C S I R O
MARINE RESEARCH

ISSUES RELATED TO SETTING REBUILDING OBJECTIVES FOR SOUTHERN BLUFIN TUNA

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Abstract

The development of a management procedure has been defined by the CCSBT as one of the highest priorities for the scientific committee (Anon. 2001). An essential component of the management procedure process is the explicit definition of management objectives and their translation into measurable and quantifiable performance indicators. Objectives related to stock status and conservation are important for management, but can be difficult to express in quantifiable terms because of uncertainty about the underlying stock dynamics and determining absolute risk (e.g. "recruitment collapse") associated with different stock levels. As such, the definition of stock status objectives involves the interface between management and science (i.e. the interface between the provision of advice and the decision making) and it is important to avoid inappropriate confounding of roles in this process. Management has the responsibility for setting its objectives. However, science has an important role in this process in advising on what is realistically achievable and the potential consequences/risks associated with different objectives.

For over 15 years, it has been agreed that the SBT stock has been depleted and that there is a need to rebuild the spawning stock. For this entire period, the 1980 spawning stock biomass level has been the only agreed rebuilding target. However, recent stock assessments and management procedure evaluation work have indicated that this target may be unattainable within the next 20 years, even if catches were reduced to zero. Within the context of the management procedure development and evaluation process, it is important for managers to understand the plausible range of stock rebuilding potential, and define the rebuilding objectives that it would like the candidate management procedures to be evaluated against. There are a number of approaches that can be used to define rebuilding objectives in this context, including:(1) empirical/historical considerations (e.g. the target of 1980 SSB), (2) spawning biomass depletion level (e.g. biomass = 0.4 of biomass at theoretical unfished equilibrium) (3) recruitment trends (e.g. assuming a stationary stock recruitment relationship, ensure that SSB is high enough to maintain mean recruitment above 0.8 of unfished recruitment) (4) stock productivity (e.g. MSY levels) and (5) relative to maximum possible rebuilding in a specified timeframe. These five approaches are discussed in the context of SBT and the currently defined operating model for testing candidate management procedures for SBT.

Introduction

Scientists and managers have distinct and separate roles in the overall fishery management process. In simple terms, fishery scientists conduct stock assessments based on a scientific evaluation of available data to provide management advice on the current status of the stock relative to the past and on the consequences of potential future management actions. Managers utilize the results of these to make management decisions (e.g. TACs, gear regulations, etc) in order to achieve objectives. In the science/management interface (i.e. the interface between the advice and the decision), it is important to avoid inappropriate confounding of roles.

One of the most critical points in this interface is the setting of the overall objectives that management is trying to achieve. In order for scientists to be able to evaluate the consequence of potential management actions (and thus provide meaningful advice) such evaluations need to be done in relation to the objectives that management is trying to achieve. Too often in fisheries, management has not set explicit objectives, which has left scientists attempting to second guess the objectives when presenting their advice. Managers, on the other hand, are often reluctant (and understandably so) to set objectives, particularly biological and conservation related ones. Such objectives require a "scientific" understanding of both what is realistically achievable and the potential long term risks (e.g. stock collapse). However, "science" cannot provide objectives – this requires value judgements on what are preferable outcomes (e.g. the concept of "scientific management objectives" is a misnomer). Nevertheless, science has an important role in this process in advising on what is realistically achievable and the potential consequences/risks associated with different objectives.

The development of a management procedure has been defined by the CCSBT as one of the highest priorities for the scientific committee (Anon. 2001). While substantial progress has been made at the technical level in terms of the development of operating models and candidate management procedures, finalization of the technical work requires the development of quantifiable performance measures which reflect management's basic objectives. Without such measures, it becomes impossible to undertake meaningful evaluation of the performance of different candidate procedures or to provide advice on the relative trade-off in objectives that might be obtained from different procedures. One of the most critical objectives for which agreed performance measures are required is the stock-status related targets that should be used in the management procedure evaluation process. The only stock status related objective that has been agreed to by the CCSBT is the rebuilding of the parental biomass to 1980 level by 2020. However, within the current set of base case scenarios being considered in the MP development process, many of them cannot achieve this objective even under a zero catch option and only one scenario can achieve this with 90% probability under a constant catch scenario equal to 75% of the current catch level. While the current base case scenarios may not represent the most plausible set of possible operating models for the SBT stock, it is important for managers to understand the plausible range of stock rebuilding potential, and define the rebuilding objectives that it would like the candidate management procedures to be evaluated against. There are a number of approaches that can be used to define rebuilding objectives. The current paper discusses these in the context of SBT and the currently defined operating model for testing candidate management procedures for SBT.

Background

The current rebuilding objective for the CCSBT is to rebuild the parental biomass to the 1980 levels by 2020. There are two aspects to the objective: (1) the target level and (2) the timeframe.

The 1980's parental biomass as a target level for the SBT stock goes back to the initial development of international management and scientific assessments arrangements for SBT. Thus, the Report of the 1983 Scientific Meeting on Southern Bluefin Tuna (the second international such meeting) "recommended that steps be taken to ensure that the spawning stock does not fall significantly below the 1980 level" (Anon 1983). This recommendation was based on concerns about recruitment overfishing. Thus, based on the information available at the time the scientific committee concluded that the spawning stock had appeared to stabilize in the period from 1976-1980 and "the stock did produce satisfactory recruitment" during this same period. It further concluded that:

> "There is no scientific basis for believing that a smaller stock would continue to produce satisfactory number of recruits. In fact the only way of determining the level to which the stock can decline before recruitment is reduced is by trial and error. Because of the long time before this stock could recover after a reduction the scientific meeting believed it would be imprudent to allow this to happen, and recommends that the spawning stock be maintained at a level near 220,000 tonnes" [the approximate level estimated for 1980]. (Anon. 1983).

Within the SBT context, the selection of a rebuilding target has involved management agreeing on an objective for what minimum level the stock should reach within a given time period. Prior to 1994, the rebuilding timeframe was set at 2010, but it was changed in that year to 2020. Since 1994, the CCSBT has either maintained its annual TAC at a constant level or has failed to agree on one. In the same time, global SBT catches have increased. While from the perspective of 1994 and the stock assessments at that time, the 2020 rebuilding timeframe was realistic. Ten years later, given the late age of maturity for SBT that is now recognized, and the current set of operating models being used in the MP process, it is not clear whether this provides a useful measure against which to measure performance.

Approaches for Defining Rebuilding Targets

There are a number of approaches that could be used to define rebuilding targets, and they differ in terms of the units or currency used to express them. Among the most direct and commonly ones considered in fisheries are:

1) Empirical/historical
2) Spawning biomass depletion
3) Recruitment declines
4) Stock productivity – MSY related
5) Rebuilding relative to maximum

Each of these approaches are described below along with a brief discussion of potential use in the SBT context.

Empirical/Historical Approach

In this approach, the state of the stock at some historical time in the past is set as a reference for rebuilding. The basis for selecting a date is based on direct observations or estimates comparing current conditions to those in the past (i.e. the stock/fishery were "alright" in the past but are clearly not where they should be now). There is no theoretical underpinning for the selection of a reference level and the reference level is a rather pragmatic choice based on comparing conditions today with those in the past. The basis of selecting a target might include an economically attractive CPUE, or no apparent recruitment overfishing. The original Scientific Committee recommendation about the 1980 level appears to contain a large element of this empirical approach.

From the perspective of 2003, it is less clear that the period prior to and around 1980 represents a period with reasonably stable and satisfactory recruitment. The current set of operating models being considered within the management procedure evaluation process yield similar trends for (relative) estimates of SSB and recruitment over the period for which there is reliable data (e.g. CPUE and relatively complete size data). The greatest differences are seen for different assumptions about the natural mortality rates (e.g. Figure 1 and 2)[1]. In all cases, the estimated trends suggest both a generally continuous and steady decline in SSB and recruitment since at least 1970, if not from the beginning of the fishery. As such, these estimated trends provide little empirical basis for selecting a reference level.

Nevertheless, the perception that the 1980 level provided a reasonable rebuilding target was not based simply on the assessment of stock trends from analytical assessments. In fact, the largest impetus for management actions in the 1980s stemmed from consideration of observable changes in the fishery and stock that were occurring at this time. Thus, the strong recommendations with respect to the need to reduce catches in 1988 was based on the following indicators (only the first of which appears to be drawn from the stock assessments):

- Reduction of unexploited parental biomass to less than 25%.
- Reduction in hook rate in the Japanese longline fishery between 1983 and 1986 of 50%.
- Contraction in the area of Japanese fishing effort to two of nine fishing areas.
- Reduction from the peak Japanese longline catch to less than 20%
- Reduction in the abundance of 4-7 year old fish in the longline fishery from 1972-86 to 10%
- Reduction in the abundance of 8-10 year old fish in the longline fishery since 1980 to about 30%.
- Reduction in the hook rate in the Japanese longline fishery off New Zealand between 1980 and 1987 to 33%.
- Disappearance of small fish from the Japanese longline fishery in New Zealand waters.
- Reduction from the peak New Zealand handline/troll fishery catches to less than 25%.
- Sudden and continued absence of SBT from NSW coast.
- Continued contraction in the area of occurrence of juvenile SBT in the Australian waters to 40%
- High exploitation rate (40%) in the Australian fishery.
- Progressive reduction in the availability of large fish to the Australian fishery since 1982-83. (Anon. 1988(

In combination, these indicators suggest both overfishing and an overfished stock – many of them are associated with the period after 1980. In particular, those related to spatial contraction (e.g. the collapse of the NSW surface fishery[2], disappearance of small fish off New Zealand, contraction in longline fishing grounds) combined with the apparent large reduction in older fish suggest that the stock sizes in the post 1980 level had been reduced to such low levels that the basic population and habitat dynamics of the stock were being disrupted. Further evidence of a major shift in the underlying dynamics comes from the rapid change (increase) in the late 1970's in the

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[1] It is important to recognize that not all of the trends in these figures should be treated as equally plausible – e.g. some of the operating model fits contain substantial lack of fits. This is discussed in Polacheck et al 2003 and also further below.

[2] Evidence of extensive use of this NSW habitat by juvenile SBT extends back to the 1930s.

growth rates of SBT (Polacheck et al 2002)[3]. In this context, the 1980 spawning biomass might continue to be considered as a reasonable empirical rebuilding target, particularly if the past is to provide the guide for setting objectives in the future. Of course, there is no certainty that rebuilding the stock to the 1980 levels would reverse all of the above indicators (e.g. that the history is reversible).

One advantage of the 1980 level in terms of the stock assessment and management procedure development process is that the estimates of current stock size relative to the 1980 level tend to be relatively consistent across a wide range of scenarios (Table 1). For the period for which these models have reasonable support in the data (e.g. 1969 when CPUE tuning indices are available), they yield quite similar trends relative to the 1980 level (Figure 1). The largest differences are in the most recent years (which are estimated relatively poorly) and for natural mortality vector 3 (see Table 7 for definition of the mortality vectors used in the SBT operating model). However, in the latter case, there are substantial residual trends in the fit to the CPUE series (Figure 3) which tend to suggest that the combination of this mortality vector and model structure are not providing a plausible representation of the historical trends. Thus the major inconsistencies across operating model scenarios might be removed if some type of relative plausibility weighting of results is incorporated into the MP evaluation procedure.

Spawning Biomass Depletion Level

“Recruitment overfishing"—when fishing reduces a stock below the threshold where recruitment notably declines—has been the mechanism associated with many fisheries collapses. For depleted stocks, the main concern is that environmental variability will combine with the vulnerable state of the resource to cause an abrupt recruitment decline and a subsequent further decline in the parental biomass. However, recruitment dynamics are poorly understood (particularly at low stock sizes) and environmental factors as well as spawning stock level can be a major contribution to inter-annual recruitment variability. In addition, estimates of productivity are often poorly estimated. All of this means that it is not feasible to meaningfully quantify the probability of a collapse for a particular stock at any particular spawning stock level and a stock can remain at low levels without collapsing, even occasionally producing large recruitments. Nevertheless, the lower the level of the parental stock and the longer it remains at low levels, the higher the probability of an abrupt recruitment decline. Detection of stock and recruitment collapse at the time they are actually occurring is nevertheless difficult because it generally takes several years of observations to reliably confirm the strength of recently recruited cohorts and it is a feature of stock assessments that the most recent estimates are generally the most uncertain.

The inability to quantify the risk of collapse and the fact that a stock has not collapsed at current catch levels can make it difficult to determine what is an appropriate rebuilding target for a depleted stock based on estimates or models of its dynamics. Nevertheless, the region of “low” spawning stock biomass levels is generally recognized as an area to be avoided in order to ensure the long term sustainability of the resource and the fisheries. Thus, setting minium depletion levels has been one approach for setting rebuilding targets based on the recognition that the robustness

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[3] Information for estimating this change in growth was not available to the 1988 Scientific Committee.

and unduly avoiding “risk” are important components of management objectives. While any specific value will have a component of arbitrariness to it, setting a specific depletion level, nevertheless, can provide a useful benchmark to measure performance against and help to ensure that there is a buffer away from the region where recruitment and stock collapses are more likely. In this context, stock levels of 25-50% of their unfished level (e.g. B_0)might be worth considering (i.e. stock levels below which the stock should not be allowed to reach and if it does go below that level, a recognition that rebuilding needs to occur).

In general, considerations of using depletion levels as a rebuilding target[4] (or a limit reference point) have focused on the recruitment/stock collapse issues. However, the issue of a stock's functional role within an ecosystem can provide an additional context for considering what might be an appropriate level. While there is little specific work on this, reducing their abundance to low levels might be expected to have cascading ecosystem effects. These effects might be expected to begin before a stock is depleted to the level that causes a high risk of stock collapse.

One advantage of using depletion levels as a rebuilding target is that there can often be a relatively high degree of concordance among different estimates of depletion across a range of assessment models and alternative hypotheses for the major dimensions of uncertainty. This has frequently been the case within the SBT stock assessments. There is also an element of this in the context of the estimates generated from the conditioning process within the current CCSBT management procedure development process. Thus, within the current base case set of operating model, estimates of depletion levels are basically insensitive to assumptions about stock productivity (i.e. steepness) and were also insensitive with respect to natural mortality vector 1 and 2 (Table 1). However, this was not the case for natural mortality vector 3, for which the estimated relative current biomass levels are ~2 times above those for the other two mortality vectors.

Recruitment Trends

Recruitment trends are often one of the most robust components estimated by stock assessment models over the period for which reasonable age and/or size data for the catch exists. In addition, recruitment levels are what determine the fishery yields and also represent future spawning potential. As such, setting rebuilding targets based on the spawning stock level that produced some percentage of the initial or unfished recruitment could provide one approach for setting a rebuilding target. However, recruitment variability relative to any trend combined with autocorrelations and potential non-stationarity means that recruitment trends can be difficult by themselves to use as a basis for setting rebuilding objectives.

In the SBT case, estimates of recent relative recruitment trends (up to the late 1990s) are relatively consistent over a wide range of uncertainties (Figure 2). Estimates also tended to exhibit small amounts of inter-annual variability. Thus, it would seem that past recruitment levels might be useful approach for setting a rebuilding target. However, the lack of inter-annual variability in the SBT recruitment trends may be an

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[4] Note that an alternative to defining depletion in terms of B_0 would be to define depletion relative to a long term (e.g. scenario) under no catch. In many cases, this would be the same as B_0 but would take into account non-stationarity in the stock and recruitment relationship if it was allowed for in operating model.

artefact of not having direct catch at age data for most fisheries, and hence fitting to catch at length data which cannot distinguish cohort strength as reliably. More importantly, in the current management procedure evaluation context, operating model recruitment levels are a function of spawning stock biomass and recruitment based rebuilding targets would have a relatively straightforward translation to a spawning biomass one. Nevertheless, in terms of considering actual performance relative to historical conditions, changes in recruitment can be an informative performance measure.

Stock productivity (e.g. MSY levels)

Historically, fishery management has frequently defined its stock-status related objective in terms of the biomass that would provide maximum sustainable yield. However, general concerns exist about the utility of using estimates of MSY as a management objective[5] (at least in terms of a target reference point for management)[6]. Among these concerns are (1) stock productivity and MSY levels have proved elusive to estimate accurately, (2) recruitment variability and associated auto-correlation combined with lags in their detection and management response can result in stock declines stock well below MSY and (3) stocks managed under MSY objectives have frequently ended up in depleted, if not collapsed, state[7].

One concern with MSY type objectives is that they are dependent upon a specified functional form for the productivity function (e.g. the stock and recruitment relationship). However, our understanding of the actual process governing productivity is poor and there may be substantial lack of fit between model predictions and the underlying functional relationship (e.g. estimates of historic spawning stock and recruitment trends compared to the "best" fit to these within a specified functional form). In particular, systematic temporal deviations can be interpreted as the result of large auto-correlations in recruitment. When such "auto-correlations" are estimated to have long time lags, then the performance of the stock in the more recent years (perhaps the whole period where extensive data exist) can be seen as providing little useful indication of what one might expect in the future. Such scenarios cannot be ruled out as implausible (e.g. regime shifts do occur). However, in the absence of strong supporting evidence that they have occurred, it is important to ensure that prior assumptions about functional relationships between stock size and productivity do not result in unrealistic expectations (either pessimistic or optimistic) relative to the actual history of the fishery. While consideration of possible regime shifts in many situations are probably warranted within the full set of uncertainties that need to be considered when evaluating management procedures, it would seem important to ensure that such scenarios do not dominate the evaluation process so that either "non-action" or "overly restrictive" management results (e.g. it can be argued that there is no need to rebuild because past higher catch levels were a fluke do to an unusual and rare period of high productivity/recruitment)[8]. As a default, it would

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[5] "The role of stock assessment is not to make best guesses as MSY, but rather to help design a fishery management system that can respond to the types of variability we see in nature" Hilborn and Walters 1992.

[6] The Precautionary Guidelines of UN Fish Stocks Agreement suggest that MSY should be treated as at most a limited reference point (United Nations 1995)

[7] This latter does not necessarily mean that the MSY objective was the cause.

[8] The issue of regime shifts is not unique to MSY rebuilding targets and is an issue that needs also to be considered for other potential rebuilding targets in a management procedure evaluation context.

seem important to ensure that a management procedure would provide reasonable and adequate performance under mild stationarity assumptions (e.g. that relatively similar productivity levels seen in the recent past will persist in to the future).

Rebuilding relative to the maximum rebuilding possible given a specified timeframe

In a rebuilding situation where there is substantial uncertainty about the productivity of a stock, it may be very difficult to specify meaningful absolute rebuilding targets to be achieved within a specified timeframe. The options in this situation would be (1) to default to the lowest level of rebuilding as set by the least productive scenario that is considered plausible and thus risk foregoing substantial rebuilding if in fact the stock was more productive or (2) to accept objectives that are unachievable if the low productivity scenarios are in fact correct. An alternative approach would be to specify a rebuilding objective in terms of some percentage of the maximum possible rebuilding (i.e. under zero catches) given a time window. Such an approach takes into account that a primary objective of management may be to ensure that its actions have a high probability of achieving some rebuilding over shorter term time horizons (i.e. that one is “heading in the right direction”). This may be particularly true for long lived and late maturing species (such as SBT) where the expected timeframes to achieve substantial rebuilding may be long. Within the CCSBT context, concerns has been express that the rebuilding object has only been focused on a goal up to 26 years in the future, without any intermediate measures about the stock’s performance in the interim.

It should be noted, that having a rebuilding objective relative to the maximum possible is not sufficient in the long term. Also, there needs to be an objective that determines when sufficient rebuilding has been achieved (e.g. repeated use of such an objective over multiple timeframes would in the long term lead to rebuilding to unexploited levels and zero catches). In other words, setting a direction to head does not alleviate the need to know when one has arrived. Nevertheless, having a stock status objective in such a relativistic framework may allow for realistic trade-offs between catches and rebuilding that do not require foregoing large amounts of catch if the more productive plausible scenarios turn out to be correct or sacrificing any chance of rebuilding if the lower productive scenarios turn out to be correct (assuming that procedures can be developed that produce such performance).

Results from SBT Operating Model Conditioning Process

Ideally, there would be concordance among different potential rebuilding objectives (e.g. empirical observations about problems with the stock would be expected to correspond to periods of low and declining stock levels). In reality, uncertainties in the model estimates of stock status and their underlying dynamics means that discrepancies are likely to exist. Different rebuilding objectives are likely to be differentially sensitive to different hypotheses for the underlying uncertainties in the modelling process. This can create a difficult dilemma in terms of selecting an appropriate target. Trying to ensure adequate performance across a range of targets may provide a better approach for providing robust management in terms of stock-status related objectives. In addition, consideration of alternative rebuilding objectives within a set of operating models can also provide insights into the importance of different uncertainty dimensions for evaluation process. Also, in some casse, it may provide indications of the plausibility and consistency of particular scenarios or hypotheses.

Table 1 to 5 provide comparisons of the results from conditioning phase of the SBT operating model for the range of hypotheses about stock productivity levels and natural mortality rates contained in the 2nd stage base case scenarios (Anon. 2003). Also included in these tables are results for the other two natural mortality vectors considered within the set of robustness trials. Provided in these tables are the best fit estimates for the current status relative to various possible rebuilding targets, as well as, the relationship between various potential rebuilding targets. These tables provide some indications of the relative importance of steepness and natural mortality rates in determining current stock status relative to possible objectives. In particular, these tables suggest (as might be expected) that rebuilding targets based on B_{msy} levels will be highly dependent upon steepness values and are basically independent of uncertainties about natural mortality rates. In contrast, the 1980 rebuilding target is substantially less sensitive to assumptions about steepness and is more sensitive to which natural mortality vector is used. Similarly, rebuilding targets based on overall SSB depletion levels are relatively insensitive to different steepness values and most of the variability is determined by which natural mortality vector is used. It is important to emphasize that not all of the scenarios represented in Tables 1-5 are necessarily equally plausible. In particular, systematic temporal deviations in the fit to the CPUE with mortality vectors 3 (and to somewhat lesser extent vector 4) appear to be one important factor contributing to the sensitivities seen to M in these tables (Figure 3)

Using B_{msy} levels as a target in the high steepness cases (particularly in the M vector 3 and 4 scenarios) suggests that these scenarios would not have provided a reliable basis for evaluating the performance of management in the past or would not have provided realistic expectations of what actually occurred. This can be seen, for example, in the M vector 3 and 4 scenarios, where the stock size has never been below the estimated B_{msy} level (Table 6), while catches since ~1990 have also been substantially below their corresponding MSY level (Figure 4). Yet, the spawning biomass is estimated to have continued to decline. For the M vector 5 scenario, the estimates of SSB suggest that the stock has never been overfished relative to a B_{msy} target. For M vector 1 and 2, the stock was only in an overfished state relative to a B_{msy} target after the major quota cuts in 1988 and the stock continued to decline for a number of years (e.g. at least to 1996) even though catches were well below their MSY level.
Finally, it should be emphasized that this paper was prepared to stimulate discussion on and is not advocating a particular solution to the question of how best to define rebuilding targets for SBT in the context evaluating the performance of management procedures.

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Table 1: Best fit estimates of 1980 spawning stock level relative to its corresponding unexploited equilibrium level (B_o) level for different realization of the SBT operating model

	Steepness		
M vector	0.30	0.55	0.80
1	0.38	0.29	0.31
2	0.45	0.37	0.36
3	0.60	0.58	0.61
4	0.53	0.52	0.54
5	0.45	0.35	0.33

Table 2: Best fit estimates of current spawning biomass (2002) relative to B_o for different realization of the SBT operating model.

	Steepness		
M vector	0.30	0.55	0.80
1	0.14	0.15	0.19
2	0.17	0.16	0.18
3	0.31	0.31	0.34
4	0.25	0.25	0.28
5	0.19	0.22	0.26

Table 3: Best fit estimates of B_{msy} relative to B_o for different realization of the SBT operating model.

	Steepness		
M vector	0.30	0.55	0.80
1	0.49	0.33	0.21
2	0.47	0.33	0.21
3	0.45	0.32	0.21
4	0.45	0.32	0.21
5	0.49	0.33	0.22

Table 4: Best fit estimates of current spawning biomass (2002) relative to 1980 B for different realization of the SBT operating model.

	Steepness		
M vector	0.30	0.55	0.80
1	0.36	0.52	0.61
2	0.37	0.44	0.50
3	0.51	0.54	0.56
4	0.47	0.49	0.51
5	0.43	0.62	0.78

Table 5: Best fit estimates of 1980 spawning biomass relative to B_{msy}.

	Steepness		
M vector	0.30	0.55	0.80
1	0.79	0.88	1.44
2	0.96	1.13	1.71
3	1.32	1.80	2.88
4	1.16	1.61	2.61
5	0.92	1.05	1.51

Table 6: The first year in which the SBT spawning biomass is estimated to be below B_{msy}.

M vector	Steepness 0.30	0.55	0.80
1	1974	1973	1990
2	1978	1982	1991
3	1990	1999	never
4	1985	1994	never
5	1975	1981	never

Table 7: The five natural mortality vectors defined for used in the SBT operating model (Anon. 2003).

Age	*Vector 1*	*Vector 2*	*Vector 3*	*Vector 4*	*Vector 5*
0	0.50	0.40	0.30	0.50	0.30
1	0.45	0.37	0.28	0.45	0.28
2	0.40	0.33	0.27	0.40	0.27
3	0.35	0.30	0.25	0.35	0.25
4	0.30	0.27	0.23	0.30	0.23
5	0.25	0.23	0.22	0.25	0.22
6	0.20	0.20	0.20	0.20	0.20
7	0.19	0.18	0.16	0.16	0.19
8	0.18	0.15	0.13	0.13	0.18
9	0.16	0.13	0.09	0.09	0.16
10	0.15	0.10	0.05	0.05	0.15

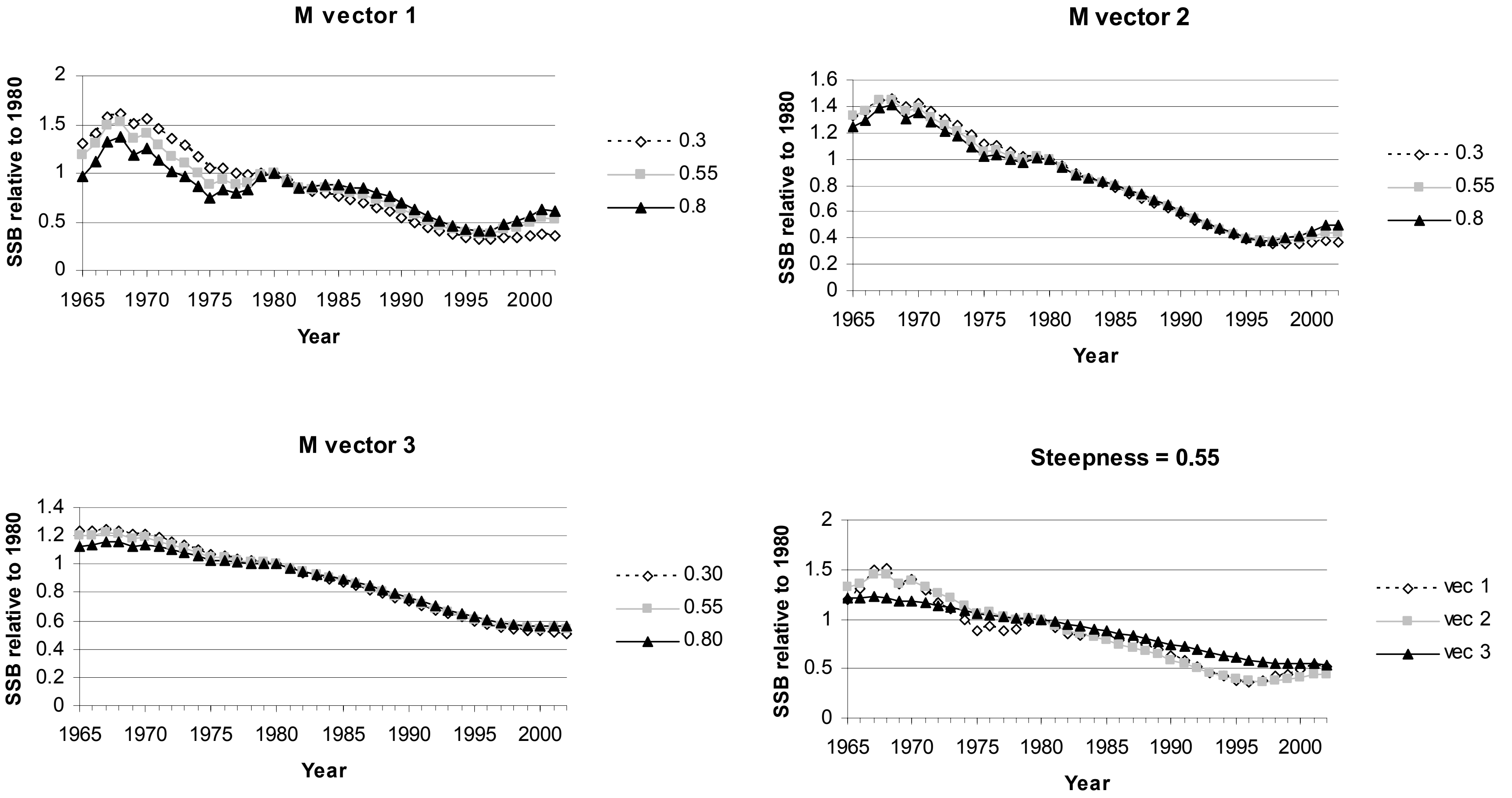


Figure 1: Comparison of best fit estimates of spawning biomass trends since 1965 relative to 1980 for different realization of the SBT operating model for the three different steepness values and natural mortality vectors

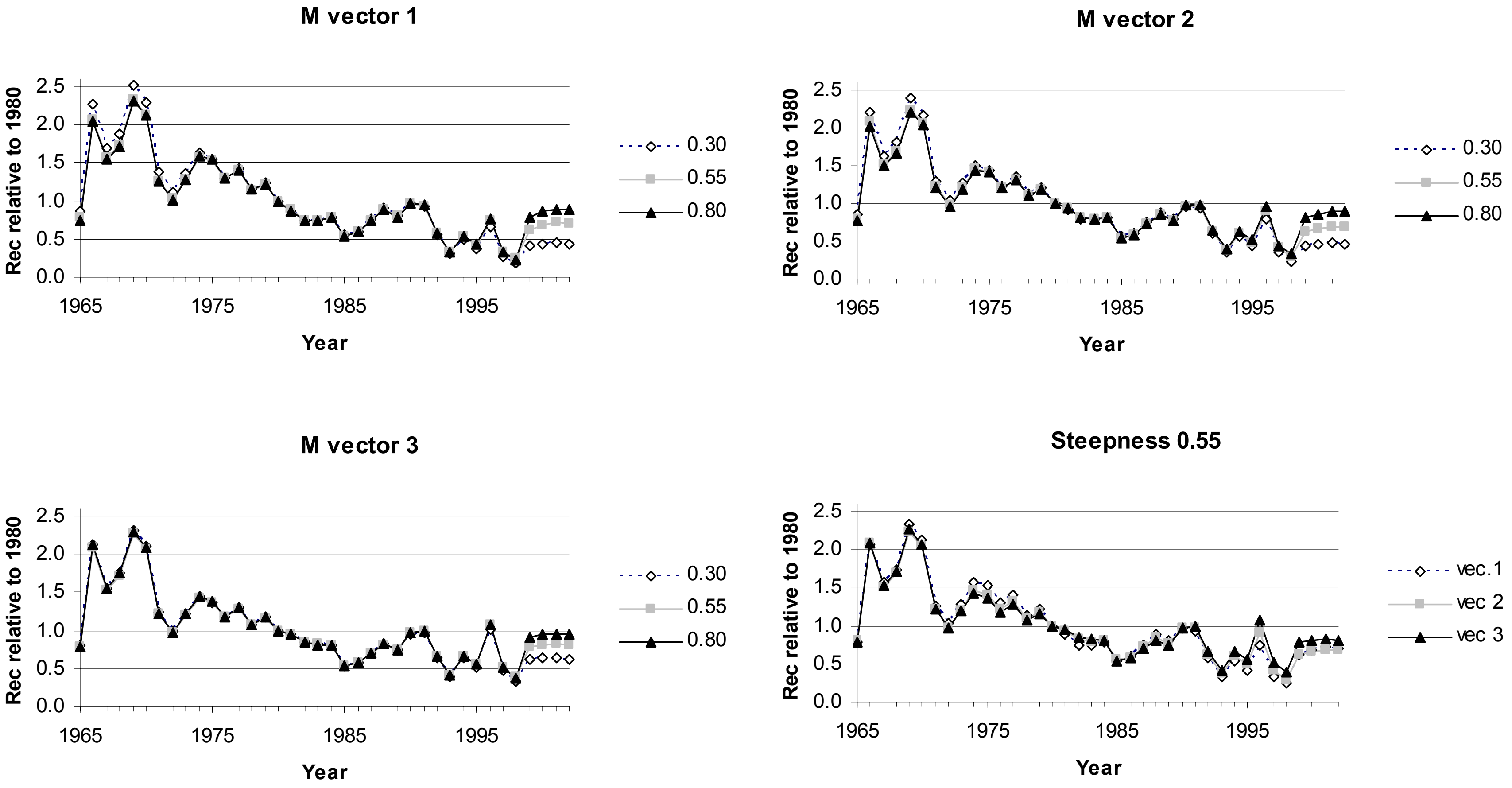


Figure 2: Comparison of best fit estimates of recxruitemt trends since 1965 relative to 1980 for different realization of the SBT operating model

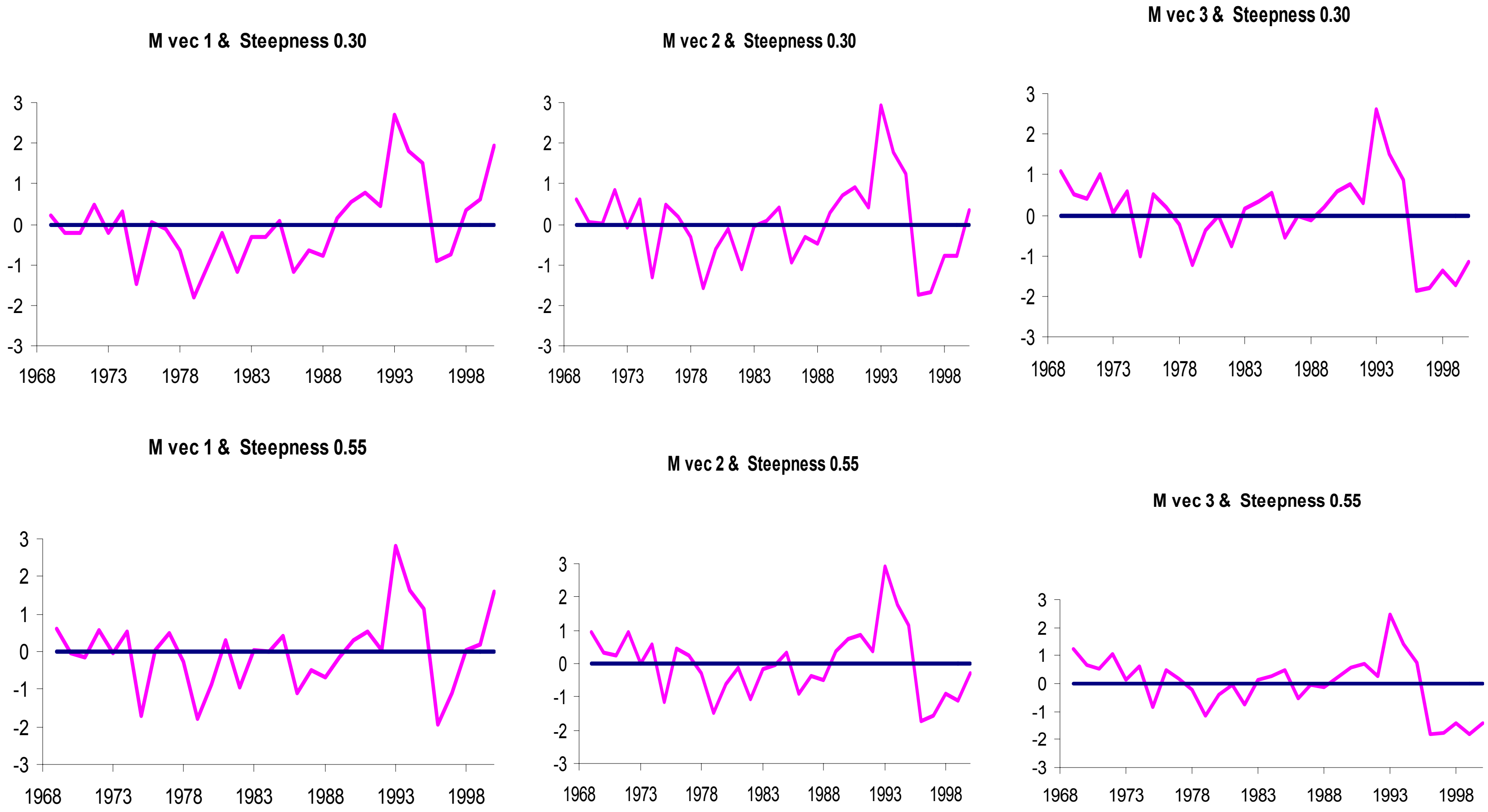
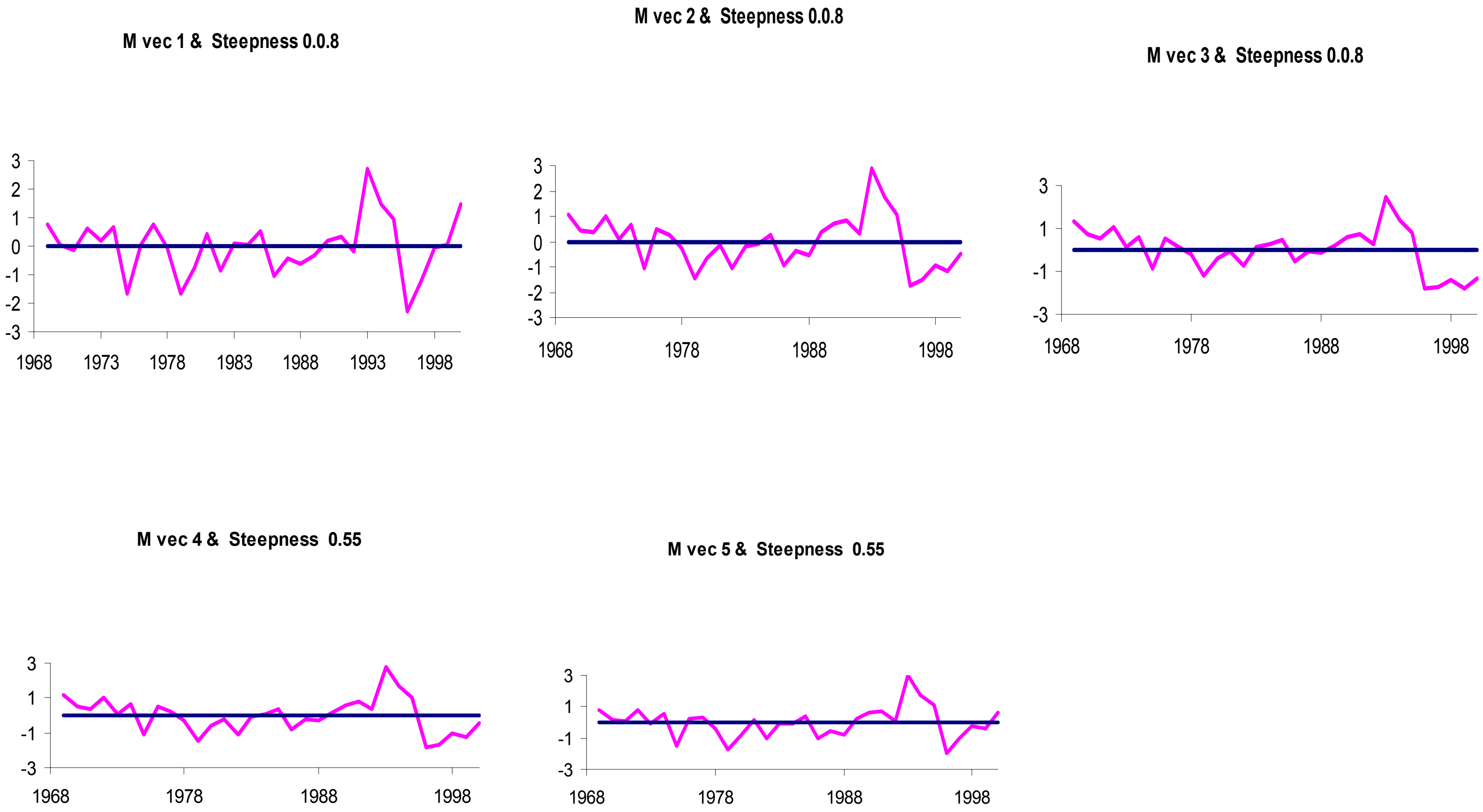


Figure 3: Comparison of temporal trends in CPUE residuals for different realizations of the SBT operating model.



M vec 1 & Steepness 0.0.8

M vec 2 & Steepness 0.0.8

M vec 3 & Steepness 0.0.8

M vec 4 & Steepness 0.55

M vec 5 & Steepness 0.55

Figure 3 (continued): Comparison of temporal trends in CPUE residuals for different realizations of the SBT operating model.

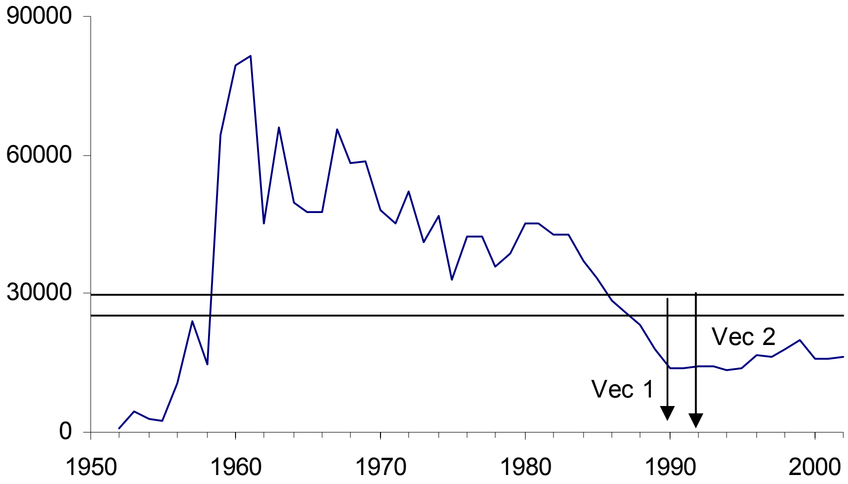


Figure 4: Estimated annual global catch of SBT in metrc tonnes compared to the range of estimated MSY catch levels (the two horizontal lines) for the SBT operating model when steepness is fixed at 0.80 for the five different natural mortality vectors. The two vertical areas indicate the year in which the spawning stock biomass levels was estimated to have been below B_{msy}. For the other three natural mortality vectors msy is never estimated to have been below B_{msy}.