Summary of the report “Review of Target and Limit Reference Points” By Laurence T. Kell (2019)

Joel Rice, August 5th 2022 in preparation for TWG CMSA 06

Introduction

The goal of this document is to summarize and develop a list of candidate (biological) reference points for chub mackerel based on the report “Review of Target and Limit Reference Points” By Laurence T. Kell (2019), here after “the review”. The text, figures and conclusions are taken from the previously mentioned document, figure references refer to the review.

The review discusses Management Frameworks, Management Strategy Evaluation, Case Studies for fisheries management, Stock Assessment (including model diagnostics) and ends with a discussion. The review covers reference points used in pelagic species fisheries by other regional fishery management organizations (RFMOs), and makes recommendations on possible options for NPFC with respect to target and limit reference points to be used for Pacific saury and chub mackerel.

The review uses case studies to illustrate the ways in which reference points are estimated, uncertainty is considered and advice provided by RFMOs and other management organizations. Additionally, the main points of relevance to NPFC chub mackerel and Pacific saury are summarized and discussed.

A summary of Target and Limit Reference Points

ICES

ICES uses both a Precautionary Approach (PA) framework with reference points to trigger management action before limits are reached and an advice rule (AR) to achieve MSY. The key reference point is the biomass limit Blim as the other limit and precautionary reference points (B_{PA}, F_{lim}, and F_{PA}) are all derived from it.

B_{lim} is defined as a deterministic point below which the biomass (SSB) of a stock is considered to have reduced reproductive capacity or the recruitment dynamics are unknown. B_{lim} is commonly derived from a stock recruitment relationship.

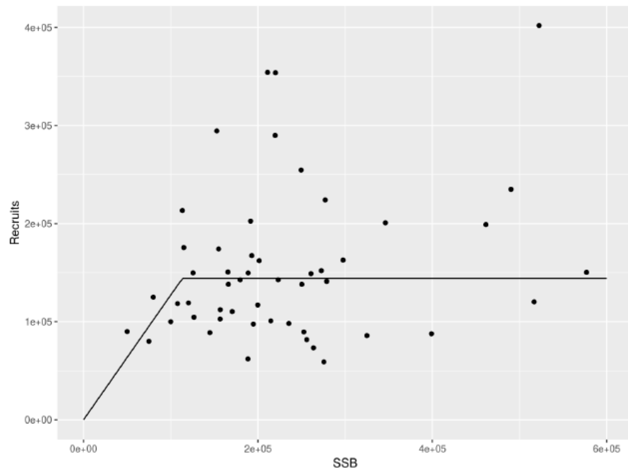

Figure 4: Segmented Regression fitted to stock recruitment pairs.

The intercept of the two lines is defined as B_{lim}, as recruitment can be seen to be generally lower when SSB is below B_{lim}. F_{lim} is then defined as fishing mortality which would reduces SSB to B_{lim}.

The PA reference points are derived taking into accounting uncertainty by assuming an estimation error (_) derived from a stock assessment. B_{PA} is then set at the 95th percentile of B_{lim}), to ensure that there is a less than a 5% chance of being below B_{lim}.

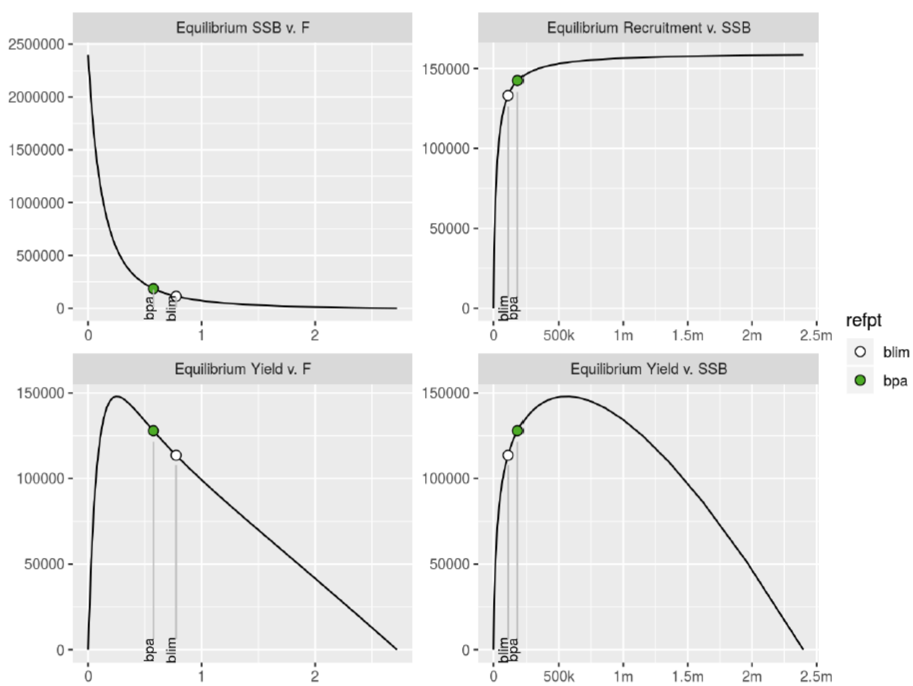

Figure 5: PA reference points

For stocks assessed using biomass dynamics models (i.e. where no age or length data are available) dynamics are modelled using a production function based a few parameters which models the combined effects of recruitment, growth, and natural mortality. It such cases it is current practice to set reference points based on the deterministic equilibrium relationship between yield, F, and stock biomass using the production function, for example that of (Pella and Tomlinson, 1969) i.e.

$$\frac{r}{p} \cdot \; B(1 - (\frac{B}{K})^p)$$

Where r is the population growth rate at small populations size, (p) is the shape of the production function, B is the biomass and K is the carrying capacity. If p = 1 then the maximum productivity (MSY) is found halfway between 0 and K, as p increases MSY shifts to the right. F_{MSY} is then the harvest rate (catch/biomass) that maximizes production. So far no F_{PA} or B_{PA} reference points have been set by ICES for stocks assessed using a biomass dynamic assessment model.

To achieve MSY ICES has adopted an Advice Rule (AR) based on two reference points F_{MSY} and $MSY_{Btrigger}$, which can be used to set catches. F_{MSY} is the fishing mortality for a given fishing pattern and current environmental conditions that gives the long-term MSY. While $MSY_{Btrigger}$ is the lower bound of SSB fluctuation around B_{MSY} and is intended to trigger a cautious response so that in cases where SSB falls below $MSY_{Btrigger}$ fishing mortality is reduced to rebuild a stock to B_{MSY} . The reduction in fishing mortality is proportional to the ratio between the size of the spawning stock and $MSY_{Btrigger}$.

Short lived species in ICES

For short-lived stocks, as for long-lived ones, the ICES MSY approach is aimed at achieving a high probability (95%) of maintaining the stock biomass above the level required to produce MSY (i.e. > B_{lim}). To do this ICES uses two reference points, MSY $B_{escapement}$ and F_{cap}. Yearly catch advice corresponds to the estimated stock biomass in excess of MSY $B_{escapement}$, but constrained to allow fishing mortality that is no higher than F_{cap}.

Additional rules include

1. If, under natural conditions of no fishing, the long-term annual probability of SSB being below B_{lim} _ 5%, then the same criteria as for long-lived stocks is used.
2. If, under natural conditions of no fishing, the long-term annual probability of SSB being below B_{lim} > 5%, then the management plan/strategy is precautionary if the maximum probability that SSB is below B_{lim} is _ 5% (after the fishery) in any year when a fishery takes place. In all other years the fishery should be closed. Accepted plans with the above or more stringent criteria should not imply an increase of the long-term annual probability of SSB being below B lim by more than a factor of 2 compared to natural conditions of no fishing.

IN TUNA RFMOs

Interim Target and Limit Reference Points (TRPs and LRPs) have been agreed for several stocks (i.e. albacore, swordfish, bigeye, skipjack, and yellowfin tuna). To provide consistent advice across the Tuna RFMOs have adopted a common management advice framework known as the Kobe Framework (De Bruyn et al., 2012) which has the main objective of keeping stocks above B_{MSY} and fishing below F_{MSY} . This requires assessment results to reported with respect to the probabilities of maintaining the stock above B_{MSY} and fishing mortality below FMSY. Advice on stock status is therefore normally given in the form of a phase plot with a green quadrant corresponding to the target region (i.e. where the stock is neither overfished ($B>B_{MSY}$) nor subject to overfishing (F FMSY).B_{TARGET} is set equal to the estimate of B_{MSY} and F_{TARGET} to F_{MSY} from the assessment, while the limits are set to multiples of B_{MSY} and F_{MSY} , e.g. for albacore, yellowfin and swordfish B_{LIM} = 0:40B_{MSY} , F_{LIM} = 1:40F_{MSY} , bigeye 0:50B_{MSY} , 1:30F_{MSY} , and skipjack 0:40B_{MSY} , 1:50 F_{MSY} . These values reflect the life histories of these species and the variability in productivity.

Because is difficult to estimate steepness in stock assessments (Lee et al., 2012), as often there is insufficient data on recruitment at low stock size and recovery from depletion to enable steepness to be reliably estimated. Therefore the WCPFC proposed a hierarchical approach to identifying limit reference points, with three levels based upon the biological knowledge and data available; namely i) Maximum Sustainable Yield (MSY); ii) spawning potential-per-recruit (SPR); and depletion based limit reference points.

The first level uses F_{MSY} and B_{MSY} but only in the case where a reliable and precise estimate of steepness is available. The second level uses F_{SPR} and 20% of SSB_0 for cases in which uncertainty in steepness is high, but the key biological (natural mortality, maturity) and fishery (selectivity) variables are reasonably well estimated. The third level does not include an F-based limit reference point if the key biological and fishery variables are not well estimated, but simply uses a B_{limit} of 20% of SSB_0.

In Mackerel RFMOS

An hierarchical approach could be developed for limit and target reference points for setting advice, where tiers depend upon the biological knowledge, available data and dynamics of the stock; tiers could be based on Maximum Sustainable Yield F_{MSY} and SSB_{MSY} : where age data are available and stock recruitment relationship and steepness or a production function can be estimated; Spawning potential-per-recruit, SPR and $F_{0:1}$: where age based estimates are available but the stock recruitment relationship can not be estimated reliably . Depletion where only indices of abundance a limit reference points limit such as a B_{lim} an be set equal to a value based on $SSB_{0.}$

Blue mackerel: Eastern Australia
The Australian Small Pelagic Fishery (SPF) is not managed to achieve reference points for stock status; rather, harvest rates are applied at one of three precautionary tiers on the basis of expert judgment in interpreting data from the most recent daily egg production method (DEPM) based on survey results. The SPF harvest strategy is used to set recommended biological catches (RBCs) and total allowable catches (TACs). This includes a three-tier system that is applied separately to each stock. The tiered system is designed to allow greater levels of catch when higher-quality research information was available on stock status. The SPF tier 1 decision rules used a maximum exploitation rate of 15% of estimated spawning biomass from a recent DEPM survey as the basis for setting RBCs. Under tier 2, maximum RBCs are set based on a maximum exploitation rate of 7.5% of the estimated spawning biomass. For tier 3, the maximum RBC was set at 500 t for each stock, reflecting that a high level of precaution is warranted when information is
lacking.

Blue mackerel: Western Australia
As in Western Australia TACs are set based on the DEPM survey and the precautionary Tier approach, where RBCs and TACs are based on a DEPM survey and application of the tier 2 decision rule (using 7.5% of the 2005 spawning biomass estimate). MSE testing has been conducted for blue mackerel (west) (Giannini et al., 2010; Smith et al., 2015). These models suggest that the current harvest strategy is appropriate, and its application would result in a low probability of the stock falling below 0.2B0 for more than 90% of the time, in line with the HSP.

Atlantic mackerel: NE Atlantic
The stock is assessed by ICES using the PA and MSY framework relative to target, limit and precautionary reference points, i.e. F_{MSY} , F_{lim}, F_{pa}, $MSY_{Btrigger}$, B_{lim}, and B_{pa}. Despite being managed using this framework the stock is now assessed as being below B_{ps} due to several years of poor recruitment coupled with high F.

Jack mackerel: South Pacific
Managed by the South Pacific Regional Fisheries Management Organization, currently the jack mackerel stock is subject to a rebuilding plan where the value of F depends on where the stock is relative to $0.8B_{MSY}$ and B_{MSY} for SSB. This means that the catch advice for the stock can be highly variable between years when the SSB is estimated to be close to these boundaries. The harvest strategy had been evaluated using MSE in 2014. The output of the 2013 jack mackerel stock assessment was used to develop the operating model, and based on two stakeholder

consultations a number of alternative plans were developed and evaluated. A number of performance statistics were used, i.e. i) the rate of biomass growth during a certain time frame ii) expected catch and catch variability, iii) risks of biomass decline, and iv) expected time to reach X% of unfished SSB (a proxy representing 80% of B_{MSY})

Pacific Herring
in 2016 an MSE process started as part of the renewal
of Pacific Herring management with the aim of supporting the development of management options and engagement of resource users.

The main objectives for the resource include to i) avoid the limit reference point of 0:30B_0 with high probability (>75-95%); ii) maintain spawning stock biomass above the Upper Stock Reference (USR) of 0:60B_0, with 50% probability; and iii) maintain spawning stock biomass at or above a target reference point biomass level of 0:75B_0 with 75% probability. Where the probabilities are calculated over three herring generations (i.e. 15 years).

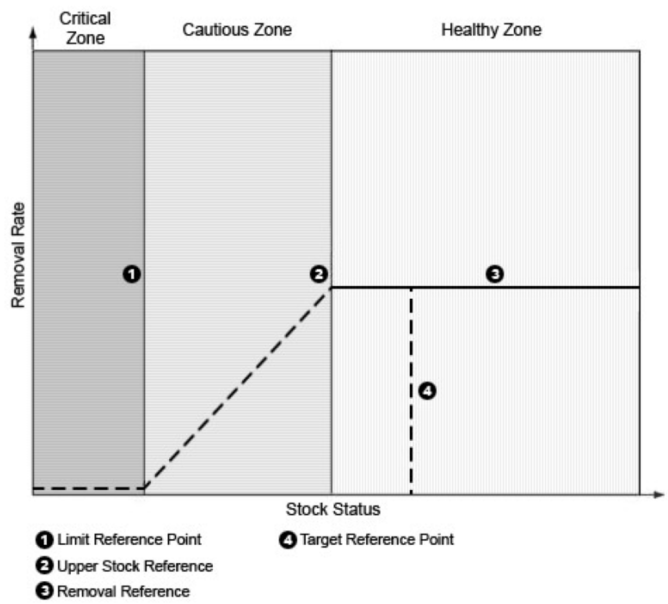

Figure 9: Critical, cautious and healthy zones, defined in terms of stock status (biomass) and removal rate.

Pacific Sardine
Fishery management was conducted by the State of California until 2000 when management authority was transferred to the Pacific Fishery Management Council (PFMC, Hill et al., 2011). Trends and status are currently assessed using the Stock Synthesis assessment model (SS Methot and Wetzel, 2013) and integrates data from research surveys and commercial catches (Hill et al., 2011). The assessment is conducted in the fall and annually estimates the pre-season age 1+ biomass. Management between 1998 and 2012 was set using a harvest control rule (PFMC, 2011), i.e.

$$HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION$$

which sets the total allowable catch (TAC) for each year, based on the current biomass (BIOMASS) less an escapement threshold (CUTOFF) below which fishing is prohibited. The harvest is determined by FRACTION which is a temperature-dependent exploitation fraction which ranges from 5 to 15%, and DISTRIBUTION the average proportion of the coastwide biomass in USA waters.

Capelin
Icelandic capelin has been acoustically surveyed since 1978, in 1979 it was recommended that the fishing

season should open with a low, precautionary quota, which would then be revised upwards after an assessment survey of the mature stock within the fishing season (Vilhjálmsson, 1994). This plan was, however, never implemented and instead preliminary catch quotas were set without adequate knowledge of the condition of the stock. the resulting catches were probably too large; causing the spawning stock to collapse and a fishing moratorium was put in place in 1982 (Vilhjálmsson and Carscadden, 2002).

Catch quotas were based on acoustic surveys before fishing commenced in August, with a final TAC being set after an acoustic survey of maturing adults during the spawning migration in January. The principal regulation at the time was to leave 400,000t to spawn under the assumption that the previous problems had to do with how to determine an appropriate preliminary quota and not the harvest control rule.

The principal harvest control rule for the Icelandic capelin, to maintain a spawning stock of 400 thousand tonnes, has not changed since 1979.

It thus seems that capelin is a type of fish that has an extraordinary sensitivity to environmental and ecological conditions, and that appropriate HCRs need to take this into account. The harvest control rule for the Icelandic capelin has been deterministic in the sense that point estimates of the spawning stock biomass have been taken at face value; that is, no provisions were made for empirical or structural (model) uncertainty. Recently, a new harvest control rule was introduced, again modelled after the harvest control rule for the Barents Sea capelin (Gjøsæter et al., 2009, 2015) where empirical uncertainty is taken into account. the new rule also reflects predation on capelin that takes place between the time of the acoustic measurements of the spawning migration and the spawning season. the final TAC will be set such that the probability of a spawning stock below a biomass limit of 150 thousand tonnes is less than 5%. the new HCR is considered to be in agreement with the precautionary approach. This change in formulation is expected to be more conservative in terms of harvest strategy than the earlier method, mostly because of higher the median of the probability distribution for the spawning stock level is expected to be close to 400,000t. Climatic considerations have until now not been taken into account in the harvest control rules despite evidence of impacts on capelin biology and distribution from climatic changes.

Discussion

The discussion covers many points regarding reference points and HCRs, and notes specifically

> "It is … unlikely that frameworks developed elsewhere can simply be translated to the North Pacific. This review showed that the life history characteristics and the dynamics of the stocks are important. Pelagic fish are key components of marine foodwebs and can show wide spatial and temporal variability and may fluctuations in abundance independently of fishing. Also when species are short lived fluctuations may occur independently of fishing, in such cases reference points derived from assumptions about surplus production derived from a stock assessment may not be robust."…. In the review of ICES and pacific stocks it was seen that
> it was insufficient to just develop limit and target reference points for use as in a harvest control rule, additional elements such as a cut-off that allowed a minimum spawning stock biomass each year, and a cap on F (Fcap) so that F was robust to assessment error were also required. It is also important to note that North East Atlantic mackerel although managed using target and limit reference points stock became over fished due to recent poor recruitments."

With respect to reference points the review notes that

Target and Limit Reference Points

A hierarchical approach could be developed for limit and target reference points for setting advice, where tiers depend upon the biological knowledge, available data and dynamics of the stock; tiers could be based on

- **Maximum Sustainable Yield** F_{MSY} and SSB_{MSY} : where age data are available and stock recruitment relationship and steepness or a production function can be estimated;
- **Spawning potential-per-recruit, SPR** and $\mathbf{F_{0:1}}$: where age based estimates are available but the stock recruitment relationship can not be estimated reliably .
- **Depletion** where only indices of abundance a limit reference points limit such as a B_{lim} can be set equal to a value based on SSB_0

The following table shows the individual reference points discussed in the review.

Management Group	Species	Reference Point	Notes
ICES	Precautionary Approach	B_{PA}	95th percentile of Blim.
ICES	Advice Rule (AR)	FMSY and MSYBtrigger	FMSY is the fishing mortality for a given fishing pattern and current environmental conditions that gives the long-term MSY. $MSY_{Btrigger}$ is the lower bound of SSB fluctuation around B_{MSY}
ICES	Short Lived Species	MSY Bescapement and Fcap	Yearly catch advice corresponds to the estimated stock biomass in excess of MSY Bescapement, but constrained to allow a fishing mortality that is no higher than Fcap. (Additional rules apply)
Kobe Framework		Fmsy and Bmsy	
WCPFC	Tier 1	FMSY and BMSY	where a reliable and precise estimate of steepness is available
WCPFC	Tier 2	FSPR and 20% of SSB0	where uncertainty in steepness is high, but the key biological (natural mortality, maturity) and fishery (selectivity) variables are reasonably well estimated
WCPFC	Tier 3	20%SBF=0, the spawning stock biomass in the absence of fishing derived from a stock assessment.	Doesnot include an F-based limit reference point if the key biological and fishery variables are not well estimated
Australian Small Pelagic Fishery	Tier 1	maximum exploitation rate of 15% of estimated spawning biomass from a recent DEPM survey	Based on the daily egg production method (DEPM) with high quality informaiton on stock status
Australian Small Pelagic Fishery	Tier 2	7.5% of the estimated spawning biomass	Based on the daily egg production method (DEPM) with moderate information on stock status
Australian Small Pelagic Fishery	Tier 3	500 t	when information is lacking
SPRFMO	Jack Mackerel	0.8BMSY and BMSY	F depends on where the stock is relative to 0.8BMSY
US and Canada	Pacific Herring	0.75B0	Target Reference Point