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FROM OBJECTIVES TO CANDIDATE PERFORMANCE INDICATORS FOR NSWO MSE

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SUMMARY

Here we provide a summary of how management objectives for the Northern Swordfish stock have been articulated in the Commission's Recommendations and Resolutions, the additional clarifications that need to be made in order to calculate these as Performance Indicators, and a summary of Performance Indicators that have been used in other Management Strategy Evaluations at the International Commission for the Conservation of Atlantic Tunas. We conclude with a list of key performance indicators which should at a minimum include: the probability that the biomass at time t is greater that the biomass that produces B_{MSY} and that the fishing mortality is less than the fishing mortality that produces F_{MSY}. $P(Bt>B_{MSY}$ & $Ft<F_{MSY})$; the probability that the stock is above the limit reference point $P(Bt>B_{LIM})$, the mean catches over t simulation years, and the average variability in yield between time periods. Additional precision from the Commission is needed over what time period Performance Indicators are to be calculated, the assessment period interval, and if additional Performance Indicators should be presented.

RÉSUMÉ

Nous soumettons ici un résumé de la façon dont les objectifs de gestion pour le stock d'espadon du Nord ont été articulés dans les Recommandations et Résolutions de la Commission, les clarifications additionnelles qui doivent être apportées afin de les calculer en tant qu'indicateurs de performance ainsi qu'un résumé des indicateurs de performance qui ont été utilisés dans d'autres Évaluations de la stratégie de gestion au sein de la Commission Internationale pour la Conservation des Thonidés de l'Atlantique. Nous concluons par une liste des principaux indicateurs de performance qui devrait inclure au moins : la probabilité que la biomasse au moment t soit supérieure à la biomasse qui produit BPME et que la mortalité par pêche soit inférieure à la mortalité par pêche qui produit FPME P(Bt>BPME et Ft<FPME) ; la probabilité que le stock se situe au-dessus du point de référence limite P(Bt>BLIM), les prises moyennes sur les années de simulation t et la variabilité moyenne de la production entre les périodes temporelles. Des précisions supplémentaires sont nécessaires de la part de la Commission pour déterminer la période temporelle sur laquelle les indicateurs de performance doivent être calculés, l'intervalle des périodes d'évaluation et savoir si des indicateurs de performance additionnels devraient être présentés.

RESUMEN

Se presenta un resumen de cómo se han articulado los objetivos de ordenación para el stock de pez espada del Atlántico norte en las Recomendaciones y Resoluciones de la Comisión, las aclaraciones adicionales que deben hacerse con el fin de calcularlos como indicadores del desempeño y un resumen de los indicadores del desempeño que se han utilizado en otras evaluaciones de estrategias de ordenación en la Comisión Internacional para la Conservación del Atún Atlántico. Concluimos con una lista de indicadores del desempeño clave que, como mínimo, debería incluir: la probabilidad de que la biomasa en el tiempo t sea superior a la biomasa que produce B_{RMS} y que la mortalidad por pesca sea inferior a la mortalidad por pesca que produce F_{RMS}. $P(Bt>B_{RMS}$ y $Ft<F_{RMS})$; la probabilidad de que el stock esté por encima del punto de referencia límite $P(Bt>B_{LIM})$, las capturas medias durante t años de simulación y la variabilidad media en el rendimiento entre periodos. Es necesario que la Comisión precise más para qué periodo deben calcularse los indicadores del desempeño, el intervalo de evaluación, y si deberían presentarse indicadores de desempeño adicionales.

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KEYWORDS

Quota regulations, Size limit regulations, Simulation, yield predictions, computer programs, resource conservation, management strategy evaluation

1. Objectives

ICCAT recommendation Rec. [15-07] articulated the Commission's decision for the development of MSE processes and harvest control rules. It identified priority stocks including bluefin tuna, albacore tuna, tropical tunas, and North Atlantic swordfish. Importantly, [15-07] defined the following working definitions: a) The management strategy evaluation (MSE) is an inclusive, interactive and iterative process for evaluating, *inter alia*, the performance of proposed harvest control rules and reference points in relation to management objectives, including the risk associated with not achieving those objectives; b) A limit is a conservation reference point based on a level of biomass (B_{LIM}) that should be avoided considering that beyond such limits, the sustainability of the stock may be in danger; c) A target is a management objective based on a level of biomass (B_{TARGET}) or a fishing mortality rate (F_{TARGET}) that should be achieved and maintained; d) A threshold is a level of biomass ($B_{THRESHOLD}$) reflecting the precautionary approach that triggers pre-agreed management actions to reduce the risk of breaching the limits. Thresholds should be set sufficiently far away from limits so that there is low probability that the limits will be exceeded; and e) Harvest Control Rules (HCRs) are decision rules that aim to achieve the target reference point and avoid the limit reference point by specifying pre-agreed management actions when $B_{THRESHOLD}$, F_{TARGET} or B_{LIM} are breached.

To avoid confusion with d) above, "A threshold is a level of biomass ($B_{THRESHOLD}$) reflecting the precautionary approach that triggers pre-agreed management actions", it is important to distinguish between objectives and so-called operational control points (Cox et al. 2013). Threshold MPs like those applied in practice by the Pacific Fisheries Management Council (Punt et al. 2008) or in the Canada US Pacific Hake Agreement´s 40:10 rule have an inflection point which is an estimated biomass threshold (as determined by the assessment model), below which first the target fishing mortality is reduced and a second threshold, at 10% of the estimated unfished biomass, below which fishing is reduced to zero. While some harvest policies that have a $B_{THRESHOLD}$ like New Zealand's Harvest Strategy Standard or analogues like $B_{TRIGGER}$ in Australia (Sainsbury 2008), Minimum Stock Size Threshold in the United States of America (Restrepo et al. 1998, Restrepo and Powers 1999), and the Upper Stock Reference in Canada's A fishery decision-making framework incorporating the precautionary approach, $B_{THRESHOLD}$ can also be equal to the target biomass. Some harvest control rules have a target biomass level of B_{MSY} but reduce the fishing mortality for all estimated biomasses below that level. Broadly, the key issue is that $B_{THRESHOLD}$ is an operational control point (Cox et al. 2013) that may be integral for the application of *some* MPs, may be different than the target reference point, or that the MPs need not have thresholds at all, for example constant exploitation rate policies (Hall et al. 1988; Parma 1990, 2002; Walters and Parma 1996).

The same nuance about operational control points and $B_{THRESHOLD}$ also applies to B_{LIM}. If the management approach is "best assessment + harvest control rule" fisheries stock assessment approach (Butterworth 2007), then HCRs are applied using the "best assessment" available and are often accompanied by negotiations. Where the HCR has been set as a matter of policy or treaty, managers need to apply the HCR as prescribed. In which case, $B_{THRESHOLD}$ and B_{LIM} become Operational Control Points (i.e. where the harvest control rule requires an adjustment to the TAC or fishing mortality). At least one problem with applying the Traditional Approach is that "best assessment" models may not be that good: their biomass estimates and reference points may be considerably in error (Walters and Ludwig 1981; Ludwig et al. 1982; NRC 1998; Walters 2003; Butterworth 2007; Magnusson and Hilborn 2007; Linton and Bence 2011). One of many consequences of assessments being unable to reliably estimate biomass for the application of MPs can be illustrated by considering the Limit Reference Point as an operational control point: first we assume that the reason for having B_{LIM} is to define a point below which there could be serious harm to the stock and that should be avoided with high probability; but when the biomass estimates are biased, or even if these estimates are unbiased but with high variance, the results are that B_{LIM} is breached unknowingly and thus with higher-than-desired probability. In such cases, to avoid breaching B_{LIM} with high probability would require that the harvest control be refined in other ways (reduce F, close fishing at biomass levels above B_{LIM}, etc.). The opposite situation is a danger too: estimation error may cause the estimated stock size to appear below B_{LIM} even when the true stock biomass is above it, thereby causing unnecessary fisheries closures (Taylor et al. 2014). For these reasons and others, MPs are selected/designed to avoid breaching B_{LIM} with high probability in the Operating Model even when the underlying assessment models are prone to estimation error.

1.1 Hierarchies of Objectives

Objectives may be structured in a hierarchy (Walters 1978; Walters et al. 1996; Schmoldt et al. 2001; Mardle et al. 2004; Elaine Ferrier 2012). For example, in the British Columbia, Canada's sablefish MSE the hierarchy of objectives in decreasing order of priority was:

1. Maintain the stock above the limit reference point in 95% of years over two generations.
2. When the spawning stock biomass falls within the cautious zone ($0.4B_{MSY} < B < 0.8B_{MSY}$), limit the probability of decline over the subsequent 10 years from very low (5%) when at the LRP to moderate (50%) when at B_{MSY};
3. at stock status levels between these two points, define the tolerance for decline by linear interpolation. Biological reference points defining stock status zones are defined by the operating model scenario.
4. maintain spawning biomass above the target reference point B_{MSY} in 50% of the projection years measured over two sablefish generations, where B_{MSY} is defined by operating model scenario;
5. maintain 10-year average annual variability in catch (AAV) of less than 15%; and 5. Maximize the median average catch over the first 10 projection years (Cox et al. 2013).

Having such a hierarchy assists greatly in MP selection. This is because it either defines the sequence with which a broad set of MPs can be eliminated. ICCAT has not yet clearly defined a hierarchy of objectives for any stock.

1.2 Management Objectives for Swordfish

The concatenation of SWO management measures laid out since 2013 articulate the Commission´s objectives in broad terms. Rec. 13-02(4) first sets out a Limit Reference Point for Northern Swordfish at 0.4 B_{MSY} in 2013. Rec 17-02 (9,10) repeats the interim limit reference point (LRP) laid out in 2013 of "$0.4*B_{MSY}$ or any more robust LRP established through further analysis". For the purposes of defining which Performance Indicators are most important for the Commission, the most germane for the Northern Swordfish stock are declared in Res 19-14, g; it defines the following conceptual objectives to develop initial operational management objectives for North Atlantic swordfish:

a. Stock Status - The stock should have a greater than [__]% probability of occurring in the green quadrant of the Kobe matrix;
b. Safety - There should be a less than [___]% probability of the stock falling below BLIM ;
c. Yield - Maximize overall catch levels; and,
d. Stability - Any increase or decrease in TAC between management periods should be less than [__]%.

Moreover, Res 19-14 states that: the MSE process could be an opportunity to confirm initial SCRS advice that size limits in North Atlantic swordfish fisheries may not be achieving their purposes. Accordingly, it is reasonable to conclude the SWO WG should, among the Management Procedures (MP) that they test, consider MPs with size limits.

2 From Objectives to Performance Indicators

Management objectives articulate benefits to be achieved and constraints to avoid (Walters 1978; De la Mare 1998; Keeney 2014). In broad terms, benefits may include things such as yield whereas constraints may be such things as reducing the cost of the management system, avoiding overexploitation, fishery closures etc. It is useful to separate objectives into so called "means objectives" and "ends objectives" (Keeney and Raiffa 1976; Gregory et al. 2012; Keeney 2014). Means objectives define how a given end is achieved and may include such things as what is practical and cost effective for the management system to apply; or process considerations like [Rec 15-07] a)'s "an inclusive, interactive, and interactive process". Ends objectives describe the consequences that essentially define the basic reasons for being interested in the decision (Gregory et al. 2012; Keeney 2014).

Multi-Objective Decision Theory, Keeney and Gregory (2005) describe so-called "attributes" that measure the achievement of objectives. Desirable attributes of these properties are as follows:

Unambiguous—A clear relationship exists between consequences and descriptions of consequences using the attribute.

Comprehensive—The attribute levels cover the range of possible consequences for the corresponding objective, and value judgments implicit in the attribute are reasonable.

Direct—The attribute levels directly describe the consequences of interest.

Operational—In practice, information to describe consequences can be obtained and value trade-offs can reasonably be made.

Understandable—Consequences and value trade-offs made using the attribute can readily be understood and clearly communicated.

In fisheries MSE, Performance Indicators are essentially the attributes defined by Keeney and Gregory (2005) in that they aim to capture a measurable quantity that reflects the achievement a given objective. Management Procedures (MPs) need to be tuned to well-specified objectives (Gregory et al. 2012) because it is difficult to evaluate how well an MP "works" when the objectives are ambiguous or vague (De la Mare 1998). Considering the list of definitions above, lending precision to such things as: the a) "risk of not achieving objectives"; what b) "should" be avoided; what c) "should be achieved or maintained"; d) "reducing the risk", e) "high/low/very low probability", "on average", "in as short a time as possible" is an essential part of MSE. It is the Performance Indicators that allow for broad aspirational objectives to be expressed more precisely (De la Mare 1998; Cox et al. 2013; Punt et al. 2016; Kronlund et al. 2018) so that they can used to discriminate between different MPs in achieving.

2.1 Properties of Performance Indicators

Performance Indicators, also Performance Metrics (PM) require three elements: the measure, a probability, and timeframes over which the metric is calculated. The measure determines the quantity that will be calculated for the PM, e.g., catch for yield objectives, F/F_{MSY} for status, average annual variability in yield for stability, and the ratio Bt/B_{LIM} for safety. Probabilities express the degree of credible belief that a given event will occur e.g., the probability that $F/F_{MSY}<1$ & $B/B_{MSY}>1$. Rec 15-07 3b requires that the Commission defines acceptable quantitative level(s) of probability of achieving and/or maintaining stocks in the green zone of the Kobe plot and (for) avoiding limit reference points. Note that PMs need not be defined in terms of reference points; other quantities such as the probability of achieving specific mean or minimum catch levels, the probability of having fisheries closed, etc. can also be considered.

Defining a timeframe over which to calculate the PM is essential. For purely prosaic reasons developers need to know over which years or sets of simulations the quantities need to be computed. More broadly however, it is also important to characterize time periods over which to calculate PMs because, depending on the stock's state, the application of a given management procedure may produce tradeoffs between short term and long-term time periods. Consider a rebuilding stock: if a stock is at low biomass at the beginning of the projection period, then the application of a given MP may result in the stock being harvested at very low levels, or fishing closed until the stock builds up to a given biomass i.e., that higher long-term yields are made at the expense of lower short-term yield. But the result of such a scenario could be that short term reductions in catch might be intolerably painful for the fishery even if a MP has desirable properties in the long term. Without defining and reporting across both specific timeframes, it is not possible to view such tradeoffs.

There are a variety of additional elements to consider regarding the timeframe over which PMs are calculated. These include: if mean or median values are to be used for reporting catch; if performance statistics should be calculated for a given year within a given time period or averaged across it; or if a % of years or % for each year across iterations is to be calculated. PMs need to be specific on each of these issues.

3 PMs and their development in other ICCAT MSE processes

3.1 Performance Indicators in the bluefin tuna MSE

Research in the Multi Criteria Decision Making field indicates that seven PMs is usually about the maximum number of such statistics that should be considered. The BFT Working Group agreed to 6 key PMs (as indicated in bold test in **Table 1**) from a broader list of PMs (Anonymous 2021a).

As an approach for trimming performance statistics to choose key PMs, SCRS/2021/047 suggested examining the correlation of individual PMs because PMs that are highly correlated do not provide additional information and could be culled from reporting to reduce duplicative information. For BFT PMs listed, there are technically two statistics reported: one east and one west, for area or stock as pertinent).

While some performance statistics for BFT will be calculated for projection year 30 only, there will be plots to display the status of the stock relative to B_{MSY} for the whole projection time period. These plots can be examined to see if any given MP gets to Br30 and if it subsequently diverges away from B_{MSY}.

Given the two-stock nature of BFT, the Working Group is considering having a performance statistic that would indicate the maximum yield that could be supported by each stock i.e. MSY. It was noted that a technical small group will consider the technical and practical elements of the calculation method in the OMs.

The BFT Group agreed that statistical distributions for PMs of interest would be represented by Zeh violin plots (Punt 2017).

3.2 Performance Indicators in the Northern albacore MSE

For the Northern Albacore stock, definition of the list of performance statistics was agreed to by Panel 2 in 2016 (Anon., 2016, see **Table 2**). Four key PMs were used, expressed in the form of radar plots with apices for stability, stock, yield and safety, to illustrate the reference case´s performance. The four PMs are the probability of being in the green quadrant, the probability of being between the B_{LIM} and B_{THRESH}, the long-term catch and the mean proportional change in catch. For reference, the primary document for the ALB MSE is the ALB MSE consolidated report (Merino et al. 2020).

3.3 Performance Indicators in the Tropical Tuna MSE

Anonymous 2021 defined two sets of PMs for western skipjack tuna MSE and a second set for the multistock tropical tuna MSE see **Table 3** and **Table 4**.

4. Candidate Performance indicators for Northern Swordfish

If the set of PMs for Northern Swordfish needs to reflect the formulation defined in Res 19-14, then it should be relatively simple to define a set of minimum PMs as is laid out in **Table 5** below.
These PMs can readily be calculated within the existing SWO MSE framework. Some additional information will be required from Panel 4. The key needed items are listed below:

i) Some precision on what the percentages probability of achieving each PM would be useful for eliminating MPs that do not meet these criteria.
ii) The time period, or time periods over which to calculated PM is/are needed by Panel 4.
iii) How percentages in each year of the time period or over the entire time period are to be calculated
iv) While average annual variability in yield (AAAV) is a common PM, in this case the SCRS will have to compute what the average variability in yield is between time periods (we assume that this period is the assessment interval) which means that this assessment interval will need to be defined too.
v)

Beyond the key performance statistics reported above, the PMs in **Table 2** provide additional options. Finally Panel 4 and the SWO Working Group may wish to supplement this table of PMs with additional PM that are of key interest but are not included in either **Table 2** or **Table 5**.

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Table 1. Performance statistics currently considered for the Atlantic Bluefin Tuna MSE. Rows in bold text indicate the key 6 statistics.

Name	Description
AAVC	**Average annual variation in catches among CMP update times t (note that except where the resource is heavily depleted so that catches become limited by maximum allowed fishing mortalities, catches will be identical to TACs) defined by:** $\boldsymbol{AAVC = \frac{1}{nt}\sum_{t=1}^{nt} \lvert C_t - C_{t-1} \rvert / C_{t-1}}$
AvC10	**Mean catches over first 10 projected years. Required to provide short-term vs long-term (AvC30) yield trade-offs.**
AvC30	**Mean catches over first 30 projected years**
AvgBr	**Average Br (spawning biomass relative to dynamic SSB_{MSY}) over projection years 11-30**
Br30	**Depletion (spawning biomass relative to dynamic SSB_{MSY}) after projection year 30**
PGT	**‘Probability Good Trend’, 1 minus probability of negative trend (Br31 – Br35) and Br30 is less than 1. Probability of 1 is biologically better. In cases where all simulations are above Br30, PGT = 1 regardless of trend. This allows further discrimination between CMPs that have comparable fraction of simulations below Br30.**
C10	Mean catches over the first 10 projected years
C20	Mean catches over projected years 11-20
C30	Mean catches over projected years 21-30
D10	Depletion (spawning biomass relative to dynamic SSB0) after the first 10 projected years
D20	Depletion (spawning biomass relative to dynamic SSB0) after projection year 20
D30	Depletion (spawning biomass relative to dynamic SSB0) after projection year 30
DNC	D30 using the MP relative to D30 had no catches been taken over the 30 projected years
LD	Lowest depletion (spawning biomass relative to dynamic SSB0) over the 30 years for which the CMP is applied.
LDNC	LD using the MP relative to LD had no catches been taken over the 30 projected years.
POS	Probability of Over-Fished status (spawning biomass < SSB_{MSY}) after 30 projected years.

Table 2. Performance indicators from SCRS/2016/015 and PA2-003, Annex 2 With changes agreed by Panel 2.

Performance measured and associated statistics	**Unit of measurement**	**Type of measurement**
1.Status		
1.1 Minimum spawner biomass relative to BMSY[1]	B_t/B_{MSY}	Minimum over [x] years
1.2 Mean spawner biomass relative to BMSY	B_t/B_{MSY}	Geometric mean over [x] years
1.3 Mean fishing mortality relative to FMSY	F_t/F_{MSY}	Geometric mean over [x] years
1.4 Probability of being in the Kobe green quadrant	B, F	Proportion of years that $B \geq B_{MSY}$ & $F \leq F_{MSY}$
1.5 Probability of being in the Kobe red quadrant[2]	B, F	Proportion of years that $B \leq B_{MSY}$ & $F \geq F_{MSY}$
2 Safety		
2.1 Probability that spawner biomass is above B_{LIM} (0.4BMSY)[3]	B_t/B_{MSY}	Proportion of years that $B > B_{LIM}$
2.2 Probability of $B_{LIM} < B < B_{THRESH}$	B_t/B_{MSY}	Proportion of years that $B_{LIM} < B < B_{THRESH}$
3 Yield		
3.1 Mean catch – short term	Catch	Mean over 1-3 years
3.2 Mean catch – medium term	Catch	Mean over 5-10 years
3.3 Mean catch – long term	Catch	Mean in 15 and 30 years
4 Stability		
4.1 Mean absolute proportional change in catch	Catch (C)	Mean over [x] years of |(Cn-Cn-1/ Cn-1|
4.2 Variance in catch	Catch (C)	Variance over [x] years
4.3 Probability of shutdown	TAC	Proportion of years that TAC=0
4.4 Probability of TAC change over a certain level[4]	TAC	Proportion of management cycles when the ratio of change[5] (TACn-TACn-1)/TACn-1>X%
4.5 Maximum amount of TAC change between management periods	TAC	Maximum ratio of change[6]

1 This indicator provides an indication of the expected CPUE of adult fish because CPUE is assumed to track biomass.
2 This indicator is only useful to distinguish the performance of strategies which fulfil the objective represented by 1.4
3 This differs slightly from being equal to 1- Probability of a shutdown (4.3), because of the choice of having a management cycle of 3 years. In the next management cycle after B has been determined to be less than Blim the TAC is fixed during three years to the level corresponding to Flim, and the catch will stay at such minimum level for three years. The biomass, however, may react quickly to the lowering of F and increase rapidly so that one or more of the three years of the cycle will have B>Blim.
4 Useful in the absence of TAC-related constraints in the harvest control rule.
5 Positive and negative changes to be reported separately.
6 Positive and negative changes to be reported separately.

Table 3 Preliminary Performance Indicators under consideration for Western skipjack and multi-species tropical tuna MSEs under consideration

40% B_0	Probability that the biomass is greater than 40%B_0
STC30	Probability that catch>30 kt (years 1-10)
LTC30	Probability that catch >30kt (years 11-20)
AAVC (annual variability in catch)	Probability that AAVC<20% (years 1-4)
STC=x	Additional STC metrics relative to x=20, 25,..40 kt

Table 4. Additional Performance Indicators identified by the TRO MSE WG

Yield	probability that CPUE of fisheries targeting eastern skipjack is lower than in the year 202*x*
Maintain SSB>SSB_{MSY}	for the less productive stock and, hence, the rest will be above MSY levels as well
Status/Productivity	probability that SSB for all three stocks is greater than $SSB_{MSY199X}$
Productivity	probability that yields at MSY are greater than MSY_{199X}
Safety	probability that B for any of the three stocks drops below the limit reference point
Yield per recruit	
Foregone yield associated with gear type	
Improvement in status of limiting or "bottleneck" stock in terms of multispecies analysis.	

Table 5. Key Preliminary Performance Indicators for SWO MSE

Candidate management objectives	**Metric**	**Time frame**
a. Stock Status - The stock should have a greater than [__]% probability of occurring in the green quadrant of the Kobe matrix;	$P(B_t>B_{MSY}$ & $Ft<F_{MSY})$	Short: t=1-10 Medium: t= 11-30 Long: t=31-**50** Full projection period:
b. Safety - There should be a less than [___]% probability of the stock falling below BLIM ;	$P(B_{t<}B_{LIM})$	Short: t=1-10 Medium: t=11-30 Long: t=31-**50** Full projection period:
c. Yield - Maximize overall catch levels;	Mean catch over t simulation years	Short: t=1-10 Medium: t= 11-30 Long: t=31-**50** Full projection period:
d. Stability - Any increase or decrease in TAC between management periods should be less than [__]%.	Average variability in yield between time period	Short: t=1-10 Medium: t=11-30 Long: t=31-**50** Full projection period: