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Development of an Empirical-Indicator based Harvest Strategy for the Australian Eastern Tuna and Billfish Fishery

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1. Introduction

In December 2005, the Australian Government launched a new fisheries policy "Securing our Fishing Future" which aims to cease over-fishing and rebuild over-fished fish stocks (Australian Government 2005). Coincident with this policy launch, the Minister for Fisheries Forestry and Conservation issued a Ministerial Direction to the Australian Fisheries Management Authority (AFMA) which included, among other significant initiatives, the requirement for AFMA to develop and implement formal harvest strategies for all Commonwealth fisheries and default decision rules for the harvest strategies to be used in the absence of justifiable alternatives (McDonald 2005). The harvest strategies for individual fisheries were to be developed in a manner consistent with the Harvest Strategy Guidelines, being developed by the Department of Agriculture, Forestry and Fisheries, with the assistance of a multi-agency steering Committee (Australian Government 2007), and in consultation with the Management Advisory Committees and Resource Advisory Groups of individual fisheries.

As no formal harvest strategy framework had yet been adopted within the Eastern Tuna and Billfish Fishery (ETBF), a need was identified to develop some form of feedback decision rule whereby the annual total allowable effort (TAE), which is to be the primary management measure upon implementation of the recently adopted management plan, can be updated based on an assessment of the performance of the fishery.

At the meeting of the ETBF Resource Assessment Group, held in April 2006, a working group was convened in order to review, identify and assess suitable harvest strategies then, based on this assessment, recommend an appropriate harvest strategy for the ETBF. The Harvest Strategy Working Group (HSWG), which met four times during 2006, adopted a harvest strategy based on the use of several derived indicators which are presently being calculated from data collected from the fishery. In this paper we outline the rationale for, and main features of, the adopted harvest strategy and illustrate the approach by applying it retrospectively to the tuna and billfish species targeted in the ETBF.

2. Components of a Harvest Strategy

2.1 Concepts and Definitions

Put simply a harvest strategy is a formal decision making process, defined by rules for setting the harvest level and a set of information and criteria on which the decisions will be based, which is designed to meet the objectives of the fishery over the long-term. The stated objective of the draft Commonwealth Harvest Strategy Policy (hereafter referred to as the Policy, Australian Government 2007) to be achieved through the implementation of harvest strategies is:

> *The sustainable and profitable utilisation of Australia's Commonwealth fisheries in perpetuity through the implementation of harvest strategies that maintain stocks at ecologically sustainable levels and, within this context, maximise the economic returns to the Australian community.*

Furthermore, the Policy defines a harvest strategy as:

> *A harvest strategy sets out the management actions necessary to achieve defined biological and economic objectives in a given fishery. Harvest strategies 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). These rules are referred to as control rules (sometimes also known as harvest control rules or decision rules).*

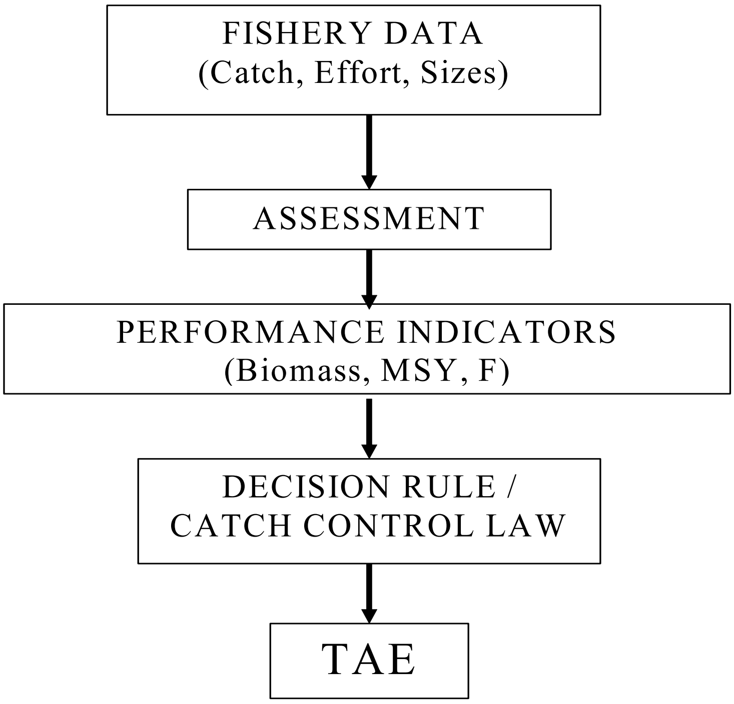
The outputs of the monitoring and assessment process is usually conveyed via a number of performance measures and performance indicators while the outputs of the harvest control rules, by specifying what management actions need to be taken, are designed to keep the fishery on track in pursuit of its defined objectives. 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".

Based on the above definitions, the main steps involved in any harvest strategy are shown schematically in Figure 1. The steps involve:

i) the collection of data from the fishery,
ii) the analysis of this data in a formal assessment process,
iii) the calculation of a range of performance indicators and measures, and
iv) the use of these performance measures within the a decision rule context for identifying a management response (e.g. setting a TAE or TAC).

The decision rule will usually make use of a range of reference points against which the status of the fishery can be assessed. Seen in this way, the harvest strategy reflects a general relationship between the status of the stock and target catch or effort levels, and forms part of the overall management of the fishery. As prescribed by Butterworth et al (1997) these steps should be pre-agreed upon by the all parties involved, typically the management agency and the fishing industry. By using performance indicators and decision rules to link outcomes of regular assessments with future management actions it allows the process to be proactive rather than reactive, and is transparent to all stake holders.

Figure 1. Components of a 'typical' harvest strategy.



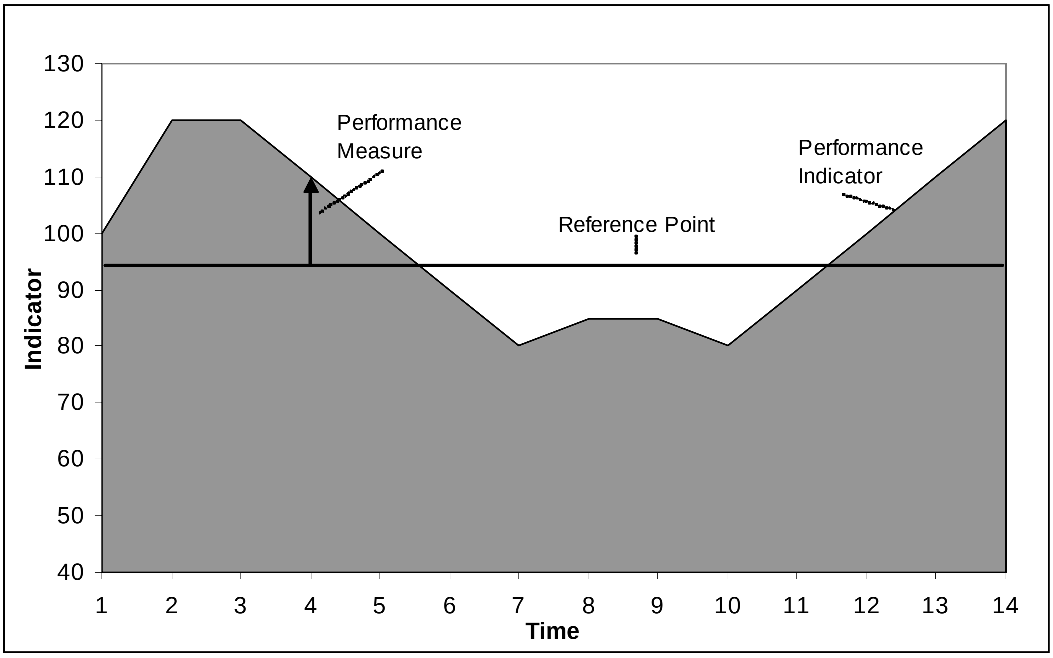
2.2 Performance Indicators, Performance Measures and Reference Points

A performance indicator conveys information about some aspect of the system under study and is usually based on some quantity estimated during the assessment process (e.g. standardised CPUE or the biomass of the exploited fish population). It should be noted that performance indicators are generally useful only if a stock assessment method can estimate them reliably. On the other hand, a performance measure conveys information about how well the system is performing relative to some management objective (e.g. it compares the performance indicator with some reference value or benchmark, say 50% B_o).

Two types of reference points, or benchmarks against which fisheries performance is measured, are commonly referred to: “Target” reference points and “Limit” reference points. Target Reference Points (TRPs) identify desirable conditions at which management should aim while Limit Reference Points (LRPs) identify critical levels which if breeched result in potentially adverse fishery situations.

A schematic representation defining the relationship between a performance indicator, a performance measure and an associated reference point is shown in Figure 2. The performance indicator is shown by the height of the greyed area and is updated each year. An example may be the time-series of standardised catch rates which are often interpreted as an index of biomass of a given stock. The reference point is indicated by the horizontal line, while the value of the associated performance measure is the vertical distance between the indicator and the reference valve. For some years the performance measure is positive, indicating that the system is performing above the set reference point criteria, whilst in other years the performance measure is negative indicating that the system is under-performing.

Figure 2. Schematic representation of the relationship between a performance indicator and associated performance measures and reference point.



Traditionally, TRPs have been considered as indicators of a stock status which are desirable targets for management. It has been assumed that managing a fishery corresponds to adjusting the inputs to, or outputs from, a fishery until the relevant variables correspond to the chosen TRPs. Such management requires active monitoring and continual readjustment of management measures on an appropriate (usually annual) time-scale. On the other hand, LRPs protect the resource and the associated industry against long-term damage, by defining and agreeing on a 'danger' zone where the continued biological or economic viability of the resource is at risk. A LRP may either correspond to some minimum condition (e.g. a low spawning biomass) or some maximum condition (a high rate of decline in stock size, or a high mortality rate) at which a management response is triggered. Integral to the LRP approach is the concept that the fishery as a 'system' will react to the approach of the fishery to an LRP by adopting a pre-negotiated response to unfavourable events. A review of the use of reference points in fisheries management is given in Caddy (1998) and Campbell (2003).

Based on these definitions the objective of the Policy stated above can be expressed more specifically in terms of reference points together with the desired level of confidence we wish to have in achieving them through the harvest strategy. In this regard, the draft Policy includes two operational objectives: Specifically, harvest strategies will:

- *Maintain fish stocks, on average, at a target biomass point (B_{TARG} or proxy) equal or greater than the stock size required to produce maximum economic yield (B_{MEY}). If a stock is below the target, then corrective action must be taken to rebuild biomass to or above B_{TARG}*

- *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). Fish stock may not fall below B_{LIM} with a likelihood of more than 10 % in one generation time.*

3: Rationale of Approach

3.1 Issues relating to Straddling Fish Stocks

The ETBF exploits stocks that are shared across a range of fisheries in the adjacent Pacific Ocean. With the exception of swordfish, the catch taken by the ETBF also represents only a small portion of the total catch taken by all fisheries from each of the respective stocks. For example, in 2005 the catch of yellowfin and bigeye tuna in the ETBF (around 1900 t and 850 t respectively) compares with the total catch of these two species of 435, 468 t and 163,419 t respectively taken in the wider western central Pacific Ocean. The situation for swordfish is somewhat different, with the ETBF catch representing around 50% of the total catch within the southwest Pacific. However, the impact of one fishery on another in each of these situations remains uncertain as the localised residency of fish within any single region and movement rates between regions currently remains highly uncertain. However, interpretations of tagging studies are indicating that there may be only moderate levels of interchange between broad regions (Sibert and Hampton 2002). As such, localised depletions within a single jurisdictional area are possible, and would explain the localised declines in swordfish catch rates observed with the ETBF (Campbell and Hobday 2003).

The Policy states that “the policy applies to fish stocks throughout their range and mortality resulting from all types of fishing.” Given the shared international nature of the ETBF this implies that the development of a harvest strategy for this fishery would need to take into account the status of stocks for the Western Central Pacific Ocean (WCPO) and account for catches (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, the policy could potentially result in Australia unilaterally reducing the catches of certain target species in the ETBF in response to WCPO wide assessments that indicate depletion below the default reference points identified, which is largely the result of catches by other nations, even though the regional components of these stocks, which are harvested by Australian fisheries, are being harvested at a sustainable level.

The use of MSY-based reference points in the Policy also presents a number of conceptual and technical difficulties in the case of the straddling and highly migratory stocks targeted in the ETBF. Whilst some of these issues are taken up below, in the case of highly migratory stocks 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 is a “whole stock” concept that has little meaning at a scale of less than an entire reproductive population. Hence, if harvest strategies are developed for a regional scale (for example yellowfin tuna in the Coral Sea), it would be of questionable validity to use reference points based on estimates of B_{MSY} or F_{MSY} from a global assessment in a harvest strategy for a regional component of the overall stock. The HSWG therefore considered that “depletion based” reference points, e.g.

current biomass as a proportion of estimated unfished biomass, or proxies thereof, were more likely to provide a more robust, and therefore more appropriate, basis for target and limit reference points.

Given these issues, it was seen 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.

3.2 Issues relating to Multi-Species Fisheries

The ETBF is a multi-species fishery in that there are a number of species which are targeted and caught. The principal target species for the ETBF are yellowfin tuna, bigeye tuna, albacore tuna, broadbill swordfish and striped marlin. A number of other retained species (e.g. rudderfish, dolphin fish) are considered to be by-product species and contribute to the total commercial value of the catch. While there is a degree of targeting involved, the majority of target species are regularly caught on the same longline shot with each species having substantially different life-history characteristics and productivities. In the context of harvest strategy development and implementation, this raises the issue of which species will drive overall catch and effort levels and the need to consider the potential for discarding of less productive/more conservatively managed species.

The Policy provides some guidelines for the development of harvest strategies for multi-species fisheries. This guidance, however, is limited to the relatively simple case of a single target species and one or more by-product or by-catch species. Additional guidance is therefore required on the application of the policy in this situation of multiple target species. For example, should the B_{TARG} of the most economically valuable species or least productive target species drive the setting of catch levels? Alternatively, should catch levels be set at the level most likely to provide the highest net return from a mix of target species over some specified period, conditional on a 10% risk of reducing any of the target species below B_{LIM}?

In light of these issues the HSWG was directed by the RAG to develop a harvest strategy for the ETBF in a two stage process. In the first stage, and which is covered by this paper, single species harvest strategies have been developed for each of the principal target species in the ETBF whilst in the second stage consideration will be given to integrating these into a single harvest strategy for the fishery.

3.3 Issues relating to MSY or MEY as Reference Points

In addition to the issues raised previously concerning the use of MSY as a reference point across shared fisheries, there are more general issues associated with the use of MSY related reference points. These relate to the stationary production dynamics assumptions (constant stock-recruitment relationship, natural mortality and growth over time) underpinning the concept (which generally do not hold). Even when these assumptions are reasonable, it can still be very difficult to estimate the stock recruitment relationship and natural mortality, which are key factors affecting estimates of MSY, B_{MSY} and F_{MSY}. Experience has shown that even for fisheries with long time-series and significant investments in research these quantities remain poorly resolved. Furthermore, simulation studies have shown that assessment models can generally estimate changes in relative abundance far more reliably than MSY-related reference points. Given this, and the fact that the relevant sections of the Ministerial Direction refer explicitly to depletion based reference points (i.e. the 20/40 harvest strategy), the HSWG adopted the approach where the minimum standards for harvest strategies be expressed in terms of depletion based reference points.

The HSWG also noted that the level of confidence associated with the estimates of stock status, particularly in relation to limit reference points, raises a number of additional issues. First, given the wide distributional range of tuna and billfish and the limited understanding of stock structure and connectivity in our region the levels of uncertainty associated with the stock status for most target species in these fisheries is high. Consequently, the adoption of levels of confidence such that the stocks should not fall below a limit reference points with a given likelihood were likely to have immediate implications for the assessment of the status of these stocks and possibly require restrictions on fishing levels. Secondly, statistical levels of uncertainty are usually associated with the results of particular models, with different models (based on different assumptions) giving different results and different levels of statistical uncertainty. It therefore remains unclear how model uncertainty (as distinct from statistical uncertainty associated with a particular model) is to the incorporated into assessing the level of confidence associated with stock status.

3.4 Model versus Empirical Performance Indicators

As with the use of MSY, the performance indicators and reference points used in the assessment and management of many fisheries are often based on biometric or econometric models of the fishery (e.g. VPAs, MULTIFAN_CL models, etc). 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 or below/above a level that will prevent biologically or economically undesirable events from happening (such as recruitment overfishing).

Estimation of reference points with stock assessment models is, however, a technically challenging problem, and even with considerable quantities of data, it seems to be an inescapable fact that these models are generally sensitive to arbitrary constraining assumptions that are required to make tractable estimators (e.g. 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 the alternative possibilities to the extent possible.

Experience has shown that once the realistic stock assessment uncertainty is admitted into the operating model(s) of an MSE framework, relatively simple models or data-based indicators can provide the basis for effective feedback decision rules that are equivalent to, or better than, decision rules based on complicated integrative assessment models. The complicated integrative models are useful for identifying the alternative possible states of nature that are consistent with the data. However, since a single model is unlikely to adequately represent the true system uncertainty, it is not obvious that a single complicated integrative model should provide a better basis of a feedback decision rule than a data-based decision rule relying on essentially the same data. Provided that the data-based decision rules have the means to extract key signals from the assessment data, they can often be "tuned" to perform very effectively. "Tuning" refers to the adjustment of parameters that control how the decision rule responds to input data. Given that multiple alternative states of nature are usually 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 (assuming that a unique optimality criterion could be identified), 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.

Furthermore, for fisheries such as the ETBF which fish only a proportion of the total spatial distribution of the entire stock(s), it is also not feasible to undertake a "stock assessment" on the local resource unless one has an adequate understanding of the relationship between the availability of the local resource and the abundance of the entire stock. In such cases, one needs to be able to define less-technical reference points but which nevertheless still convey information related to some aspect concerning the condition of the local resource, i.e. they should be based on variables which are themselves related to, or are influenced by, the basic reference variables F and B (Caddy 1998). For example, CPUE is usually taken as an indicator of available population biomass. Often called empirical (or data-based) indicators, examples include:

i) CPUE based Indicators

The quintessential low-cost index for monitoring resource abundance is commercial catch-per-unit-effort. This is based on the assumption that catch rates are proportional to fish abundance (or related in some other quantifiable way), so that changes in catch rates reflect changes in abundance. However, there are many potential problems with commercial CPUE, 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. 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 changes for other reasons as well, including changes to target species, fuel prices and management restrictions. If the coverage is not comprehensive in space and time, assumptions must be made about abundance in times/areas that are not fished. In multi-species fisheries such as the ETBF, the proportion of the total effort targeted at each target species changes over time within and among years and is difficult to determine. Nevertheless, standardisation of catch rates against the factors that influence targeting practices and effort creep can help to overcome these problems.

ii) Size based Indicators

Various changes in the underlying population may be inferred from changes in the size-composition of the catch. Suggested performance indicators include:

a) Mean and upper-95 percentile fish weights in catch – the use of mean size as a reference point may be based on yield-per-recruit analysis or may consider recruitment in relation to the size at first maturity. For example, a target may be to aim for an exploitation rate such that the average 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).
b) Percentage of catch within various size classes
c) Percentage of mature fish in the catch

d) Ratio of mean size in the catch and size at 50% maturity.
Various methods have also been proposed for estimating total mortality from size composition data (e.g. Sparre et al, 1989), but these methods inevitably involve assumptions about fishery selectivity and natural mortality, which are generally poorly known.

iii) Spatially based Indicators

It is assumed that following the start of a fishery, several stages may occur as progress is made from unfished to overfished conditions, and that this transition may be picked up by a simple spatial index of aggregation for i-1,2,3…N unit areas, such as that proposed by Gulland (1955):

$$I_g = [\mathrm{Sum}(C_i) / \mathrm{Sum}(E_i)] / [\mathrm{Sum}(CPUE_i) / N]$$

If this is the case, simple indices of concentration could be used to formulate limit reference points designed to pick up unfavourable changes. The results of simulations might be used to specify situations where CPUE becomes low and uniform or where the area fished contracts in size with over-exploitation.

While the use of empirical indicators may seem to be less rigorous than using integrated assessment models, they also may have the advantage of simplicity. 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 use of empirical indicators will need to be tested both in simulation and in practice in order to detect and overcome possible problems of practical implementation. However, while the empirical based approaches to identifying performance measures and related reference points may lack the theoretical rigour usually associated with the more familiar model-based reference points, initial results indicate the utility of this approach (Hilborn 2002).

4. Outline of Primary Decision Rule

The management framework for the ETBF is presently predicated on setting an annual Total Allowable Effort (TAE). For updating the TAE we adopted a modified version of the empirical approach known as Tier 4 in the Australian South East Scalefish and Shark Fishery (Campbell 2002, Anon, 2005). Based on the Tier 4 approach, in any year changing the TAE involves using the formula:

$$TAE_{t+1} = TAE_t(1 + \beta.S_{CPUE})$$

where β is a control parameter referred to as the feedback gain factor,
and S_{CPUE} is the slope of a linear regression of the CPUE over the last *y* years from *t-y+1* to *t*.

In any year where S_{CPUE} >0 the TAE set in the following year will be greater than the TAE in the year just ended, whilst in any year where S_{CPUE} <0 the TAE set for the following year will be less than the TAE in the year just ended.

Logic indicates that the above harvest strategy will tend to decrease the TAE following years of declining CPUE (indicating a decrease in resource availability possibility due to over-exploitation) and increase the TAE after years of increasing CPUE (indicating an increase in resource availability possibly due to under-exploitation). However, a simple worked example indicates that application of this harvest strategy over the long term will tend to stabilise the TAE around the value it had in the year the rule is first applied (Campbell 2006). It will therefore not allow the stock to rebuild if it is presently overfished nor will it allow a long term increase in *F* if the stock is presently only lightly fished.

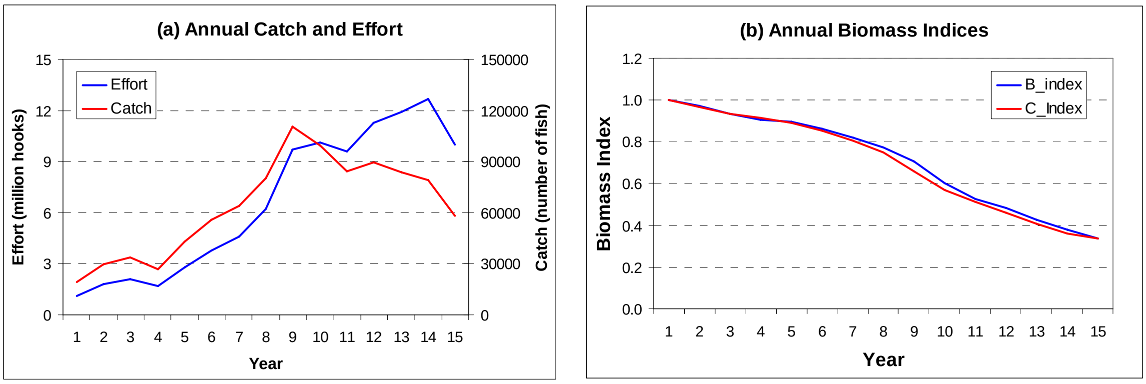
The problem stems from the fact that the change in TAE is premised on the slope of the statistic used (CPUE in this instance) and that this slope takes as its reference point the zero slope which corresponds to the situation where the TAE remains unchanged. When there has been some rebuilding of the stock (corresponding to years of increasing CPUE) then the above rule results in the TAE being increased which just results in fishing the stock down again. Alternatively, when the stock has been declining for several years (corresponding to years of decreasing CPUE) then the above rule results in the TAE being decreased which just results in the stock increasing again. This pattern is repeated over time. Thus even though the TAE may increase and decrease in any year, over the long term the TAE remains, on average, similar to the TAE in the year that the strategy was first applied. In turn, this TAE is based on the present CPUE value.

A solution to this problem is to instead of taking the present CPUE as the reference value, to set a different target value, ideally one based on that which allows the fishery to exploit the resource at some long-term optimum and sustainable level (Campbell 2006). The slope of the CPUE is then based on the angle subtended by the trend line in the CPUE and the line joining the present CPUE value to this target valve which is to be achieved over a nominated number of years. (NB: in the previous rule the slope is based on the angle subtended by the trend line in the CPUE and the horizontal.)

A simple example highlights the above two rules. The example is based on a simple annual biomass production model for a hypothetical stock and fishery and which is initially run for 15 years. The time series of catch and effort is shown in Figure 3a while the corresponding time series of biomass and CPUE shown in Figure 3b. Note, the effort time-series was chosen to mimic that in the ETBF whilst the catch time-series mimics that of the swordfish catch in this fishery. The respective annual indicators of biomass (B_index) and CPUE (C_index) are scaled relative to their initial values.

Based on this example, the biomass has been driven down to less than 40%*Bo* and this is also reflected in the corresponding CPUE indicator. If B_{TARG} = *50%Bo* then the stock is considered to be over-fished. A harvest strategy was then applied at the start of the 16th year based on an initial application of the harvest strategy after the 15th year. The following two alternatives were trialed:

Figure 3. Time series of (a) effort and catch and (b) relative biomass and CPUE in the hypothetical fishery used in the worked example described in the text.



HS-1) Slope to Horizontal – this is the default SESSF Tier 4 rule with the simple slope of the CPUE indicator taken over the previous 5 years.

$$TAE(t+1) = TAE(t)*[1+Slope(CPUE)]$$

HS-2) Slope to Target, $CPUE_{TARG.}$ We take 50% of the initial *CPUE* as the target reference point for rebuilding *CPUE* (and biomass). Again, the slope of the *CPUE* is taken over the previous 5 years and the nominated number of years to reach $CPUE_{TARG}$ is also taken to be 5 years. The situation corresponding to the first application of this rule after the 15th year is shown schematically in Figure 4 (when $CPUE_{TARG}$ is to be achieved in year 20). Having calculated the Slope-to-Target as defined above, the TAE is then adjusted in a similar manner as before:

$$TAE(t+1) = TAE(t)*[1+Slope\text{-}to\text{-}Target(CPUE)]$$

Figure 4. Schematic representation of the different slopes used in the harvest strategies outlined in the text. Harvest Strategy 1 uses the slope from the horizontal of the CPUE over the past 5 years while Harvest Strategy 2 uses the slope for the Target Reference Point (TRP) over the past 5 years.

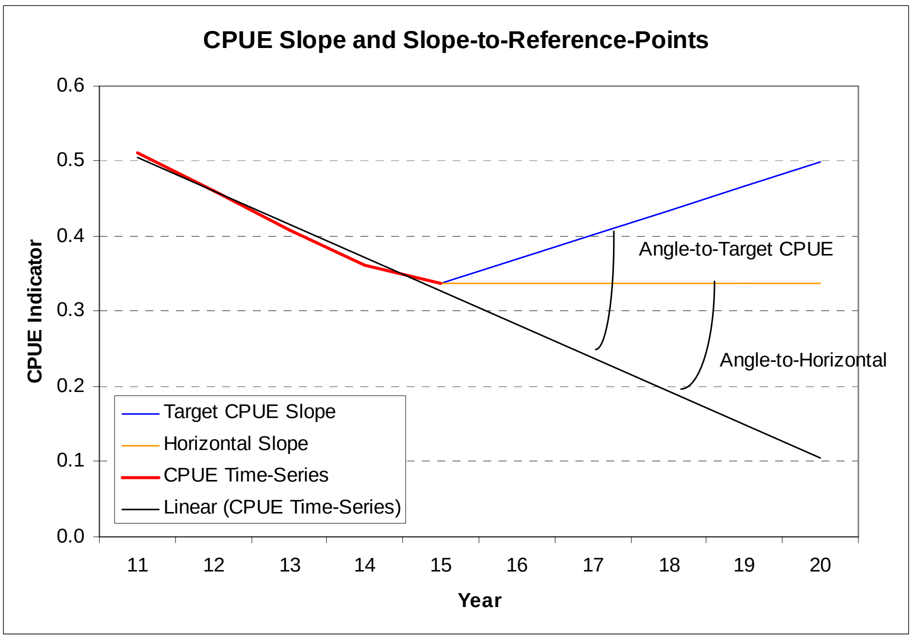
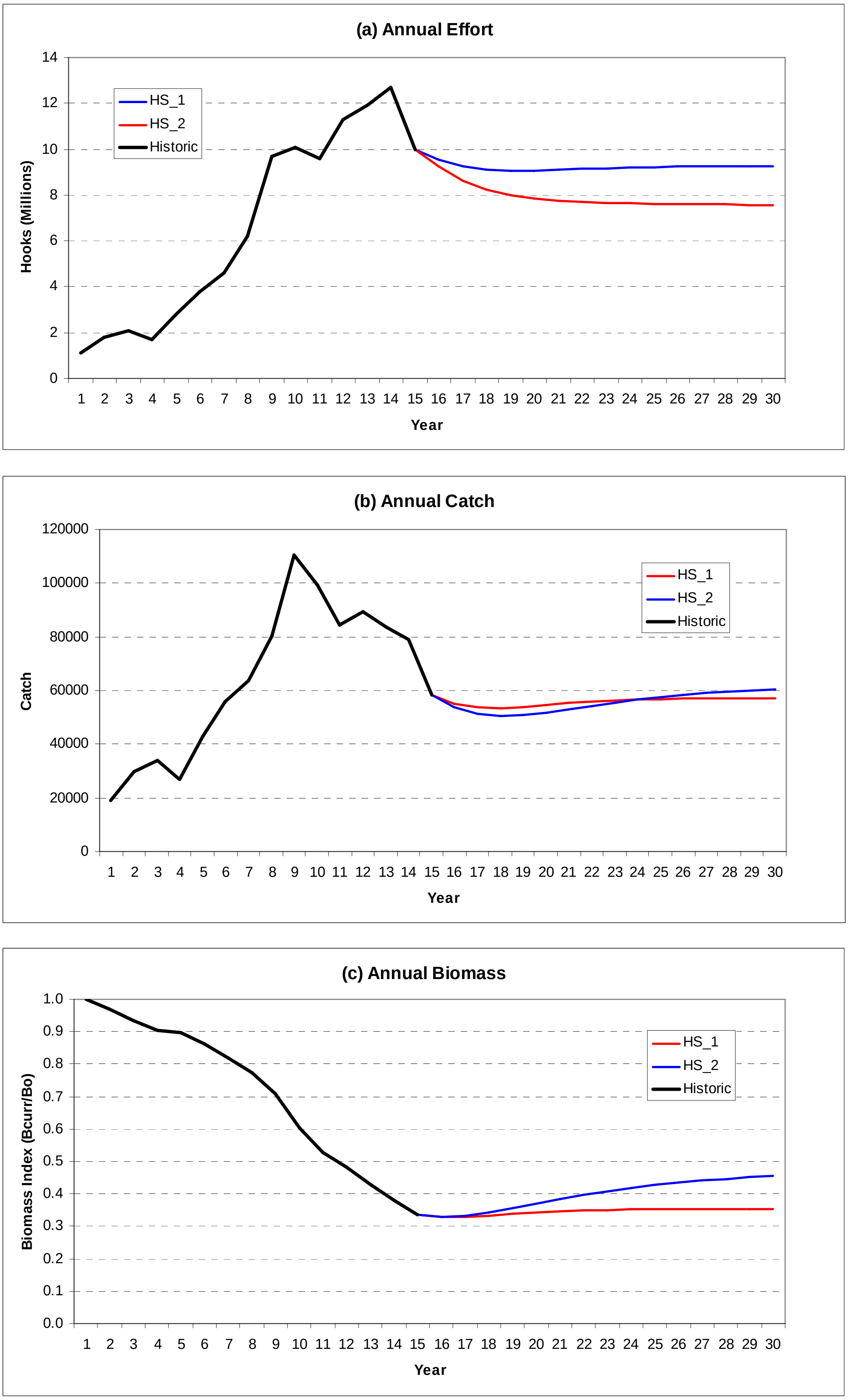


Figure 5. The time-series of (a) effort, (b) catch and (c) biomass (together with their corresponding historical values) under the application of various harvest strategies for years 16-30.



The hypothetical fishery was then projected forward another 15 years under annual effort levels determined by application of each of the above harvest strategy rules at the end of each year. The future time-series of effort, catch and biomass (together with the historical values) are shown in Figures 5a-c respectively. As expected, HS-1 stabilises effort and biomass around the values they had at the end of the historical period whilst HS-2 allows rebuilding of the stock to the defined target reference point. Given that the biomass under HS-1 remains at around 35%Bo, and in what for this example is considered to be an over-fished 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 the HS-2 strategy are also apparent from the above results. Over the fifteen year projection period, the average effort level under HS-2 is 7.9 million hooks compared to 9.1 million hooks under strategy HS-1. On the other hand, the average catches over that period are very similar (and indeed remain higher into the future under strategy HS-2). Hence, the catch-per-effort (or fishing efficiency) is, on average, 16% higher under strategy HS-2 compared to the HS-1. Such an increase in efficiency underpins a much more profitable fishery.

5. Outline of Overall Decision Tree

In the absence of an integrated model-based stock assessment for each of the five principal target species in the ETBF, from which local performance indicators of exploitation (*F*) and biomass levels (*B*) can be inferred, the Harvest Strategy Working Group recommends the use a more qualitative assessment methodology which uses a range of empirical size- and CPUE-based performance indicators to infer biomass levels for different size-classes ("recruitment", "prime-sized" and "old" fish) in the exploited fish populations. These relative biomass 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 TAE in the fishery. The overall "assessment" combines these individual assessments and decision-rules in a staged Decision Tree process with the possible adjustment of the TAE at each stage (c.f. Figure 6). This Decision Tree based assessment is undertaken independently for each species. Once undertaken for each of the principal target species, or other species of interest, the results can be used to infer a recommended TAE for the overall fishery. (Note, a similar process can be used to update a Recommended Biological Catch, RBC, for each species.)

5.1 Underlying Rationale

The use of size data has a long and well established precedence in fisheries assessment and management (Gulland 1969; Hilborn and Walters 1992) and the changes which occur in the size structure of exploited populations are widely recognized and accepted. In general terms, as a stock is increasingly exploited the proportion of large fish in the population steadily declines as older size classes are depleted. Should exploitation become heavy enough to cause recruitment collapse the size structure may then begin to increase in average length, because small fish are no longer entering the stock and what is left of the population increases in age (and size).

Figure 6.

Level 1: Adjust TAE based on status of CPUE-Prime Indicator

TAE(t+1) = *TAE*(t)*[1+β.Slope-to-Target(*CPUE-Prime*)]

Level 2: Assess status of rate of change in CPUE-Prime

RISING | STABLE | FALLING

Level 3: Assess status of Old Fish relative to SPR_{40} Thresholds

A. If *CPUE-Old* above & *Proportion-Old* above
B. If *CPUE-Old* above & *Proportion-Old* below
C: If *CPUE-Old* below & *Proportion-Old* above
D: If *CPUE-Old* below & *Proportion-Old* below

Level 4: Assess status of Recruits (RISING)

A. Stock ↑ or Effort Creep
- Is *CPUE-Recruits* high?
- Yes: No change No: Reduce TAE

B. SPR ↓ (effort creep) and/or Stock ↑
- Is *CPUE-Recruits* high?
- Yes: No change No: Reduce TAE

C. Unusal Transient Dynamics
- No change

D. SPR ↓ (effort creep) or Recruitment ↑
- Is *CPUE-Recruits* high?
- Yes: No change No: Reduce TAE

Level 4: Assess status of Recruits (STABLE)

A. All Stable or Lightly Fished
- No Change

B. SPR ↓ (effort creep)
- Is *CPUE-Recruits* decreasing?
- Yes: 2x Reduce TAE No: Reduce TAE

C. Recruitment ↓ or transition state
- Is *CPUE-Recruits* decreasing?
- Yes: Reduce TAE No: No Change

D. SPR ↓ (effort creep) and/or Recruitment ↓
- Is *CPUE-Recruits* decreasing?
- Yes: 2x Reduce TAE No: Reduce TAE

Level 4: Assess status of Recruits (FALLING)

A. Failing Recruitment?
- Is *CPUE-Recruits* decreasing?
- Yes: 2x Reduce TAE No: Reduce TAE

B. Unusal Transient Dynamics
- 2x Reduce

C. Failing Recruitment?
- Is *CPUE-Recruits* decreasing?
- Yes: 2x Reduce TAE No: Reduce TAE

D. General Stock Decline
- Is *CPUE-Recruits* decreasing?
- Yes: 3x Reduce TAE
- No: 2x Reduce TAE

Age–structured models of population dynamics (e.g. Cohort Analysis, Virtual Population Analysis (VPA)) combine age data (or size as a proxy for age), and relative abundance indices (e.g. CPUE), (potentially along with additional fisheries independent data) to estimate historical abundance of successive year classes as they pass through the fishery.

Froese (2004) has argued that even without sophisticated stock assessment (or perhaps even instead of) fisheries assessment and management can be kept simple by monitoring three simple size based indicators of stock status:

1. Percent of mature fish in the catch with the target of ensuring this is 100%
2. Percent of fish in the catch of optimum length with the target of ensuring this is 100%
3. Percent of 'mega-spawners' in the catch with the target of 0% and 30-40% being representative of a stock in good status if no upper size limit exists.

The Decision Tree developed by the Harvest Strategy Working Group applies these basic and widely accepted principles to qualify the decisions of the primary CPUE based decision rule and so guard against some situations that might otherwise prevent the primary CPUE based decision rule being precautionary.

In effect, the Decision Tree attempts to extract information about the population dynamics in a simplified manner that is analogous to an age-structured model, such that changes in size structure provide additional information that is not apparent from the simple CPUE trend. For example a steady creep in fishing efficiency through gradually improving fishing gear could maintain or increase overall catch rates masking an underlying decline and escalating fishing pressure. The primary CPUE based decision rule by itself would reward the overall catch rate trend by maintaining or possibly even increasing catch levels. However, if the proportion and/or catch rate of the largest fish is declining, the Decision Tree will in most cases over-ride a stable, or increasing catch rate of the prime size classes, and dictate catch decreases. This would be in keeping with the logic of the Cohort Analysis which correlates declining abundance of the largest size classes with increasing fishing pressure and declining stock abundance. So where a catch rates remain stable or increase, but declining abundance of older fish is detected by the Decision Tree the primary CPUE based Decision Rule would be over ridden because increasing fishing power is indicated as the cause of the stable or increasing trend in CPUE.

6.2 Information Used in the Decision Tree

Four types of information are derived from the catch rate and size data for each stock. 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. The size data are somewhat arbitrary divided into small, medium and large fish which in the Decision Tree are respectively termed *Recruits*, *Prime* and *Old*. In fisheries assessment the term recruitment or recruits generally has a specific meaning and is applied to the youngest year class being fished. It should be noted that within the Decision Tree this definition is not being strictly followed, it refers simply to the smallest part of the size distribution, and for each particular species the size class may include several of the youngest age classes, or alternatively just a part of the youngest age class.

The four types of information used are the *Standardized CPUE* of each of the three size classes and the *Proportion of Old* fish.

6.3 Application of the Decision Tree

i) Level 1: Primary Determination of Recommended Biological TAE

As discussed above, the first part of the harvest strategy process is to assess the standardized CPUE of the prime size classes (*CPUE-Prime*) in relation to pre-agreed target CPUE levels and determine the change in effort required to move the present trend in CPUE levels to the target over a given time period. The new Recommended Biological TAE ($RBE_{(t+1)}$) is initially estimated on the basis of the previous RBE(t) multiplied by the slope of the trend line that CPUE would need to follow to get to the Target Level (either up or down) within a pre-agreed time frame (cf. Equation (2) in the previous section.)

The preliminary $RBE_{(t+1)}$ derived from the Primary Decision Rule applied in Level 1 will be modified or affirmed by application of the Decision Tree. The application of the Decision Tree identifies and resolves situations which would remain undetected or ambiguous if *CPUE-Prime* alone were used; stock declines masked by effort creep, recruitment failure, and/or pulses.

The Decision Tree framework has three additional levels. At each level questions are asked about size and 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, and so the next question to be asked about the size and catch rate data.

ii) Second Level of the Decision Tree based on CPUE-Prime

In the second level of the Decision-Tree the question asked is whether *CPUE-Prime* is:

- Rising,
- Stable, or
- Falling.

Stability is assessed on whether or not the annual rate-of-change in *CPUE-Prime* is within a given limit (say x% of the average CPUE over a nominated number of years, say 5) This second assessment level uses the simple trend in *CPUE-Prime* to determine which of the three main limbs of the Decision Tree will be used in each year’s assessment. In the tabular representations of the Decision Tree the three main limbs are represented by the three columns across the bottom half of Figure 7.

iii) Third Level of the Decision Tree based on CPUE Old and Proportion Old

In the third level of the Decision Tree the same four questions are asked about *CPUE-Old* and *Proportion-Old* regardless of the outcome of the previous level of the Decision Tree. Both CPUE and Proportion of these fish are used as their contrast to each other, when it occurs, is highly informative in the assessment process and increases the discriminatory power of the assessment process. Depending on whether *CPUE-Prime* was judged in the first level to be Rising, Stable, or Falling the outcome under each of these answers (A-D) can be quite different.

The four third level questions all take the general form: "If *CPUE Old* is above/below Target Level and *Proportion Old* is above/below Target Level" and the four answers (A-D) cover all four possible true combinations of this generalized question.

The Target Level for both *CPUE-Old* and *Proportion-Old* will be determined using historic data and population modelling so that they correspond to the target level of egg production or Spawning-per-Recruit (SPR) mandated by policy. While the policy paper is still be finalized it is referred to here as SPR_{40}.

Thus the four questions being asked at this second level are:

A. Is the CPUE of Old fish above and Proportion above the reference point of SPR_{40}.
B. Is the CPUE of Old fish above but Proportion below the reference point of SPR_{40}.
C. Is the CPUE of Old fish below but Proportion above the reference point of SPR_{40}.
D. Is the CPUE of Old fish below and Proportion below the reference point of SPR_{40}.

In the tabular form of the Decision Tree shown in Figure 7 this third level of the Decision Tree is represented by the four questions contained in the box that stretches horizontally across the middle of the figure. Depending on the answer to this question (A-D) the assessment proceeds down the limb (Rising, Stable, Falling) of the Decision tree determined at the second level of the Decision Tree, to the matching category (A, B, C or D) in the bottom half of the table.

iv) Fourth Level of Decision Tree based on CPUE-Recruits

In some cases a fourth and final level of assessment is applied using the *CPUE of Recruits*. The idea with this smallest class of fish is that they are sub-optimal for the market, and biologically speaking best kept out of the fishery. However, trends in their rate of by-catch can provide information about recruitment trends to the fishery, both recruitment pulses or recruitment declines can be very informative for the assessment process. 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.

5.4 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 indicator can be assessed or other parameters in the rules to adjust the RBE. A listing of the all parameters used in each level of the Decision-Tree is given in Table 1 together with some suggested values based on initial simulation studies undertaken by the Harvest Strategy Working Group. Target values for indicator variables will ultimately be based on proxy values for target levels to be specified in the Policy whilst appropriate values for the other parameters will be better assessed within the recently commenced CSIRO project "Integrated evaluation of management strategies for multi-species longline fisheries."

Table 1. Listing of the parameters used in the Decision-Tree.

Decision Level	Parameter	Suggested Value
Level 1	Number of years over which the slope of *CPUE-Prime* is calculated Target value for *CPUE Prime* Feedback gain factor	5 years 50% CPUEo TBA*
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 y years – see below) Number of years mean *CPUE-Prime* is calculated over	5% per year 5 years
Level 3	Target value for *CPUE-Old* Target value for *Proportion-Old*	SPR_{40} SPR_{40}
Level 4	Value of *CPUE-Recruits* to define high recruitment Decrease in *CPUE-Recruits* to define declining recruitment Number of years mean *CPUE-Recruits* is calculated over	70% CPUEo 10% per year# 5 years

* To Be Assessed based on simulation studies
\# Change defined in a similar manner as for the Level 1 parameter

6. Example: Retrospective Application to the ETBF

In order to illustrate the above Decision-Tree approach to adjusting the annual TAE within the ETBF, we apply the methodology to the time-series of CPUE and size-based performance indicators for yellowfin tuna and broadbill swordfish covering the nine financial years between 1997/98 and 2005/06. Although the fishery has not been managed by a TAE over this period, for this exercise we apply the harvest strategy after the first five years (i.e. at the end of the 2001/02 season) to ascertain what the recommended TAEs may have been had this management regime actually being applied at that time. This process is repeated for each year up to the last year. (Note, it is important to understand that these examples do not give the actual TAEs which would have been recommended had the harvest strategy been adopted after 2001/02 as the time-series of performance indicators in the fishery would have been different from those actually observed had these TAEs actually been implemented. This is because the annual effort in the fishery since 2001/02 under a TAE may have been different to that actually deployed and consequently the impact on the stock would have been different resulting in different performance indicators).

6.1 Yellowfin Tuna

The time-series of effort, catch and performance indicators (standardised CPUE and catch-proportions by size) for yellowfin tuna in the ETBF for the financial years 1997/98 (9798) to 2005/06 (0506) are shown in Figure 7 and Table 2 (taken from Campbell 2007 and Campbell et al 2007). Note that the relative CPUE index for each size class has been “rescaled” such that the average of the index over the first five years is equal to 1. The mean of the nominal yellowfin CPUE observed for each size-class in the fishery over this period is also shown (giving a total CPUE of 6.05 fish per 1000 hooks across all sets).

Table 2. Fishery statistics and summary performance indicators for yellowfin tuna in the ETBF.

Financial Year	Effort (M. Hooks)	Catch (No. Fish)	Performance Indicators: Relative CPUE Index Recruits	Prime	Old	Catch Proportion by Size (%) Recruits	Prime	Old
9798	7.69	42,343	1.282	0.816	0.740	26.3	53.0	20.7
9899	10.00	69,901	0.936	1.634	1.269	13.9	65.5	20.6
9900	9.99	41,450	0.791	0.554	1.079	24.5	39.1	36.4
0001	10.09	58,807	0.769	1.101	0.738	17.0	63.1	19.8
0102	11.80	75,980	1.222	0.895	1.175	26.3	48.0	25.7
0203	12.71	111,955	2.006	1.469	1.081	22.8	59.3	17.9
0304	11.15	78,018	1.799	0.929	1.018	30.3	51.5	18.2
0405	9.41	65,012	1.563	1.098	1.002	27.5	53.8	18.7
0506	8.55	51,948	1.949	0.696	1.045	35.9	41.1	23.0
0607								

	Mean CPUE 1st Five Years			Mean CPUE 1st Five Years		
Scaled Index	1.000	1.000	1.000	21.6	53.7	24.6
Nominal CPUE	1.14	3.38	1.53			

Parameter Values

For this example, the target CPUE adopted is to maintain the CPUE of prime-sized fish at the average of that observed in the fishery during the first five years (i.e. between 1997/98 and 2001/02). Hence *CPUE-Prime*(target)=1.0. Also, as the SPR_{40} values remain unknown, the following proxies for the two Level 2 parameters were used:

Average of *CPUE-Old* over the first 5 years = 1.0

Proportion-Old = 20%

Finally, as a nominal value of *CPUE-Recruits* for an unfished fishery is also unknown, we used the following proxy:

Average of *CPUE-Recruits* over the first 5 years = 1.0

The value of the other parameters is as given in Table 1, whilst sensitivity tests indicated a value of 1.0 for the feedback gain factor, β.

Level 1 - Primary Determination of the RBE

The first step in applying the harvest strategy is to the primary determination of the RBE. This is 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 pictorially in Figure 8a. Based on the values of *CPUE-Prime* in Table 2, the value of the Slope-to-Target is -0.0583. As there is a downward trend in *CPUE-Prime*, and the current values of *CPUE-Prime* is less than CPUE-Target, the initial application of the decision-rule (where we have set the parameter β=1) adjusts the effort level in 2001/02 of 11.8 million hooks down to 11.1 million hooks. The result is shown in Table 3.

Figure 7. Time-series of (a) effort and yellowfin catch in the ETBF, (b) standardised CPUE of recruits, prime and old yellowfin, and (c) proportion of recruits, prime and old yellowfin in the total yellowfin catch.

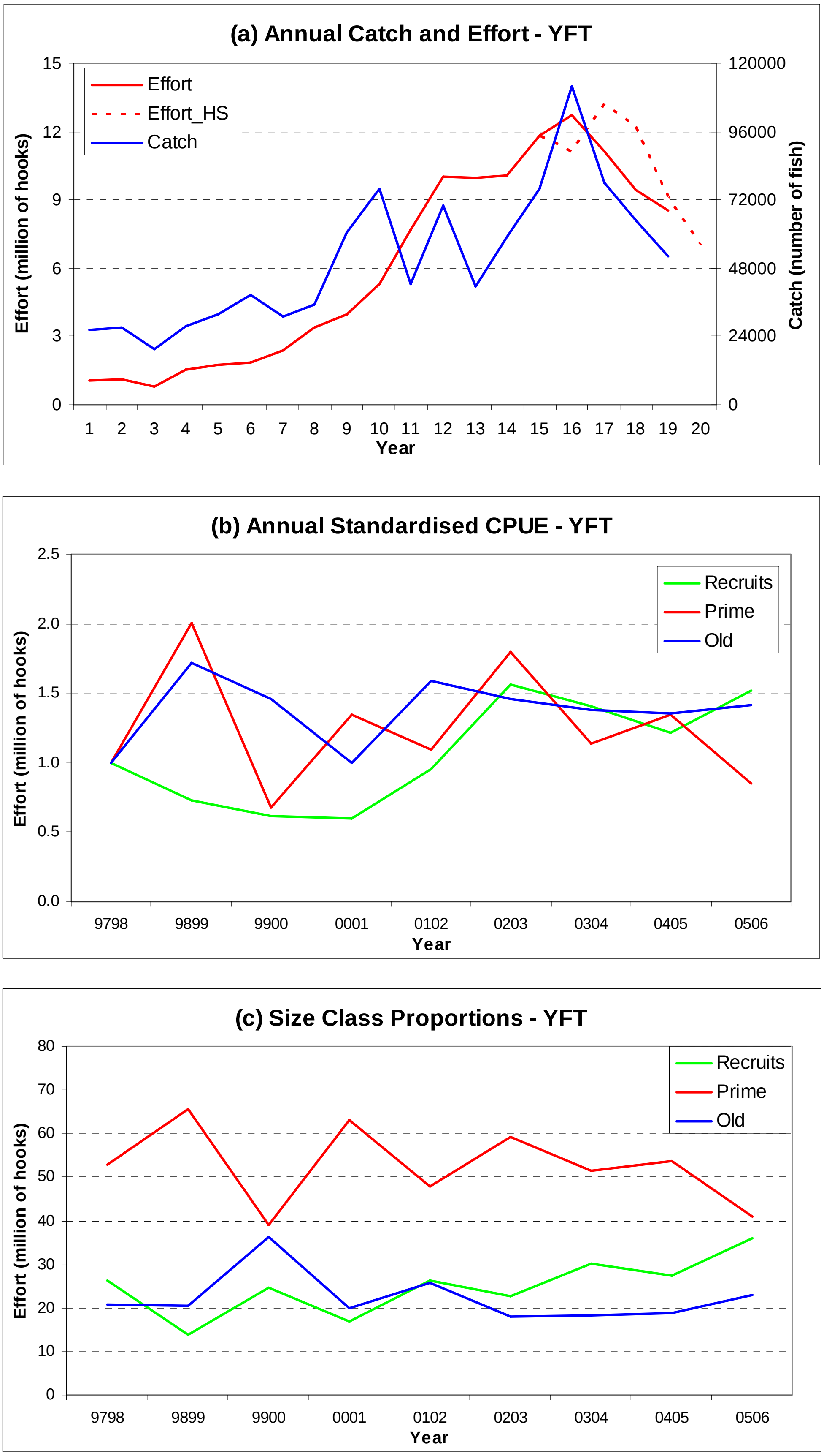


Table 3. Listing of assessment outcomes and recommended TAEs based on a retrospective application of the decision-tree to the time-series of yellowfin tuna performance indicators in the ETBF.

	Assessment Year				
Decision-Tree	0102	0203	0304	0405	0506
Effort in Previous Year	11.8	12.7	11.2	9.4	8.6
Level 1					
Slope-to-Target	-0.0583	0.0949	0.0973	0.0221	-0.1383
Recommended TAE	11.1	13.9	12.2	9.6	7.4
Level 2					
Relative Prime CPUE Slope	-3.7%	0.1%	11.3%	0.2%	-7.6%
Prime CPUE Slope Status	Stable	Stable	Rising	Stable	Falling
Level 3					
Old CPUE Status	Above	Above	Above	Above	Above
Old Proportion Status	Above	Below	Below	Below	Above
Option	A	B	B	B	A
Level 4					
Is recruitment high?	Yes	Yes	Yes	Yes	Yes
Is recruitment declining?	No	No	No	No	No
TAE multiple	1	0.95	1	0.95	0.95
Recommended TAE	11.1	13.2	12.2	9.1	7.0

Level 2 Assessment

The next step is to assess (based on the assessment of additional performance indicators) which of the three columns in the decision-tree is applicable for making a possible adjustment to the recommended TAE found at Level 1. The outcomes of this assessment process are shown in Table 3. In the initial assessment year, the change in *CPUE-Prime* (relative to the average value of *CPUE-Prime* over the 5 assessment years) is found to be -3.7%. Hence first decision-rule in this step indicates that the CPUE be classified as "Stable" (as the absolute value of this change is within the 5% change defined for this situation).

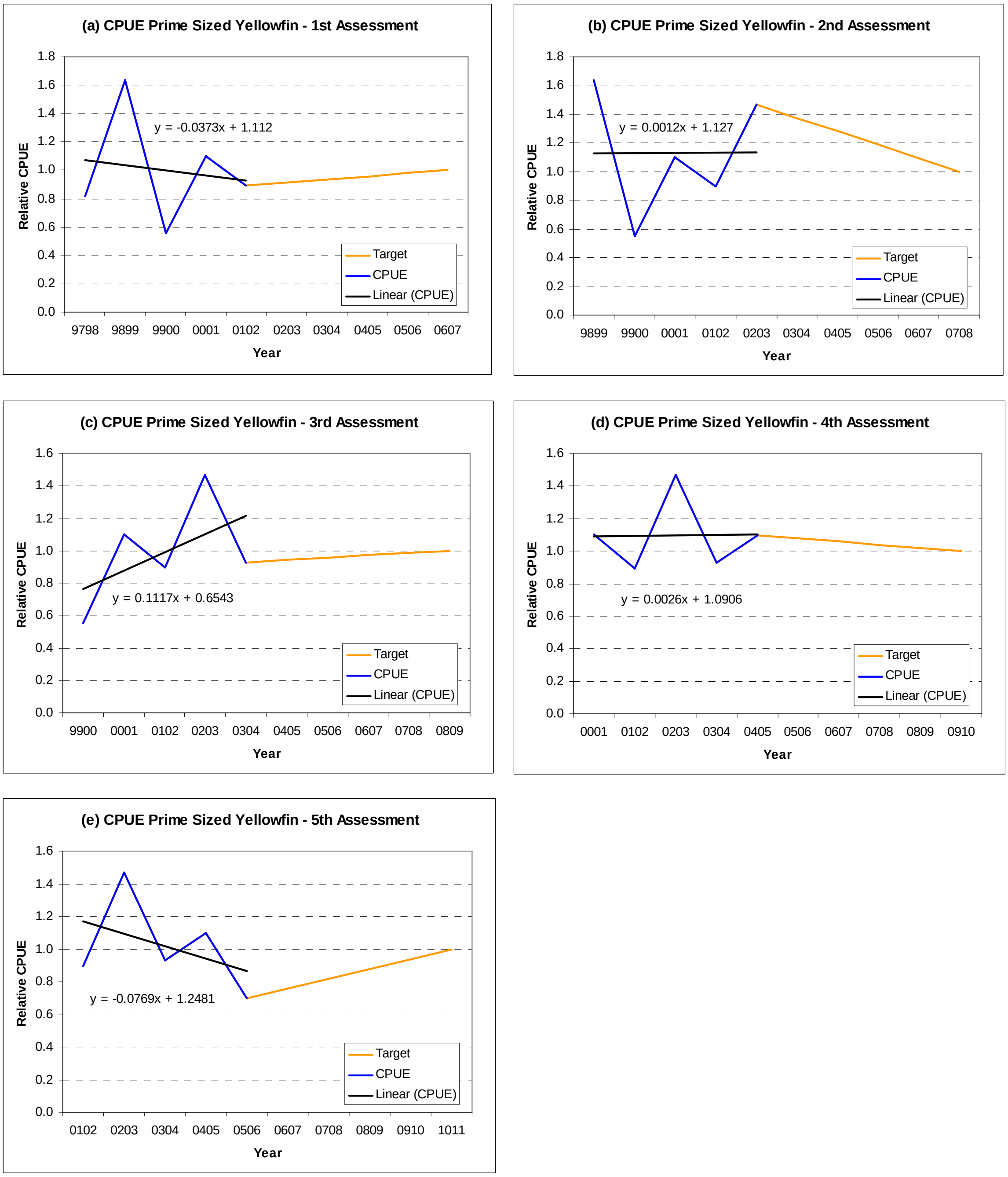
Level 3 Assessment

At this third level, we compare the values of the two indicators *CPUE-Old* and *Proportion-Old* against their corresponding target values. In the initial assessment year both indicators are found to be above their reference values thereby dictating that Option A in the decision-tree is applicable. Combining the results of the Level 2 and Level 3 assessments there dictates that the "Stable-A" option in the decision-tree matrix is chosen for any further adjustment of the recommended TAE.

Level 4 Assessment

At this final stage, we apply an adjustment multiple to the TAE recommended in Level 1 assessment based on the decision-tree matrix option chosen from the outcomes of the two previous assessment levels. Some of these options request a Level 4 assessment of the status of the yellowfin recruits (cf. Figure 9). In the initial assessment year this is not applicable and indeed the "Stable-A" cell indicates that no additional adjustment is required to the TAE of 11.1 million hooks which was recommended in Level 1.

Figure 8. Time-series of historical CPUE of prime sized yellowfin tuna used in each annual assessment. The time-series of future CPUE if there was to be a linear rebuilding of the stock to the target CPUE level is also shown. The slope-to-target used in the decision tree is found by adding together the slope of the historical CPUE series and the slope of the final CPUE to the target CPUE.

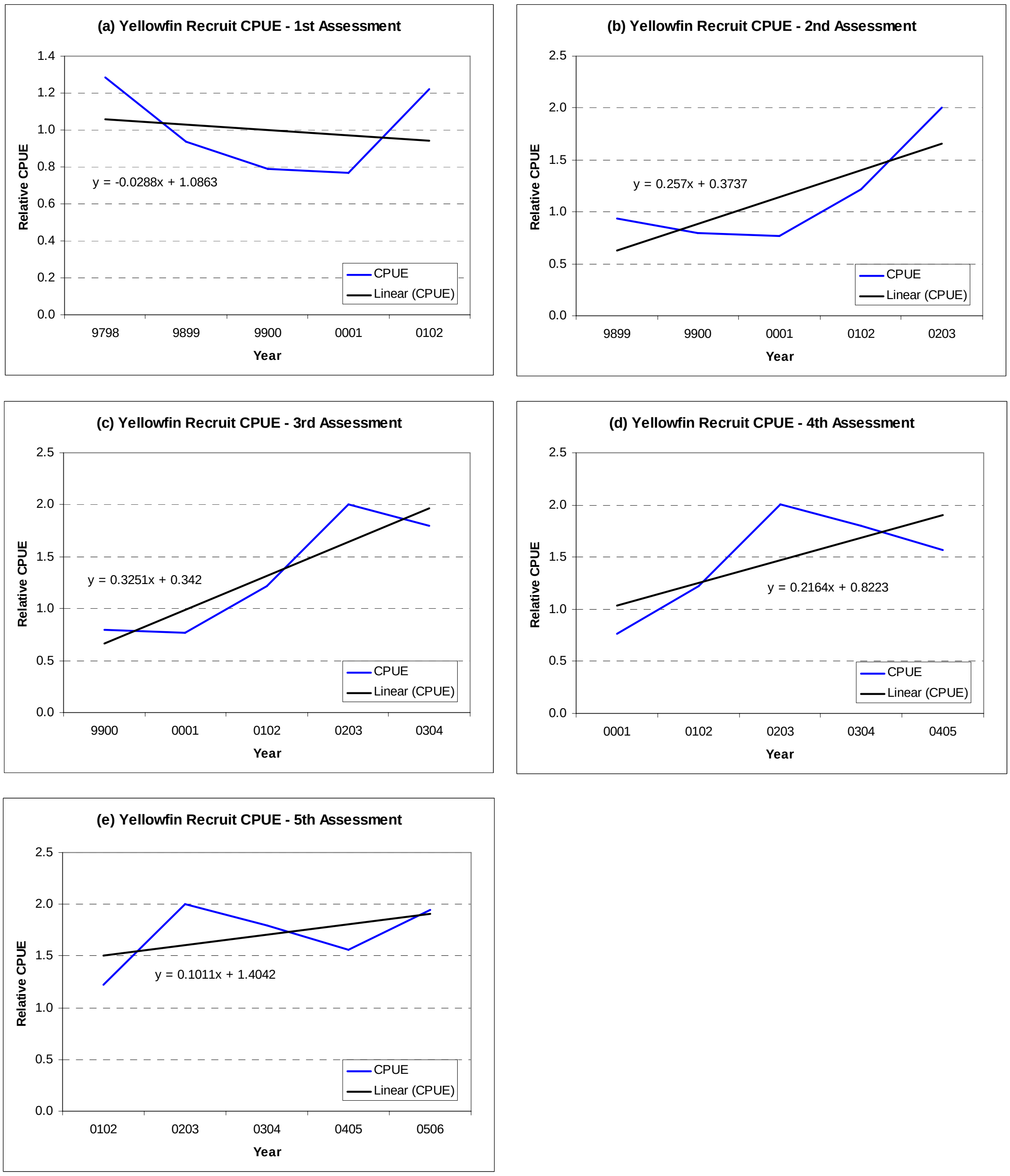


Application of Harvest Strategy in Successive Years

To continue the example, the decision-tree process outlined above was applied to the data for the next four years in the fishery, adjusting the effort in the fishery from that actually deployed during the previous year. The results are shown in Table 3 whilst the recommended TAEs are displayed against the actual observed efforts in Figure 8a. The recommended TAE is seen to be 13.2 million hooks if initially applied after the

0203 assessment (although the *Proportion-Old* is below the 20% limit recommended the *CPUE-Prime* is above the CPUE-Target), 12.2 million hooks if initially applied after 0304, 9.1 million hooks if applied after 0405, and falling to 7.0 million hooks if applied after 0506 (when *CPUE-Prime* is below CPUE-Target and is defined as “Falling”).

Figure 9. Time-series of historical CPUE of recruit sized yellowfin tuna used in each annual assessment. The linear trend in the recruitment index is indicated by the solid line.



6.2 Broadbill Swordfish

The time-series of effort, catch and performance indicators for broadbill swordfish in the ETBF are shown in Table 4 and Figure 10 (Campbell 2007, Campbell et al 2007). The parameter values used in the decision-tree are the same as in the application of the harvest strategy to yellowfin tuna described previously. The Level 1 and Level 4 assessments are shown pictorially in Figures 11 and 12 whilst the adjustments to the TAE based on the results for each assessment level are given in Table 5.

Table 4. Fishery statistics and performance indicators for swordfish in the ETBF.

			Performance Indicators					
Financial	Effort	Catch	Relative CPUE Index			Catch Proportion by Size (%)		
Year	(M. Hooks)	(No. Fish)	Recruits	Prime	Old	Recruits	Prime	Old
9798	7.69	32,913	1.026	1.656	1.541	14.3	60.9	24.8
9899	10.00	33,814	0.827	0.963	1.030	24.4	52.0	23.6
9900	9.99	43,785	1.210	0.867	1.068	25.0	48.8	26.3
0001	10.09	31,805	0.877	0.820	0.732	22.0	54.6	23.4
0102	11.80	37,546	1.059	0.694	0.629	29.0	50.8	20.1
0203	12.71	34,727	1.095	0.509	0.533	32.9	45.4	21.6
0304	11.15	26,151	0.796	0.439	0.440	26.7	50.2	23.1
0405	9.41	25,735	0.900	0.555	0.480	28.8	49.6	21.6
0506	8.55	25,069	1.207	0.551	0.464	35.9	44.8	19.3
0607								

	Mean CPUE 1st Five Years			Mean CPUE 1st Five Years		
Scaled Index	1.000	1.000	1.000	22.9	53.4	23.6
Nominal CPUE	0.85	2.15	1.00			

Table 5. Listing of assessment outcomes and recommended TAEs based on a retrospective application of the decision-tree to the time-series of broadbill swordfish performance indicators in the ETBF.

	Assessment Year				
Decision-Tree	0102	0203	0304	0405	0506
Effort in Previous Year	11.8	12.7	11.2	9.4	8.6
Level 1					
Slope-to-Target	-0.2712	-0.2086	-0.2318	-0.1685	-0.1139
Recommended TAE	8.6	10.1	8.6	7.8	7.6
Level 2					
Relative Prime CPUE Slope	-20.7%	-14.0%	-17.5%	-13.0%	-4.4%
Prime CPUE Slope Status	Falling	Falling	Falling	Falling	Stable
Level 3					
Old CPUE Status	Above	Below	Below	Below	Below
Old Proportion Status	Above	Above	Above	Above	Below
Option	A	C	C	C	D
Level 4					
Is recruitment high?	Yes	Yes	No	No	Yes
Is recruitment declining?	No	No	No	No	No
TAE multiple	0.95	0.95	0.95	0.95	0.95
Recommended TAE	8.2	9.6	8.1	7.4	7.2

Figure 10. Time-series of (a) effort and broadbill swordfish catch in the ETBF, (b) standardised CPUE of recruits, prime and old swordfish, and (c) proportion of recruits, prime and old swordfish in the total swordfish catch.

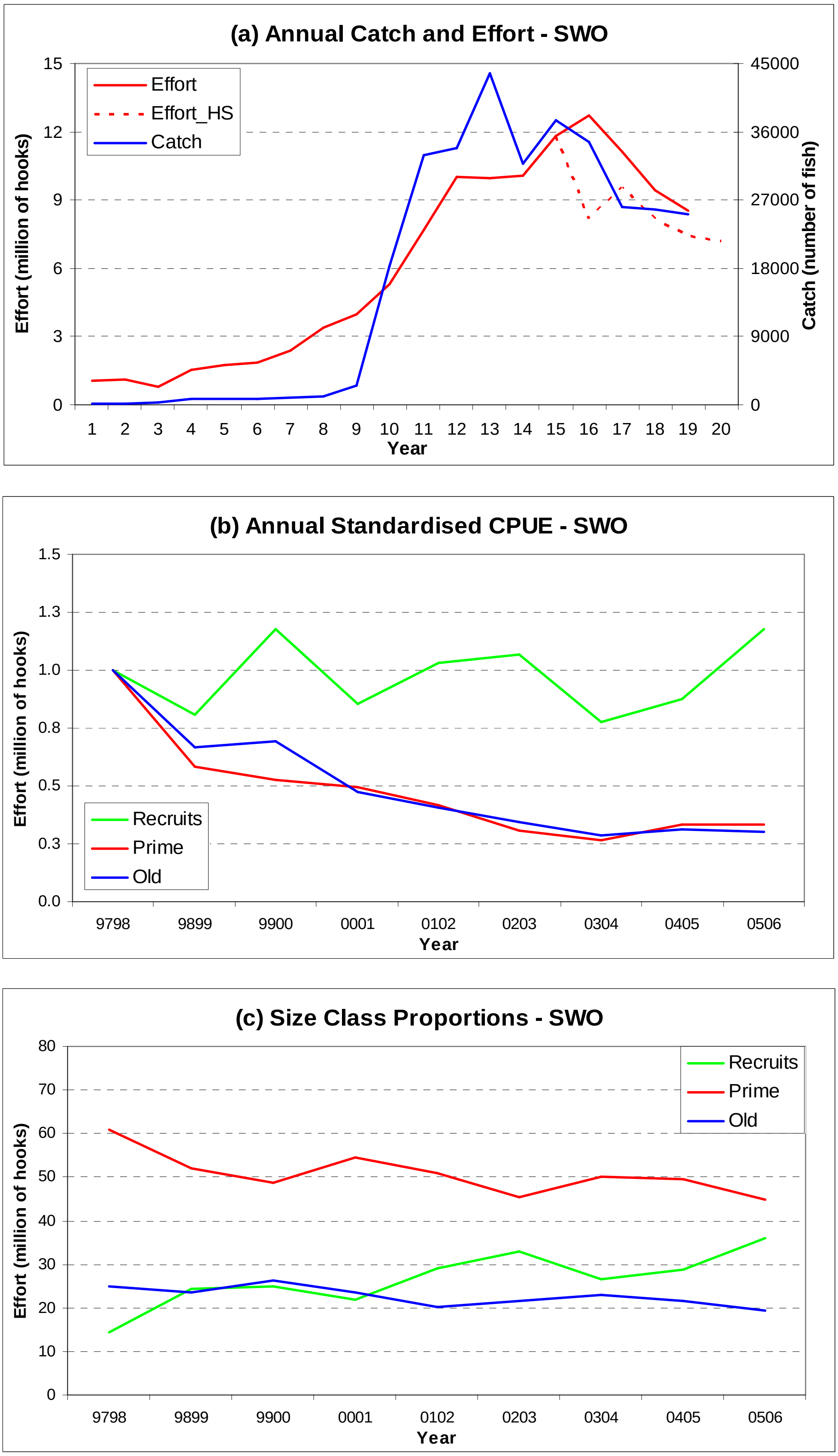


Figure 11. Time-series of historical CPUE of prime sized broadbill swordfish used in each annual assessment. The time-series of future CPUE if there was to be a linear rebuilding of the stock to the target CPUE level is also shown. The slope-to-target used in the decision tree is found by adding together the slope of the historical CPUE series and the slope of the final CPUE to the target CPUE

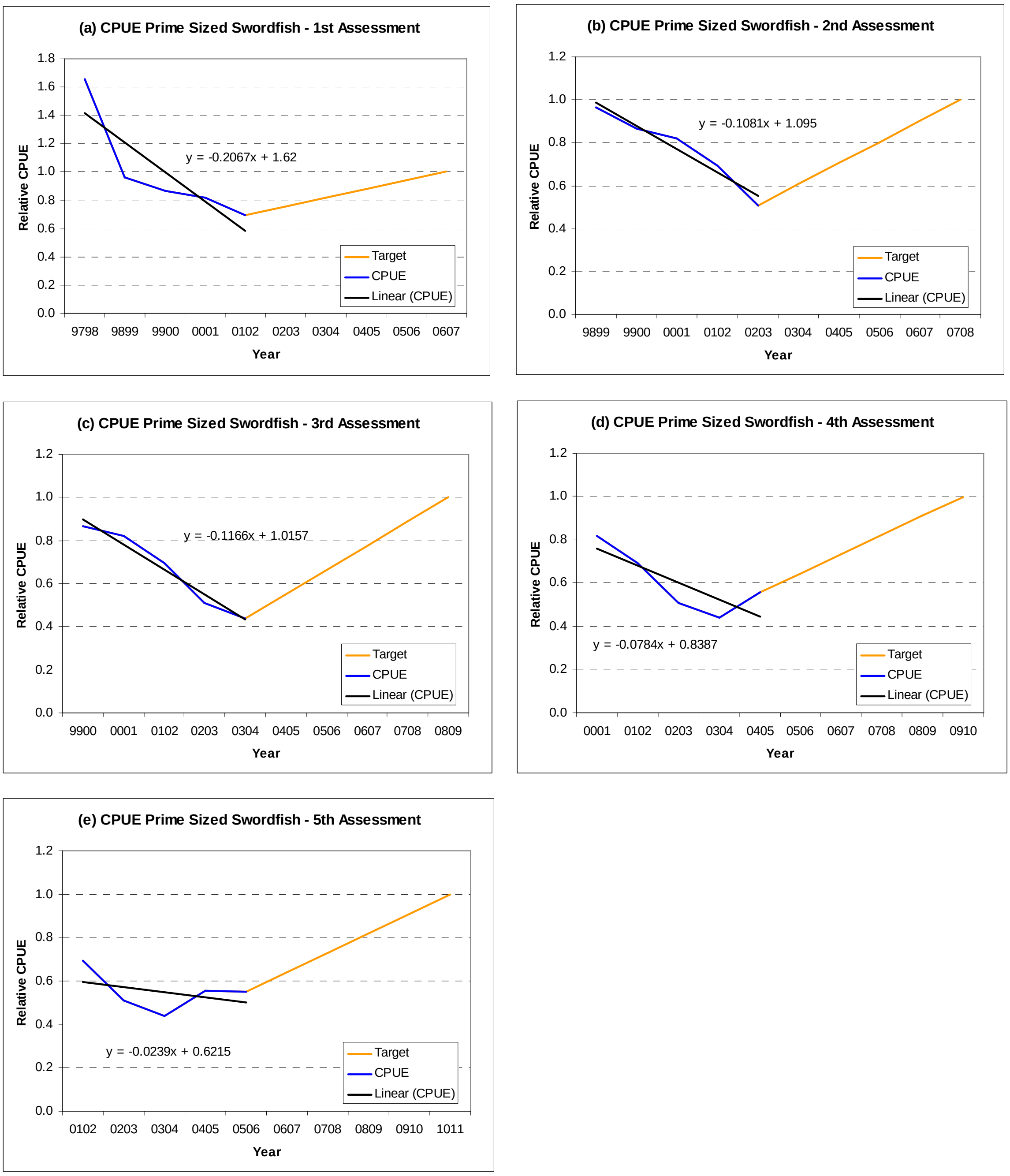
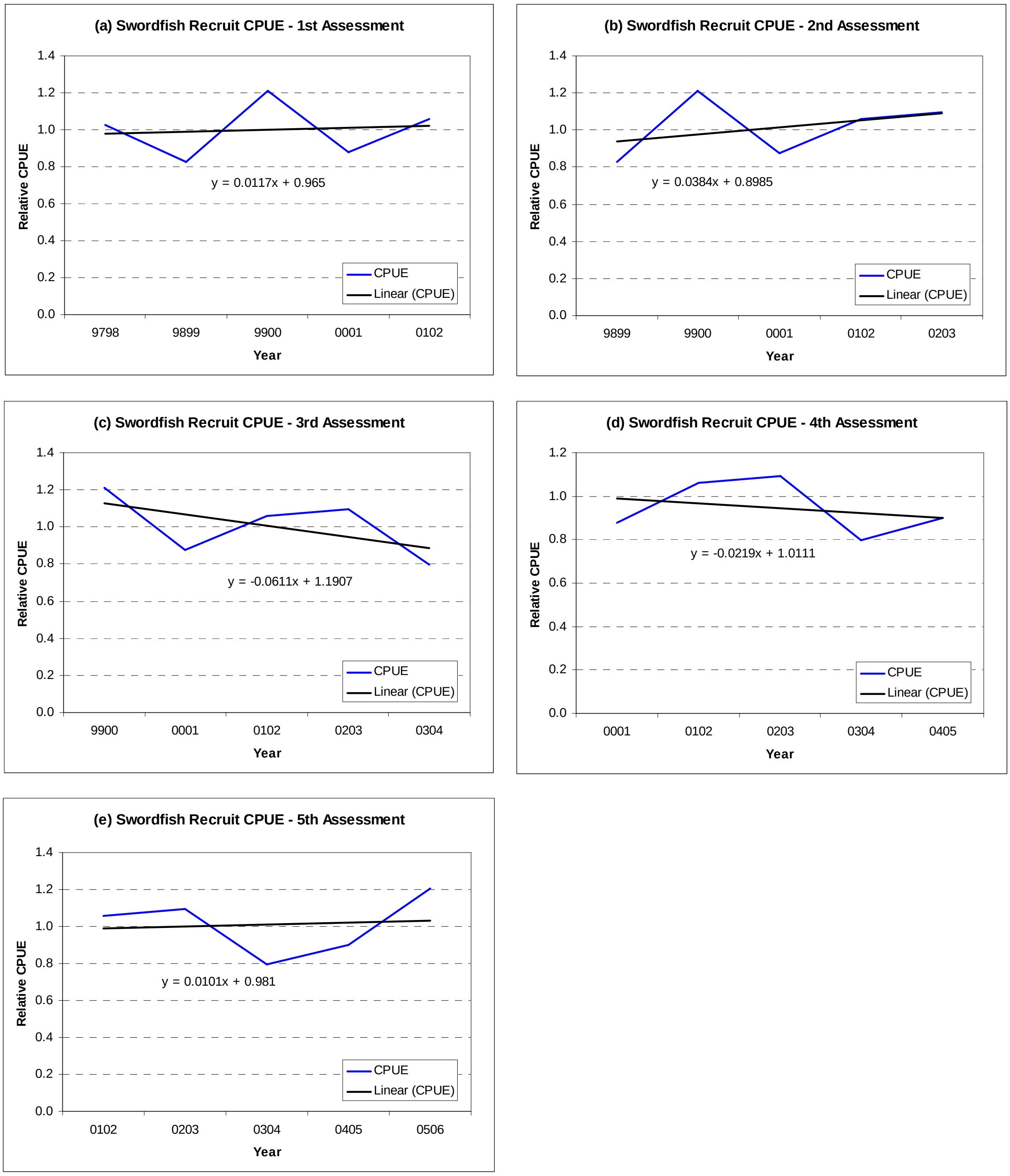


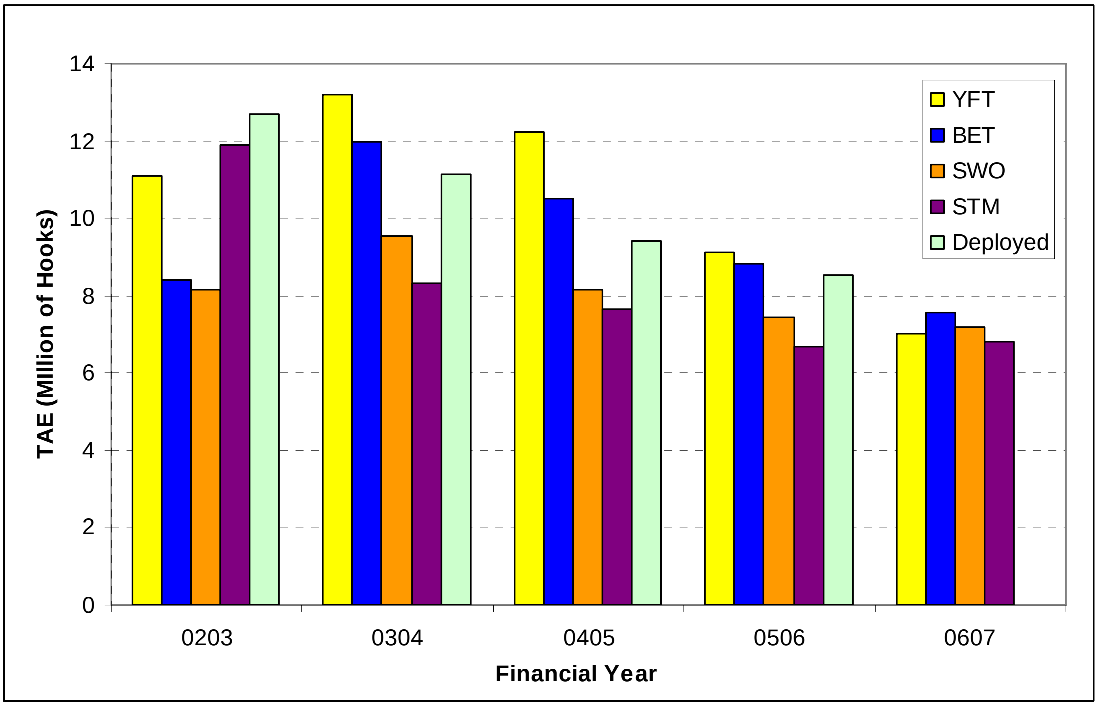
Figure 12. Time-series of historical CPUE of recruit sized broadbill swordfish used in each annual assessment. The linear trend in the recruitment index is indicated by the solid line.



7.3 Comparison across Species

A comparison of the annual recommended TAEs for yellowfin tuna and broadbill swordfish is show in Figure 13 together with the results of applying the harvest strategy to both bigeye tuna and striped marlin in a similar manner. Apart from 0203 the recommended TAEs for the two tuna species have been generally similar and above the number of hooks actually deployed in the fishery, while the recommended TAEs for the two billfish species have also been similar but lower than the number of hooks actually deployed in the fishery.

Figure 13. Time-series of recommended TAEs based on the example of applying the harvest strategy to four of the main target species together with actual annual longline effort deployed in the ETBF.



As discussed previously, the application of the harvest strategy will be applied to each of the five principal target species in the ETBF and, if desired, to other species of interest provided that the data for calculation of the performance indicators is available. Application of the harvest strategy to each species separately, however, only provides a recommended TAE for that given species. As there can be only a single TAE applied in the fishery these recommended TAEs will need to be integrated in some manner to inform a single recommended TAE. Whilst the mean of integrating these species-specific TAEs is yet to be determined, a simple example would be to just calculate the mean of the species-specific TAEs.

8. Discussion

8.1 Strengths and Weaknesses

Whilst the harvest strategy outlined in this paper is yet to be implemented, the retrospective application to the ETBF indicates that the harvest strategy appears to be operating sensibly and the initial indicative TAEs were generally as expected. However, as highlighted previously, 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 measures) 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 with 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 (above the Target Reference Point), rather than keep you away from where you don't want to go (near/below the Limit Reference Point).
- Relies on information from the Australian fishery (CPUE and size) to infer and "learn" about economically and ecologically sustainable catch levels.
- Including size indicators for growth and recruitment over-fishing through the decision tree makes it more "robust" to potential biases in CPUE.
- Should be "robust" to uncertainty about linkages between regional and broader WCPO stocks. That is, it should respond to declines and increases in regional stock status, regardless of whether they are generated by domestic or international fleets.
- The approach is applicable to all target species and so provides a consistent framework for integrating multi-species considerations.
- The HS framework should be cost neutral within current monitoring and assessment processes.

A further strength of the strategy is the fact that the performance indicators and associated decision rules are, in the main, based on simple empirically derived quantities. Unlike model based indicators such as fishing mortality, *F*, and absolute biomass, *B*, catch rates and the size of fish are readily observed in the fishery and understood by industry members. As such, the inherent relationship between these readily observed and understood quantities and the decision rules makes changes in either easier to understand and reconcile by fishery stakeholders. This is unlike the situation where performance indicators are based on complex resource models which to many stakeholders are not well understood and are considered to be some sort of "black box" with unknown internal mechanics. The lack of a direct relationship and understanding between the inputs and outputs of such models, combined with an inherent suspicion of the underlying model assumptions, all too often leads to a sense of distrust between parties and a failure to agree upon and implement any 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. Whilst standardised catch rates have long been used as proxy indicators of underlying resource availability and/or abundance, it is also understood that the relationship between these two quantise is possibly complex and not fully understood. Furthermore, the data is often lacking to more fully account for all the differences in gear types and targeting practices which are know to occur in the fishery. This is especially pertinent in multi-species fisheries, such as the ETBF, where vessels can switch target species depending on both resource availability and market conditions. This creates difficulties in monitoring and measuring the effective effort targeted at individual species which in turn can bias indices of abundance based on standardised catch rates. 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 data. More complex models may assimilate a wider range of information pertinent to the fishery with the aim of balancing the short-coming 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 process with the aim of balancing a range of potentially confounded indices.

8.2 Issues for Further Consideration

The illustration of the recommended harvest strategy to the ETBF, as outlined in the previous section, provided the first opportunity to "*road-test*" the recommended harvest strategy using actual data from the fishery. Further work using this approach will be used to evaluate and fine-tune the existing Decision-Tree and identify appropriate parameters values. A formal evaluation of the overall harvest strategy is also being undertaken by the recently commenced project "*Integrated evaluation of management strategies for multi-species longline fisheries*" being undertaken by CSIRO (Davies 2006). This work will extend initial testing undertaken by the HSWG of the harvest strategy using an operating model framework (Campbell et al 2007) by "conditioning" the operating model to historical data, the "tuning" of the decision framework to meet specific performance measures, and use of a Management Strategy Evaluation framework to examine the trade-offs between the relative risk of breaching reference points, the level of catch and cost of monitoring and assessment.

Issues to be addressed by this project include the identification of the target values and associated decision-rule parameters for each species (c.f. parameter list in Table 1). For example, in the application of the harvest strategy the target reference points for each species were scaled so that the parameter values used in the Decision-Tree were the same for each species. Whilst this approach may have some merit (especially in identifying an appropriate value for the feedback gain factor, β) the relationship between these "scaled" reference points and the relevant biological reference values for each indicator (e.g. target value for *CPUE Prime*) will need to be determined.

Another issue which should be investigated is the number of years over which the "assessment" is conducted. Again, in the examples presented here the trend in the CPUE-indicators was assessed over a five year interval. The sensitivity of the results to using a shorter or longer period needs to be assessed, as is the question of whether or not a longer period may be more applicable to those species which display high inter-annual variation in the indicators (as seen in the yellowfin tuna indicators). It may be that the assessment period is somehow correlated with the life-history parameters of the species being assessed.

There are also a number of additional adjustments one can make to the Decision-Tree process discussed in this paper. For example, one may adopt a rule where the TAE (or TAC) is only adjusted where the recommended change is greater than some threshold (say 5-10%). Similarly, the maximum change in the TAE (or TAC) may be limited to some threshold (say 20%). Some form of stability in the fishery may be desired by only making changes every 2-3 years. On the other hand, once the fishery is considered to be in an overfished state (i.e. the indicator values are below the target values) then one could apply an additional rule where the recommended TAE (or TAC) is linearly decreased based on the Limit-to-Target reference values adopted for the fishery. This would ensure that the fishery is closed when the indictors values fall below there appropriate Limit Reference Points.

The issue of whether the TAE to be updated in the Level 1 assessment should be based on the previous TAE applied in the previous year or the actual effort deployed in that year, or perhaps some average of the either effort over a number of previous years, also needs to be investigated. No doubt there are a number of such alterations to the present formation of the decision-rules which can be suggested and tested. The question of combining the species-specific recommended TAEs also needs to be resolved. With five principal target species in the ETBF it is questionable as to whether all species need to be taken into consideration for this purpose. For example, one could argue that if one integrates across the recommended species-specific TAEs of only those species considered to be the most at risk (for example, bigeye tuna, swordfish and striped marlin) then the resulting TAE would also be applicable to those other species which are perhaps more robust and resilient to higher levels of fishing effort.

There is also a need to consider issues associated with implementing the harvest strategy in a multi-species context. While the current approach is equally applicable to all target species, and so provides a consistent framework for integrating multi-species considerations, there is nevertheless a need to develop a framework which integrates these into a single set of fishery-wide reference points. The key steps in this process will be establishing the performance measures for total catch whilst still taking into account the status of each individual species.

Finally, the adoption of an appropriate harvest strategy in the ETBF will serve a number of purposes. First, without management feedback loops, high levels of combined effort may lead to overexploitation and/or overcapitalisation in the fishery. Alternatively, if effort 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 operate with greater confidence and transparency and should eliminate the need for hasty and ad hoc management responses based on unforeseen outcomes. In this manner, management actions can be seen as being pro-active instead of being reactive to conditions prevailing in the fishery.

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