the overall weight distribution respectively. This gave cutoff processed weights of 20 kg and 68 kg respectively. Based on life-history relationships for SWO these cutoff weights indicated that the *Recruit* size class consisted mainly of immature fish (<3% mature) while the *Old* size class consisted of 100% mature fish (DeMartini et al. 2000, Young and Drake 2004, Young et al. 2008).

Due to the inflated number of zero catch observations (enhanced due to apportioning the catch into size classes) it was considered best practice to standardize the CPUE data as a two stage delta-GLM process: one stage being concerned with the pattern of occurrence of positive catches, and the other stage with the mean size of the positive catch rates (Campbell 2004). Both the probability of a positive catch and the size of a positive catch rate were modeled as linear combinations of seventeen factors, including year, quarter, and area effects (plus interactions), six fishing-gear effects, six environmental effects, and two that account for cooperative or competitive effects between vessels. The models were fitted to the data for 124,790 sets covering the period

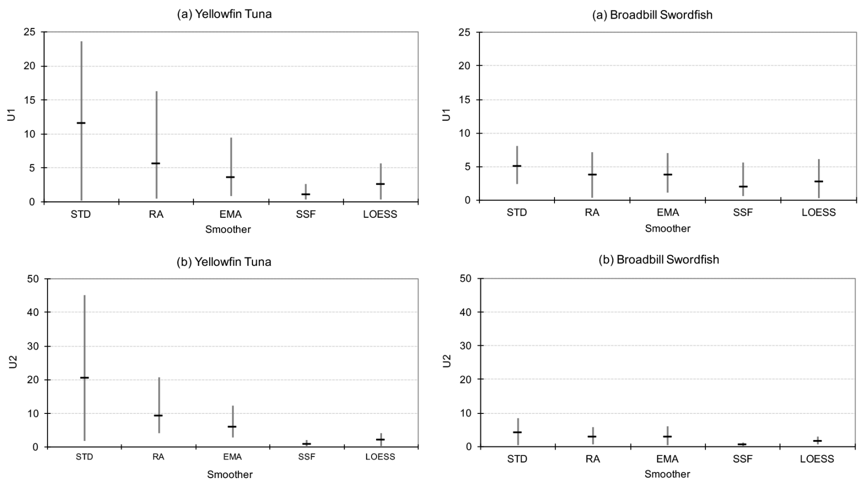

Figure 8. Two measures of utility applied to the TAC multiplier, *M*, based on the standardized CPUE series (STD) and each of the four smoothed CPUE time series: (a) the range and mean of the absolute annual change in the multiplier between adjacent years, (b) the range and mean of the smoothness between assessment years. Results are shown for both yellowfin tuna and broadbill swordfish.

from July 1997 to December 2012. A full description of the data, the models, and factors used to standardize the catch rates is provided in Campbell (2013b).

Identification of target CPUE

The target CPUE value was initially based on the historical time series of catch rates in the fishery and the identification of a reference period (1997-2001) during which the mean catch rate was seen by the industry as an economically desirable target (Davies et al. 2007, Prince et al. 2011). However, after a stock assessment for SWO within the southern WCPO was recently completed (Davies et al. 2013) it was used to identify a target CPUE which was more consistent with the Policy. First, the level of depletion (*%Bo*) of the stock during the reference period was identified from the reference model used in the stock assessment and related to the standardized CPUE of prime-sized fish in the ETBF. Using the means of $CPUE_{ref}$ and $\%Bo_{ref}$ over the reference period the catch rate corresponding to the MEY proxy of 48%*Bo* was then calculated as follows:

$$CPUE_{48\%Bo} = \frac{48\%Bo}{\%Bo_{ref}} * CPUE_{ref} \qquad (8)$$

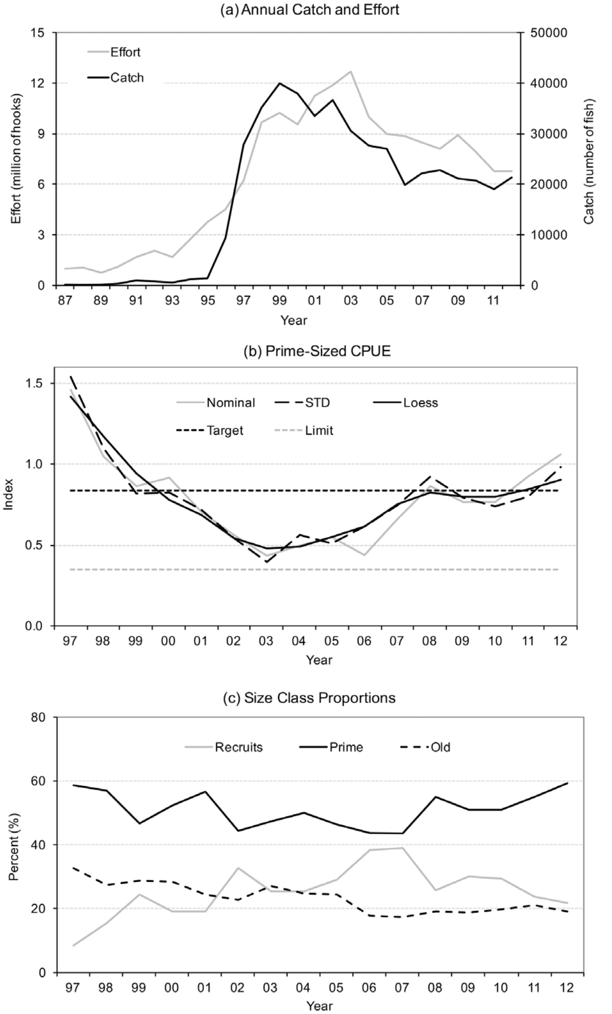

Figure 9. Time series of (a) effort and broadbill swordfish catch in the ETBF, (b) nominal, standardized and LOESS smoothed CPUE of prime sized swordfish, and (c) the proportion of recruits, prime, and old fish in the total swordfish catch. The CPUE indices have been rescaled such that the mean over the first five years is equal to 1.

Table 2. Fishery statistics, and performance indicators, for broadbill swordfish caught in the Eastern Tuna and Billfish Fishery required as input to the Decision Tree. The CPUE indices for each size class have been rescaled such that the mean over the first five years is equal to 1. Note: Effort is in millions of hooks and catch is in number of fish.

			Performance Indicators					
			Relative CPUE Index			Catch Proportion by Size (%)		
Year	Effort	Catch	Recruits	Prime	Old	Recruits	Prime	Old
1997	6.20	27,926	1.00	1.42	1.52	8.5	58.8	32.7
1998	9.68	35,261	1.01	1.17	1.23	15.6	57.1	27.3
1999	10.23	39,952	1.01	0.94	0.94	24.4	46.8	28.9
2000	9.52	37,836	0.99	0.78	0.73	19.1	52.5	28.3
2001	11.27	33,516	1.00	0.69	0.57	19.2	56.5	24.3
2002	11.89	36,738	1.03	0.54	0.45	32.8	44.5	22.8
2003	12.69	30,484	1.04	0.48	0.40	25.5	47.5	27.0
2004	10.01	27,670	1.02	0.49	0.39	25.3	49.9	24.8
2005	8.97	27,043	1.26	0.55	0.42	29.1	46.4	24.5
2006	8.85	19,887	1.60	0.62	0.47	38.4	43.7	17.9
2007	8.45	22,254	1.70	0.75	0.54	39.0	43.6	17.4
2008	8.10	22,870	1.55	0.82	0.57	25.8	55.0	19.2
2009	8.90	21,147	1.42	0.80	0.56	30.2	51.0	18.8
2010	7.89	20,750	1.39	0.80	0.59	29.3	51.0	19.7
2011	6.78	19,000	1.34	0.85	0.65	23.7	55.1	21.2
2012	6.77	21,367	1.27	0.90	0.71	21.7	59.3	19.0
Mean over 1st five years			1.00	1.00	1.00	17.36	54.34	28.30

and identified as the target CPUE. Consistent with the harvest strategy Policy a corresponding CPUE ($CPUE_{20\%Bo}$ corresponding to 20%*Bo*) was also determined and recommended as an appropriate limit CPUE: The annual values of the CPUE-*Prime* indicator together with the recommended target and limit reference values are shown in Fig. 9b.

Application of Decision Tree

The first step in applying the harvest strategy is the primary determination of the RBC based on calculating the slope of CPUE-*Prime* over the previous five years relative to the slope required to achieve the target CPUE over the next five years. This initial assessment is shown in Fig. 10a. The value of the Slope-to-Target is 0.0387. As there is an upward trend in CPUE-*Prime*, and the current values of CPUE-*Prime* is higher than the target CPUE, application of the primary control rule sets the RBC to 103.9% of the TAC in the previous year as shown in Table 3.

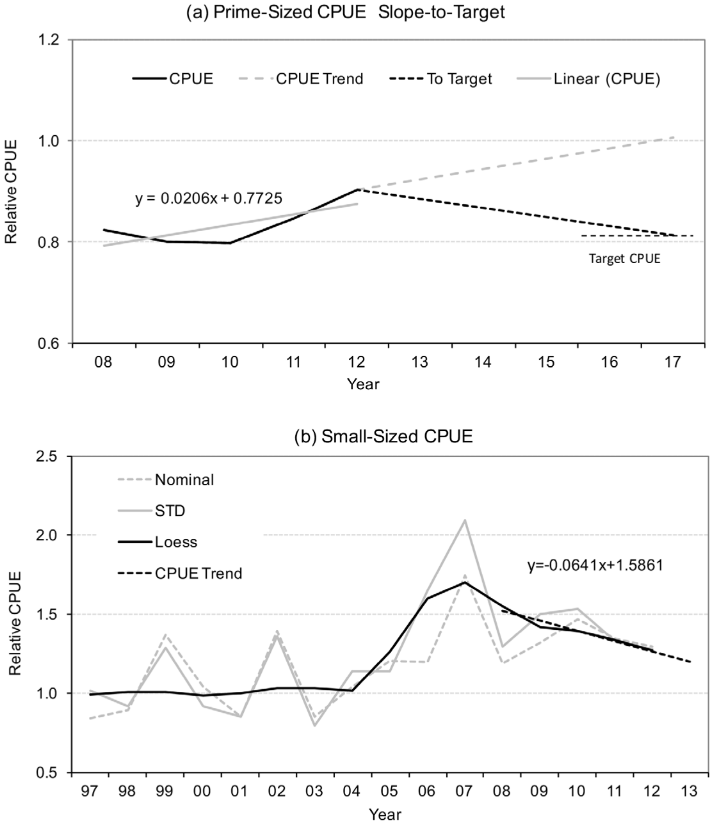

Figure 10. Graphical representation of (a) the derivation of the slope-to-target parameter in the primary control rule, and (b) the time-series of CPUE-Recruits and the slope over the previous five years used in level 4 of the Decision Tree.

The next level determines which of the three columns in the Decision Tree is applicable for making a possible adjustment to the RBC found at level 1. As the annual change in CPUE-*Prime* (relative to the average value of CPUE-*Prime* over the five assessment years) is found to be 2.5% the decision rule indicates that the CPUE be classified as "Stable" as this change is less than the 5% reference value.

At the third level, the values of the two indicators CPUE-*Old* and Proportion-*Old* are compared against their corresponding reference values. The former (0.71) is above its reference value while the latter (19%) is below thereby dictating that option B in the Decision Tree is applicable. Combining the results of the level 2 and level 3 assessments

Table 3. Assessment outcomes and recommended biological catch based on the application of the Decision Tree to the broadbill swordfish performance indicators at the end of the 2012 fishing season.

Decision-Tree		Indicator Value	Indicator Status	Outcome RBC
Start				100% TAC_t
Level 1	Slope-to-Target	0.039	Increase	103.9% TAC_t
Level 2	Relative Prime CPUE Slope	2.5%	Stable	
Level 3	Old CPUE Status	0.71	Above	
	Old Proportion Status	19.0	Below	
	Option		B	
Level 4	Is recruitment high?	1.27	Yes	
	Is recruitment declining?	-6.4%	No	
	Multipier	0.95	Decrease	98.7% TAC_t

dictates that the "Stable-B" option in the Decision Tree is chosen for any further adjustment of the RBC.

At this final stage, the Decision Tree option chosen requests an assessment of the status of CPUE-*Recruits* (Fig. 10b). As there is a decline in this indicator, which may indicate an apparent decline in SWO recruitment over the last five years, the RBC is adjusted by a single application of the reduction factor of 0.95 reducing the RBC to 98.7% of the TAC in the previous year. This RBC is then conveyed to the managers of the ETBF for determination of a final TAC.

Discussion

Data- or information-poor fisheries lack the capacity required for applying standard assessment techniques placing serious constraints on the type and number of indicators that can usually be collected and used for management (Caddy 2010). There is a need, therefore, to re-evaluate the reliance on traditional stock assessment models and re-assess the utility of simpler procedures that make greater use of empirical indicators collected directly from the fishery. Over the past decade considerable effort has been directed toward this need and a variety of alternative harvest control rules based on empirical indicators have been developed (see Carruthers et al. 2014 for review). The Decision Tree approach described here continues this development extending the use of the "traffic-light" approach advocated by Caddy (1998, 2002).

Strengths and weaknesses of approach

While the harvest strategy outlined here has only recently been implemented in the ETBF, a fully data-conditioned harvest strategy evaluation of an earlier version of the strategy (i.e., minus the CPUE smoother and including the original CPUE target) across all main target species indicated that the logic of the Decision Tree was sound and affirmed the overall utility of the approach (Kolody et al. 2010, Prince et al. 2011). A number of alternative versions of the harvest strategy were evaluated, including options for the number of years (3, 5, or 8) over which the CPUE slope in the primary control rule is calculated, the feedback gain factor (0.01-1.0), and the use of TAC change constraints. Due to the confounded interactions of some control parameters, similar and sufficient performance could be achieved in different ways. The Decision Tree was shown to make the performance more conservative on average, but it was not clear that the performance was appreciably different from what resulted when the lower levels were removed and the primary control set to be slightly more conservative. Results also indicated that if the resources in the ETBF are well mixed with those across the broader WCPO then unilateral action by Australia may not have much conservation effect on the stock, and could cause economic impacts on the ETBF. In light of this result, and due to the small proportional size of the catches of tunas in the ETBF in comparison to those taken by other fleets, and the inability to modulate the majority of the fishing mortality according to the outcomes of the harvest strategy, implementation of the harvest strategy is presently limited to the two target billfish species.

The development of any robust harvest strategy and the quality of the resulting management measures based on the outputs of the applied decision rules are dependent on the quality of the performance indicators and reference points upon which these rules are built. In this regard, the present harvest strategy is seen as having a number of strengths and weaknesses. The effectiveness of the approach is also likely to be predicated on the quality of the population dynamics assumptions upon which the decision rules are parameterized and evaluated.

Identified strengths of the harvest strategy include the following:

- The decision framework is target driven, i.e., it is designed to keep you where you want to be.
- The Decision Tree extracts information about the population dynamics of the resource under management, albeit in a somewhat simplified manner.
- Assuming stable selectivity and growth patterns, the incorporation of size-based indicators provides additional information that

is not apparent from simple CPUE trends and makes the decision framework more robust to potential biases in CPUE.

- It should be robust to uncertainty about linkages between regional and broader WCPO stocks, i.e., it should respond to declines and increases in regional stock status, regardless of whether they are generated by domestic or international fleets.
- The strategy is applicable to all target species and so provides a consistent framework for integrating multispecies considerations.
- Within the ETBF the strategy framework should be cost neutral by utilizing current monitoring and assessment processes.
- The general approach is seen as being widely applicable and relatively easy to implement with minimal technical expertise and especially suited to data-poor fisheries.

A further strength is that the performance indicators and associated decision rules are mainly based on simple empirically derived quantities which, unlike model-based indicators, are readily observed and understood by industry members. As such, the inherent relationship between these quantities and the decision rules makes changes in either easier to be understood and reconciled and has facilitated a greater acceptance of the strategy and its implementation by industry (B. Jefferies, Australian Tuna Boat Owners Association, pers. comm.). This is unlike the situation where performance indicators are based on complex models which to many stakeholders are not well understood and without clear explanation can lead to a sense of distrust between parties and a failure to agree upon and implement the associated harvest strategy.

On the other hand, the simple empirical nature of the performance indicators used in the decision rules can also be seen as a weakness of the present strategy, as they lack the theoretical rigor associated with quantitative model-based approaches. While standardized catch rates have long been used as proxy indicators of underlying resource abundance, it is also understood that the relationship between these two quantities is complex and not fully understood. Furthermore, the data are often lacking to more fully account for all the differences in gear types and targeting practices that can influence catch rates. This is especially pertinent in multispecies fisheries, such as the ETBF, where vessels can switch target species depending on both resource availability and market conditions. On the other hand, more complex models also rely on the analysis of these same confounded indices and may be biased by the same influences, as no analytical approach can overcome the inherent problems in fundamentally flawed or noisy data. More complex models may assimilate a wider range of information pertinent to the fishery with the aim of balancing the shortcoming of any single bit of information. In the same way the harvest strategy adopted here assimilates additional information on trends in the proportions and catch rates of small, prime, and large fish within the Decision Tree framework with the aim of balancing a range of potentially confounded indices.

The assumptions about stable selectivity and growth patterns also need to be checked as these are particularly important in the consideration of the size-based indicators. For example, a sequential decline in the CPUE-*Old* indictor may be due to a decline in abundance of this size class or a change in selectivity. While temporal changes in selectivity due to changes in fishing gears and practices can hopefully be captured in the standardization of each CPUE component, the influence of any selectivity changes on the catch proportion indicators would also need to be monitored and adjusted if required. An understanding of selectivity helps provide an understanding of what components of the stock (e.g., juveniles, mature adults) are found within the various size classes and, in turn, help provide a clearer biological interpretation of the Decision Tree. While the percentile cutoffs used above roughly delineated juvenile and adult fish, it may be preferable to start with a biological reasoning from the start. Cope and Punt (2009) further demonstrate the importance of selectivity when inferring meaning from length proportion information.

The determination of appropriate target (and limit reference points if required) can also be problematic. As indicated above, a target reference point was initially based on the historical time series of catch rates in the fishery and the identification of a reference period during which the mean catch rate was seen by the industry as a desirable target. While such an approach can be "informed" it lacks the rigor of modeled based approaches which may help elucidate a target depletion level.

As the limited implementation in the ETBF demonstrates, the utility of this approach is restricted to those fisheries where the main sources of fishing mortality on the resource being managed can be modulated through application of the harvest strategy. If the resources within the ETBF are strongly linked with those across the broader WCPO, then the long-term sustainability of these resources will depend more on the decision made by the Western Central Pacific Fisheries Commission than on the local implementation of this harvest strategy. However, if extended by local adaptation across the entire range of a fishery, rather than a single component within a fishery, the empirical approach presented here has potential to provide a cheaper, scale-less approach to stock management (Prince et al. 2011).

Issues for further consideration

A management strategy evaluation of the existing harvest strategy to take account of the refinements since it was originally designed (i.e., the CPUE smoother and new target reference points) is ongoing and will extend the initial evaluation undertaken by Kolody et al. (2010). The harvest strategy could be extended to take account of other changes observed in the fishery (e.g., spatial contraction or expansion of the fishery) and there are also a number of meta-rules that could be added. For example, to avoid small incremental changes, which may be driven to some extent by uncertainties in the indicators, one may adopt a rule where the TAC is only adjusted where the recommended change is greater than some threshold (say 5%). Similarly, the maximum change may be limited (say 10%) to avoid overly large adjustments in a single year. On the other hand, if the fishery is considered to be in an overfished state then one could apply an additional rule where the recommended TAC is linearly decreased based on the limit-to-target reference values adopted for the fishery. This would ensure that the fishery is closed if the indictor values fall below their appropriate limit reference points.

While the harvest strategy as implemented in the ETBF is designed to adjust an annual TAC the same strategy can also be used for adjusting a total allowable effort (TAE) in an effort controlled fishery. However, in this situation the question of how best to combine the species-specific recommended TAEs needs to be considered. It may be appropriate, for example, to only integrate across the recommended species-specific TAEs of those species considered to be the most at risk (for example BET, SWO, and STM) as the resulting TAE would also be applicable to those other species which are perhaps more robust and resilient to higher levels of fishing effort.

In conclusion, the adoption of an appropriate harvest strategy in the ETBF has served a number of purposes. First, if effort and catch levels can be adjusted in an appropriate manner, the risk of not achieving either the conservation and/or economic objectives should be diminished. Second, an appropriate harvest strategy will assist managers to operate with greater confidence and transparency and should eliminate the need for hasty and ad hoc management responses based on unforeseen outcomes. Management actions can be seen as being proactive instead of being reactive to conditions prevailing in the fishery. Third, adoption of a harvest strategy based on the use of simple empirical indicators collected directly from the fishery has facilitated a greater understanding and ready acceptance of the overall management approach and its implementation by all stakeholder groups.

Finally, the harvest strategy approach outlined here fulfills to some extent the prediction made by Hilborn (2003) that traditional model-based stock assessments that produce an annual estimate of stock size (or a distribution) that is then used to determine management actions would cease to be used, arguing that there would be a move toward using management procedures in which regulations are modified using rules based on empirical data or very simple models (Geromont and Butterworth 2015b). The use of complex models would be relegated to the role of testing these management procedures for robustness. Indeed, the process that has been described here and adopted in the ETBF is a step in this direction.

Acknowledgments

The authors wish to thank Peter Ward, Kevin McLoughlin, Andy Bosworth, and Ian Freeman for their contributions to the Harvest Strategy Working Group together with members of the Tropical Tuna Resource Assessment Group for feedback on the development of the harvest strategy. Thanks are also extended to two anonymous reviewers for their useful comments. This work was funded by the Australian Fisheries Management Authority and CSIRO Wealth from Oceans Flagship.

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