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Red, Green and Yellow: Thoughts on Stock Status and the ICCAT Convention Objectives

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Summary

The ICCAT Convention has the stated objective of maintaining populations at levels which will permit maximum sustainable catch. The current interpretation of this objective by SCRS seems to be that fishing mortality should be maintained at or below F_{MSY} and biomass should be maintained at or above B_{MSY}. But achieving both of these simultaneously is not always possible when there is variability at recruitment. For example, fishing forever at F_{MSY} will result in a biomass that will fluctuate above and below B_{MSY} so that F_{MSY} and B_{MSY} will be rarely attained at the same time. In this paper I provide preliminary empirical estimates of how much B may vary around B_{MSY} when fishing at F_{MSY} for seven ICCAT stocks depending on the variability in recruitment estimated in recent stock assessments. The results show that this variability is as high as a coefficient of variation of 24% (all other life history characteristics being constant), which is considerable. As noted by the SCRS ad hoc WG on the Precautionary Approach that met in 1999, one approach for managing at F_{MSY} would be to define a corresponding biomass limit that would be below B_{MSY}, the distance between the two being perhaps related to recruitment variability. I propose that further work be conducted to develop stock-specific biomass limits corresponding to F_{MSY}, perhaps during a 2009 meeting of the Methods Working Group.

Keywords: Tuna stocks; biological reference points; overfishing; overfished

Introduction

One of the main tasks of a scientific body like the SCRS is to assess the status of the stocks in relation to management objectives. For ICCAT, the stated objective according to the Convention is to maintain the stocks at levels which will permit the maximum sustainable catch (the SCRS uses the terms Maximum Sustainable Yield, MSY, interchangeably). This has been interpreted as maintaining fishing mortality at or below F_{MSY} and biomass at or above B_{MSY}. In recent years, stock status has been successfully presented to managers in a simplified form that depicts current F and current biomass relative to F_{MSY} and B_{MSY} in a single "phase plot"; the various quadrants have been colorized and faces have been added to assist visually with the determination of stock status relative to the Convention objectives (**Figure 1**). This format has been proposed for other tuna RFMOs as well (Scott, 2007).

In this paper I raise the issue that the current interpretation of the ICCAT texts may be too strict and that in fact it leads to inconsistencies in making status determination. I examine empirically several datasets for ICCAT stocks to recommend alternatives.

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The Convention

The Convention (available from http://www.iccat.int/Documents/Commission/BasicTexts.pdf) states its conservation objective in the Preamble and then in more detail in paragraph 2(b) of Article IV:

> [The Commission shall be responsible for] "studying and appraising information concerning measures and methods to ensure maintenance of the populations of tuna and tuna-like fishes in the Convention area at levels which will permit the maximum sustainable catch and which will ensure the effective exploitation of these fishes in a manner consistent with this catch;"

What does this mean exactly? One interpretation, which is the basis for the current construction of the phase plots by SCRS is to ensure that $F/F_{MSY} \leq 1$ and $B/B_{MSY} \geq 1$. An alternative interpretation, which has been offered before and which I believe is worth re-thinking, is to ensure that $F/F_{MSY} \leq 1$ and allow the life history characteristics of the stock determine the corresponding B/B_{MSY} "levels which will permit ... MSY".

Maximum Sustainable Catch

Often, scientists think about maximum sustainable catch (MSY) in the context of deterministic surplus production models. In these models, given the parameters that govern stock dynamics, a single equilibrium F_{MSY} is associated with a single equilibrium biomass, B_{MSY}, so that constructing a phase plot with the quadrants determined by $F/F_{MSY} \leq 1$ and $B/B_{MSY} \geq 1$ is rather natural and consistent with the model dynamics. (We would almost always like to represent current status as a cloud of points that depicts uncertainty in F/F_{MSY} and B/B_{MSY}, but my point about one-to-one correspondence between the two quantities still applies to each point in the cloud).

But, in an age-structured world where recruitment varies, the situation is different because when the stock is exploited at a fixed level of F biomass will fluctuate around some average. Ricker (1975) gives a definition of MSY that explains the concept rather clearly:

> "MAXIMUM SUSTAINABLE YIELD (MSY OR Y_S): The largest average catch or yield that can continuously be taken from a stock under existing environmental conditions. (For species with fluctuating recruitment, the maximum might be obtained by taking fewer fish in some years than in others.) Also called: maximum equilibrium catch (MEC); maximum sustained yield; sustainable catch."

Ricker's publication took place slightly after the adoption of the ICCAT Convention. Gulland (1968, 1969), which wrote slightly more contemporary articles, used two different definitions to make the same point: Maximum Sustainable Yield is used for deterministic situations such as what would be described by simple production models; Potential Yield (or "average potential yield") would address the case of variable year-class strength.

To me, these are two rather important points in the definitions of MSY or Average Potential Yield given by Ricker and Gulland: (1) That MSY is a quantity that is obtained <u>on average</u>, and (2) that MSY is attained by taking more fish in some years than others, depending on recruitment fluctuations. Therefore, if a stock is managed by fishing at F_{MSY} each year, both the annual yield and the annual biomass level will fluctuate. In Gulland's (1968) words,

> "The proper management is best basically defined in terms of the desired size of first capture and fishing mortality coefficient, though the latter may well be best attained in practice by regulating the total catch, determined annually according to the abundance of the stock."

The Convention Objective, again

The SCRS *ad hoc* Working Group on the Precautionary Approach spent considerable time in 1999 thinking about targets, limits, and the ICCAT Convention and concluded (ICCAT, 2000):

> "Based on language in the ICCAT Convention, F_{MSY} is probably the most appropriate fishing mortality-based target reference point. However, note that the corresponding B_{MSY} is only appropriate as a target in an average or equilibrium sense; i.e. in natural systems where F_{MSY} is the target, biomass should be expected to fluctuate around B_{MSY}, so there should be no unnecessary cause for alarm when biomass falls somewhat below B_{MSY}. Thus, it may make more sense to consider F-targets in conjunction with biomass limits, rather than biomass targets, *per se*. On the other hand, B_{MSY} may be a better rebuilding target than B_{limit}, because this will enhance the probability of rebuilding the age structure as well as the biomass of a previously-depleted stock."

I will focus on the last sentence at a later stage in the paper, because I believe that rebuilding stocks should be handled differently. What is more relevant to this point in the discussion is the suggestion that one should not be too alarmed if, in any given year, the stock's biomass falls somewhat below the expected value of B_{MSY} when managing to achieve F_{MSY}. The current status determination used by the SCRS triggers an alarm as soon as biomass falls any amount below the expected value of B_{MSY} such that the stock appears to have entered a "danger zone". And this can be problematic if F_{MSY} is being realized because managers will be getting mixed signals: "The good news is that management is consistent with the Convention objective to achieve F_{MSY}; the bad news is that management is inconsistent with the Convention objective to maintain the stock at or above B_{MSY}." An alternative situation would be to follow the suggestion of the Precautionary Approach WG quoted above: If the target is F_{MSY}, define a biomass limit (B_{limit}) that is somewhat less than B_{MSY}. Clearly, we should think harder about how much a healthy stock could fall below the expected value of B_{MSY} if managed at F_{MSY}, and that would be useful information to present to managers.

Variability and Life History Characteristics

If a stock is exploited at F_{MSY}, how will biomass fluctuate? The answer to that question depends on a number of factors, including the environment. But I will focus on factors that we have a better handle on, i.e., the stock's dynamics given its life history characteristics. Fromentin and Fonteneau (2001) examined the dynamics of various Atlantic tropical and temperate tuna species depending on their life history characteristics: growth, natural mortality, longevity, and recruitment. They found, not surprisingly, that at a given exploitation rate (including zero) spawning biomass and yield fluctuated over time, with the duration of the cycles being related to the longevity of the species.

Fromentin and Fonteneau's (2001) paper assumed that each species had a hypothetical stock-recruitment relationship with a fixed level of variability around it. In this paper I have taken an empirical approach and I focus exclusively on the impact that recruitment variability can have on variability in spawning biomass when fishing at F_{MSY}. For this purpose, I used data from seven stocks that had recently been modeled with age-structured assessments. These datasets are not necessarily the base case of each assessment: I used the age-structured model runs with the longest time series I could locate in the assessment backups, as my intention was to characterize recruitment variability with as much empirical data as possible. For each dataset I did the following:

1- If the data are in quarters, convert it to annual series (recruitment) and rates (M, growth, selectivity)
2- De-trend the recruitment time series by fitting a loess regression. Add the residual from the loess fit in each year to the series overall median in order to obtain an overall distribution of recruitments.
3- Given the median recruitment and the other life history parameters, find F_{MSY} (this is the same as F_{MAX}, given that de-trended recruitment does not vary with stock size)
4- Estimate an initial age structure corresponding to the median recruitment and exploitation given by F_{MSY}

5- Project the stock forward for 1,100 years fishing at F_{MSY} and selecting recruitment randomly with replacement from the distribution in step 2. Use the results from the last 1000 simulated years to describe variability in SSB.

The approach followed to characterize recruitment variability in step 2, above, assumes that the variability of recruitment does not depend on stock size. Alternative approaches could be followed, but this one should suffice for the purpose of examining variability in recruitment and variability in SSB.

Results

Table 1 documents the data sources and life-history parameters used for the seven stocks examined. **Figure 2** shows the fitted loess regressions and the resulting de-trended recruitment distributions used to project the stock forward. **Figure 3** shows the trajectories in SSB during projection years 501-600 for western bluefin and western skipjack. Note that bluefin, which has a higher longevity, shows apparent cycles of longer duration (see also Fromentin and Fonteneau, 2001).

Table 2 summarizes the resulting projected SSB values for the seven stocks. The variability of SSB fishing at F_{MSY} ranged from a CV of 3% (Mediterranean swordfish) to as high as 24% (north Atlantic albacore and western bluefin tuna).

B_{limit}: How much below B_{MSY}?

Clearly, how much below (and above) the expected value of B_{MSY} a stock will fluctuate will depend on its life history characteristics. One obvious approach would be to use simple simulation tools, such as applied in this paper, to evaluate the potential variability in B around B_{MSY} when fishing at F_{MSY} on a stock-by-stock basis. Another approach would be some sort of meta-analysis that would provide a useful "rule-of-thumb". As an example of the latter, in the context of providing guidance for determining stock status in accordance to US regulations --which defined F_{MSY} as the limit--, Restrepo et al (1998) proposed that the corresponding biomass limit could be given by

$$B_{limit} = B_{MSY} * \max\{0.5, 1-M\}$$

That is, the proposed limit would be given by the expected value of B_{MSY}, reduced in proportion to natural mortality (but not reduced below one half of B_{MSY} in case M is very high). Here natural mortality is essentially encapsulating the principal life-history characteristics into one parameter. For temperate tunas like bluefin that have a low natural mortality the biomass limit would be closer to B_{MSY}, and for tropical tunas that have a high natural mortality the limit would be $B_{MSY}/2$.

Figure 4 shows how the ad hoc default suggested by Restrepo et al. (1998) would perform for the seven stocks simulations in this paper. The coverage of $B_{MSY}*\max\{0.5, 1-M\}$ is practically 100% for the tropical stocks and for Mediterranean swordfish. For the temperate tunas it is partial: 21.4%, 11.7% and 7.8% of the simulated SSB values for western bluefin, eastern bluefin and northern albacore, respectively, fall below this ad hoc limit. This is not necessarily a bad result from a conservation point of view, as these temperate species are more vulnerable to fishing and more conservative limits would help avoid overfishing.

There are, of course, other potential "rules of thumb". For example, in the U.S., the current proposed rules for implementing the US fisheries management legislation define the B limit corresponding to F_{MSY} as

$$B_{limit} = \max\{B_{MSY}/2, B^*\}$$

where B* is the biomass at which rebuilding to B_{MSY} would be expected to occur within 10 years if fishing at F_{MSY} (U.S. 2008).

Discussion and conclusions

This paper presents what I believe to be a problematic issue when transmitting stock status information to the Commission. This issue is important to consider for stock such as Atlantic bigeye tuna for which the latest assessment estimates F/F_{MSY}=0.87 ("not overfishing") and B/B_{MSY}=0.92 ("overfished"). I believe that a reasonable alternative interpretation of the ICCAT Convention could result in changing the second determination from "overfished" to something like "below B_{MSY} but not overfished". Of course, when it comes to interpreting the ICCAT Convention, it becomes a policy matter. Therefore, it is the Commission that should ultimately adopt the status determination criteria that it deems are consistent with the Convention. But, on the other hand, it is within the purview of the SCRS to offer reasonable alternatives to choose from. **Figure 5** depicts what I believe is one such reasonable alternative.

A special case is that of stocks that have been depleted and are under a rebuilding plan usually have B_{MSY} as a rebuilding target. This is quite reasonable, especially taking into consideration the desirability of (a) rebuilding the age structure, and (b) avoiding a "relapse" into a depleted state. In these cases, it may be quite reasonable to define

$$B_{limit} = B_{MSY}.$$

But, for stocks that are being exploited at or near F_{MSY}, the limit at which they are determined to be overfished should be lower than B_{MSY}. How much lower, depends on their life history characteristics, especially in terms of recruitment variability. The ad hoc limit given by B_{MSY}*max{0.5, 1-M} is a simple alternative that is intuitively appealing and seems to have reasonable coverage according to the simulation results in this paper. But there are certainly other alternative approaches that the SCRS may want to explore, perhaps through more extensive simulation analyses along the lines of those conducted by Fromentin and Fonteneau (2001).

As a final thought, I believe that the problem highlighted in this paper would probably disappear if the Commission adopted explicit targets and explicit limits for management that were distanced from each other, for example as recommended by the *ad hoc* Precautionary Approach Working Group (ICCAT, 2000). There are approaches for distancing limits and targets as some function of uncertainty (e.g. see Shertzer et al, 2008). But, until that adoption of explicit targets and limits happens, it may be useful to better define what "overfished" means in the context of the current ICCAT Convention.

Recommendations

This document is being presented just in time for the 2008 SCRS meeting and given the amount of work that needs to be done at that meeting, it is not my intention to engage colleagues in a thorough debate. Instead, I recommend that this issue be examined more thoroughly in 2009, perhaps under the methodological umbrella of the Methods Working Group (or any other group that the SCRS deems appropriate). As a start, I propose to consider the following terms of reference:

i. Develop approaches for estimating biomass limits corresponding to F_{MSY}-based management
ii. Estimate corresponding biomass limits on a stock-by-stock basis for potential consideration by SCRS

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REFERENCES

Fromentin, J.-M., and A. Fonteneau. 2001. Fishing effects and life history traits: a case-study comparing tropical versus temperate tunas. Fisheries Research 53, 133-150.

Gulland, J.A. 1968. The concept of maximum sustainable yield and fishery management. FAO Fisheries Technical Paper No. 70.

Gulland, J.A. 1969. Manual of methods for fish stock assessment. Part I: Fish population analysis. FAO Manuals in Fisheries Science, No. 4.

ICCAT (2000). Report of the *ad hoc* Precautionary Approach working group. Col. Vol. Sci. Pap. 51: 1941-2056.

Restrepo, V.R., G.G. Thompson, P.M. Mace, W.L. Gabriel, L.L. Low, A.D. MacCall, R.D. Methot, J.E. Powers, B.L. Taylor, P.R. Wade, and J.F. Witzig. 1998. Technical guidance on the use of Precautionary Approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-F/SPO-31.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations.. Bulletin 191, Fisheries Research Board of Canada.

Scott, G.P. 2007. A common format, among Tuna RFMOs, for the presentation of the state of the stocks. ICCAT Col. Vol. Sci. Pap. SCRS/2007/142.

Shertzer, K.W., M.H. Prager, and E.H. Williams. 2008. A probability-based approach to setting annual catch levels. Fish. Bull. 106:225–232.

U.S. 2008. Magnuson-Stevens Act Provisions; Annual Catch Limits; National Standard Guidelines. Federal Register, Vol. 73, No. 111: 32526-32547.

Table 1. Data sources and life history parameters for the seven stocks examined.

	Age Group														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BFT-W	**"Case 4", 2008 assessment (1960-2004 recruitments)**														
Weight	4.6	11.6	25.6	33.6	57.5	76.8	111.0	136.9	176.0	289.0					
Mature	0	0	0	0	0	0	0	1	1	1					
M	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14					
Sel.	0.03	0.21	0.20	0.36	0.42	0.51	0.56	0.61	0.69	1.00					
BFT-E	**"Run 14", 2008 assessment (1955-2004 recruitments)**														
Weight	6.0	10.6	18.7	33.2	53.1	74.8	96.6	119.9	145.7	213.2					
Mature	0	0	0	0.5	1	1	1	1	1	1					
M	0.49	0.24	0.24	0.24	0.24	0.2	0.175	0.15	0.125	0.1					
Sel.	0.31	0.52	0.68	0.40	0.17	0.36	0.33	0.27	0.83	1.00					
SKJ-W	**"Run 1 MFCL", 2008 assessment (1952-2003 recruitments)**														
Weight	0.125875	1.654	5.155075	9.522375	13.7408										
Mature	0	0.375	1	1	1										
M	0.8	0.8	0.8	0.8	0.8										
Sel.	0.01	0.23	1.00	0.12	0.12										
YFT	**"Run 3 VPA", 2008 assessment (1970-2003 recruitments)**														
Weight	1.1	2.2	8.7	29.5	55.0	78.5									
Mature	0	0	0	1	1	1									
M	0.8	0.8	0.6	0.6	0.6	0.6									
Sel.	0.23	0.70	0.36	0.58	1.00	0.23									
ALB-N	**"R 76 MFCL", 2007 assessment (1930-2002 recruitments)**														
Weight	3.1	6.4	10.3	14.4	18.3	21.9	25.1	27.8	30.1	32.0	33.6	34.9	36.0	36.8	37.5
Mature	0	0	0	0	0.5	1	1	1	1	1	1	1	1	1	1
M	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sel.	0.45	0.93	0.38	0.28	0.56	0.83	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BET	**"Run 3 MFCL", 2007 assessment (1961-2002 recruitments)**														
Weight	2.8	11.1	26.5	47.4	73.5	103.7	136.9	172.0							
Mature	0	0	0	1	1	1	1	1							
M	0.90	0.53	0.51	0.66	0.94	0.85	0.81	0.70							
Sel.	0.35	0.22	0.39	0.69	0.85	0.96	1.00	0.99							
SWO-M	**2007 assessment (1985-2002 recruitments)**														
Weight	1.8	8.6	16.5	30.5	48.4	68.2	87.2	106.8	126.2	142.1	190.3				
Mature	0	0	0	0.5	1	1	1	1	1	1	1				
M	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2				
Sel.	0.05	0.28	0.93	1.00	0.84	0.75	0.70	0.77	0.52	0.45	0.45				

Table 2. Summary of the simulated spawning stock biomass for seven stocks fished at F_{MSY} for 1000 years assuming stock-specific levels of recruitment variability.

	BFT-W	BFT-E	SKJ-W	YFT	ALB-N	BET	SWO-M
Mean	12203	191778	50847	13994	17342	41391	67636
Median	11738	190135	50565	13741	17076	40974	67654
Min	6093	144839	25278	10530	6404	19285	62299
Max	25350	246319	77672	21431	34478	54293	72841
SD	2753	17980	9305	1693	4132	4275	1851
CV	0.23	0.09	0.18	0.12	0.24	0.10	0.03

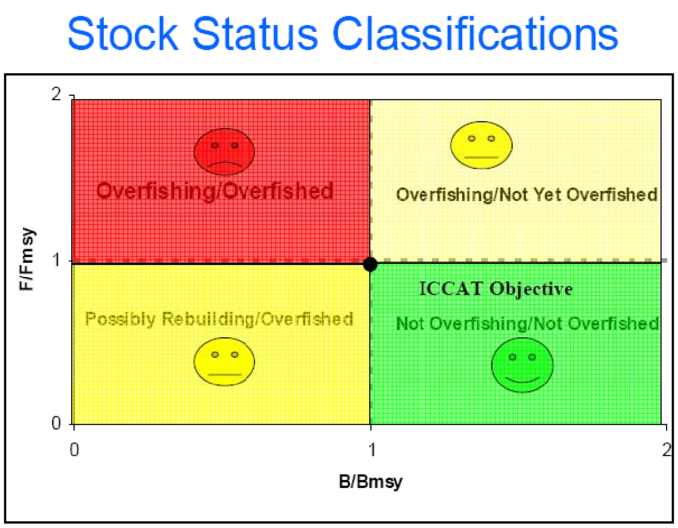


Figure 1. From Scott (2007): "*Stock status quadrants used for characterizing stock status relative to the ICCAT Convention objective. Paired values of F/F_{MSY}>1 and B/B_{MSY} <1 (or their proxies) imply the stock is in the 'red' or danger zone and is considered both overfished and undergoing overfishing. Cases where B/B_{MSY}<1 and F/F_{MSY}<1 indicate the stock is overfished but possibly rebuilding and is in a 'yellow' or caution zone. Likewise, if F/F_{MSY}>1 and B/B_{MSY}>1 the stock is considered undergoing overfishing but is not yet overfished and is in a 'yellow' or caution zone. Cases where $B>B_{MSY}$ and $F<F_{MSY}$ indicate the stock is in a condition which meets the ICCAT Convention objective. The smiley symbols aid in transmitting these implications*."

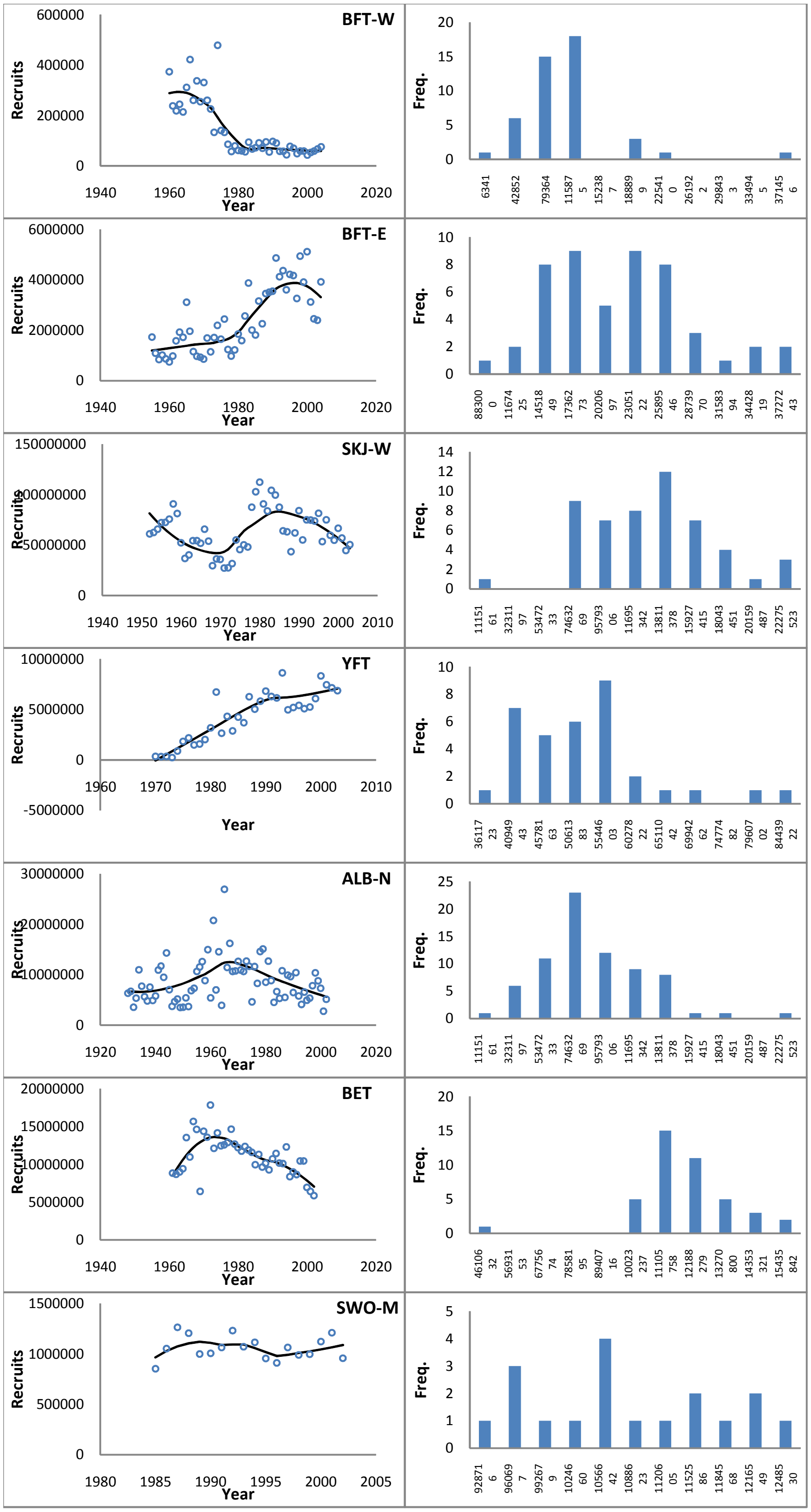


Figure 2. Left: Annual time series of recruitment for seven ICCAT stocks and fitted localized regressions (loess). Right: Distribution of recruitment after de-trending for the seven stocks (see text).

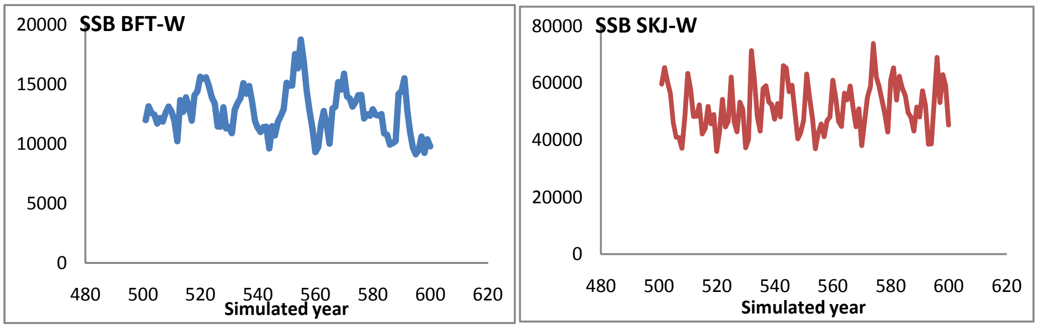
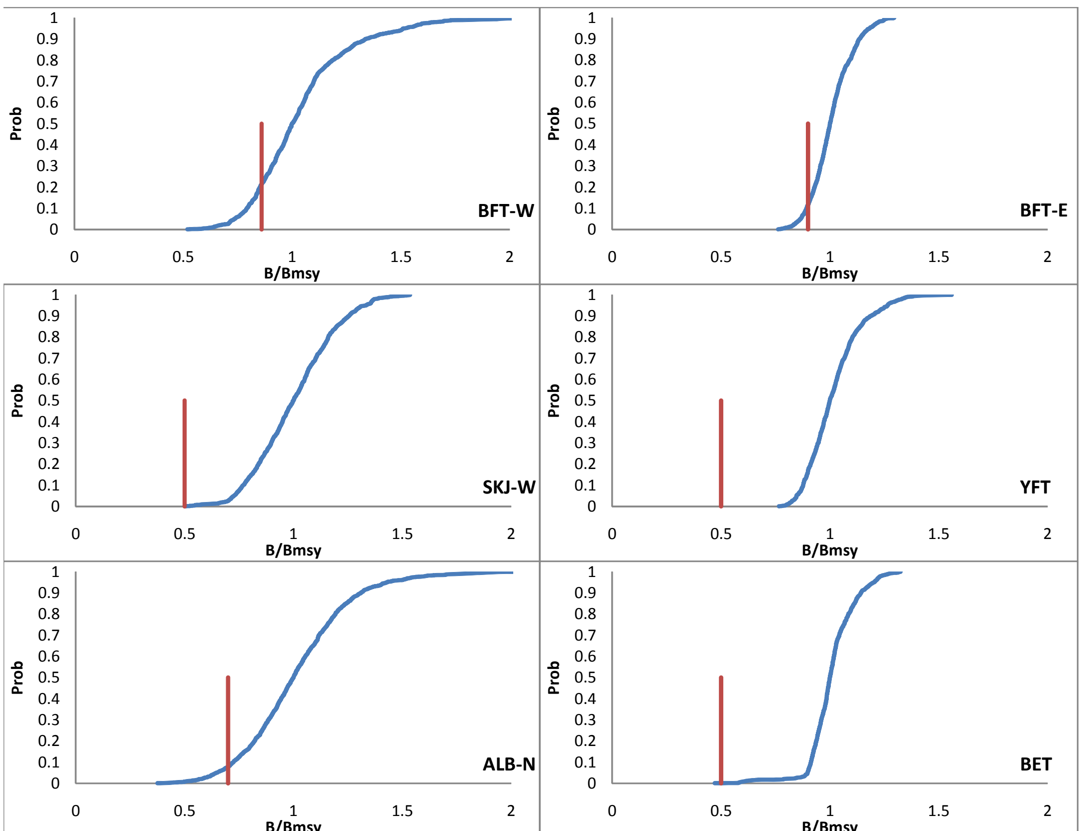


Figure 3. Example of result trajectories of spawning biomass for two of the stocks (western bluefin and western skipjack for a part of the simulated years.



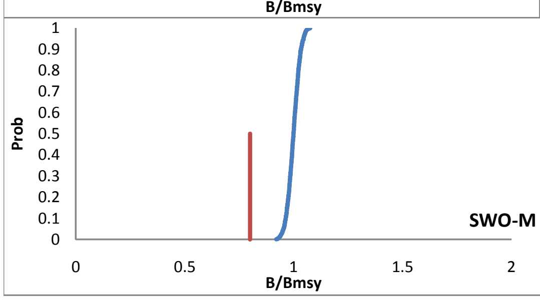


Figure 4. Cumulative probability distributions of B/B_{MSY} for seven simulated stocks exploited at F_{MSY}. The vertical red lines correspond to the median B/B_{MSY} multiplied by (1-M) or ½, whichever is greater.

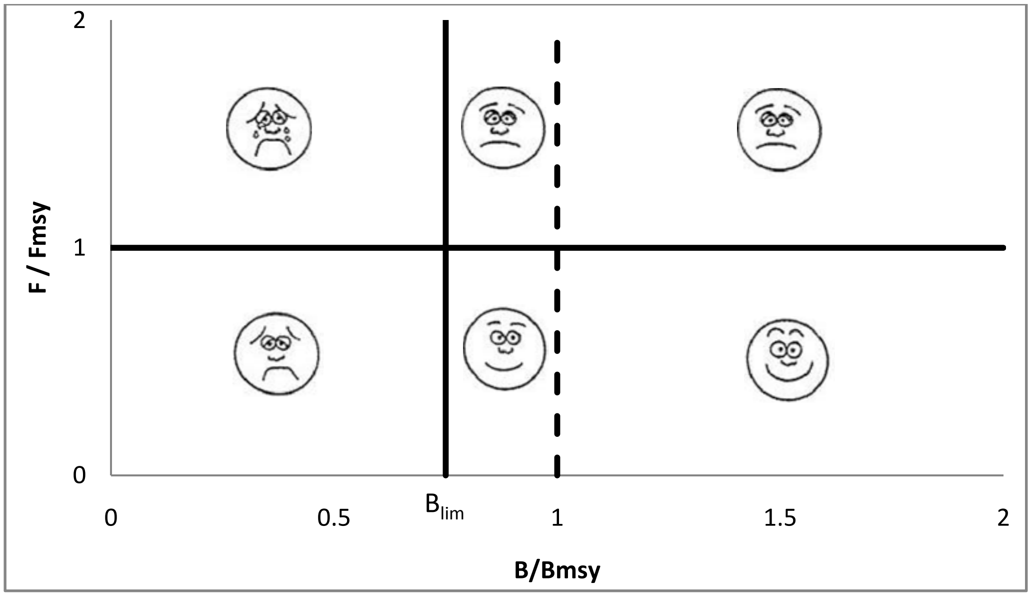


Figure 5. One way in which stock status could possibly be characterized relative to ICCAT's objectives. If the target is F_{MSY} (F/F_{MSY}=1, the horizontal line) then the stock size will be equal to B_{MSY} on average (depicted by the dashed vertical line), but will fluctuate due to recruitment variability to levels as low as B_{lim} (depicted by the solid vertical line; here the exact placement of B_{lim} relative to B_{MSY} is arbitrary). As in Figure 1, faces have been added to aid transmission of the implications of the stock being in a given zone in the phase plot. The phase with the happiest face would be achieved on average when managing to attain a fishing mortality lower than F_{MSY}.