SCREENING AND VALIDATION OF LENGTH BASED INDICATORS

Laurence T. Kell[1], Brian Luckhurst[2], Ai Kimoto[3], Coílín Minto[4]

SUMMARY

Regional Fisheries Management Organisations have the responsibility to manage not just the main commercial stocks but also by caught species that may be endangered, threatened or protected and the associated communities. Although ICCAT has over hundred species in its database only 15 stocks have been formally assessed. This is due either to lack of data, capacity or management recommendations. The lack of formal assessments may hamper progress towards Ecosystem Based Fisheries Management. We therefore evaluate Length Based Indicators that could be used to assess stock status for stock where data are limited. To do this we use length compositions from data rich stock assessments to derive Length Based Indicators and then compare them to estimate of fishing mortality relative to F_{MSY}.

KEYWORDS

Data Poor; Ecosystem Based Fisheries Management; Length Based Indicators; Simulation, Stock Assessment; Value-of-Information.

1 Centre for Environmental Policy, Imperial College London, London, United Kingdom.

2 brian.luckhurst@gmail.com, 2-4 Via della Chiesa, 05023 Acqualoreto (TR), Umbria, Italy.

3 ICCAT Secretariat, Corazón de María, 8. 28002, Madrid,SPAIN

4 Marine and Freshwater Research Centre, Galway-Mayo Institute of Technology, Dublin Road, Galway, Ireland.

Introduction

ICCAT has recently amended its Convention (PLE_108/2019) to include, inter alia, that the Commission and its Members, in conducting work under this Convention, shall act to:

(a) apply the precautionary approach and an ecosystem approach to fisheries management in accordance with relevant internationally agreed standards and, as appropriate, recommended practices and procedures;

(b) use the best scientific evidence available;

(c) protect biodiversity in the marine environment;

As part of Ecosystem Based Fisheries Management (EBFM) Regional Fisheries Management Organisations (RFMOs) like ICCAT have increasingly to assess not only the main target species but also bycaught Endangered, Threatened and Protected (ETP) species and the associated ecological communities. In many cases, however, the data available are insufficient to use traditional stock assessment methods based on catch and age data and indices of abundance. For example although ICCAT list over a hundred species in its database, currently only 15 tuna and billfish species have been formally assessed. This is due either to lack of data, capacity or management recommendations. This lack of formal assessments may hamper progress towards EBFM.

It has been recommended that the length composition of the catches available in the ICCAT database could be used to assess status and to inform management advice for data limited stock (ICCAT, 2017a). For example ICES (Nicholson and Jennings 2004) in data limited situations use length based indicators (LBIs), derived from length–frequency distributions, which can be compared to reference points related to conservation, optimal yield and maximum sustainable yield (MSY). We therefore evaluate screen potential LBIs that could be used for data poor ICCAT stocks. To do this we use data rich ICCAT Stock Synthesis (Methot and Wetzel 2013) assessments for *Thunnus albacares, Thunnus obesus, Xiphias gladius, Kajikia albida, and Makaira nigricans.* The assessments use catch, indices of abundance and length compositions, we used the length compositions to derive potential LBIs and then compare them to the historical estimates of fishing mortality relative to F_{MSY}.

Material and Methods

Potential LBIs are presented in Table 1, grouped in terms of: i) conservation/sustainability; ii) optimal yield; and iii) MSY considerations; reference points, indicator ratios and their expected values are also shown.

Seven indicators were derived from the length composition used in the ICCAT assessments. These were L_{95}, L_{25}, L_{max5}, P_{mega}, L_{mean}, L_{bar} and L_c. Where L_{95} is the 95th percentile of the length distribution, L_{25} is the 25th percentile of the length distribution, L_{max5} the mean length of largest 5%, P_{mega} the proportion of individuals above L_{opt}+10%, L_{mean} the mean length of individuals > L_c where L_c is length at 50% of modal abundance, and L_{bar} is mean size.

To assess stock status various life history parameters are used as reference points, i.e. L_{mat} (length at maturity), L_{opt} ($2/3L_\infty$) and $L_{F=M}$ ($0.75L_c + 0.25L_\infty$) where L_c int this case is length at first capture and L_∞ is the length at an infinite age. L_{opt} is the length at which a cohort achieves the maximum biomass and $L_{F=M}$ is the mean length when fishing mortality is equal to natural mortality (M).

In data rich cases L_{opt} and $L_{F=M}$ could be derived from a yield per recruit analysis.

Table 1 Length based indicators with reference points

Indicator	Calculation	Reference point	Indicator ratio	Expected value	Property
$L_{max5\%}$	Mean length of largest 5%	L_{inf}	$L_{max5\%}$ / L_{inf}	> 0.8	Conservation (large individuals)
$L_{95\%}$	95th percentile		$L_{95\%}$ / L_{inf}		
P_{mega}	Proportion of individuals above L_{opt} + 10%. (L_{opt} is estimated from L_{inf}).	0.3 – 0.4	Pmega	> 0.3	
$L_{25\%}$	25th percentile of length distribution	L_{mat}	$L_{25\%}$ / L_{mat}	> 1	Conservation (immatures)
L_c	Length at 50% of modal abundance*	L_{mat}	L_c/L_{mat}	> 1	
L_{mean}	Mean length of individuals > L_c	$L_{opt} = {}^2/_3\ L_{inf}$	L_{mean}/L_{opt}	≈ 1	Optimal yield
$L_{max}y$	Length class with maximum biomass in catch	Lopt = ${}^2/_3\ L_{inf}$	L_{maxy} / L_{opt}	≈ 1	
L_{mean}	Mean length of individuals > L_c	$L_{F=M} = (0.75L_c + 0.25L_{inf})$	L_{mean} / $L_{F=M}$	≥ 1	MSY

L_{opt} and $L_{F=M}$ can also be derived using natural mortality (M) and the growth rate (k) from the von Bertalanffy growth equation, using the M/k ratio. In a data poor case this is often assumed to = 1.5. They can also be expressed in a more generalized form to allow for any value of M/K (Jardim *et al.*, 2015)

$$L_{opt} = L_\infty \frac{3}{3+\frac{M}{K}}$$

$$L_{F=\gamma M, K=\theta M} = \frac{\theta L_\infty + L_c(\gamma+1)}{\theta+\gamma+1}$$

When these indicators are compared to the proxy reference points used as targets and limits equilibrium conditions are assumed, namely that total mortality and recruitment have been constant for a period as long as the lifetime of the time-series and selectivity follows a logistic curve (i.e. is flat-topped). Strong year classes, however, may reduce the mean length, suggesting high mortality when the situation is good. Selectivity of the fisheries, however, may mean that the length frequencies do not reflect the population structure (Pons et al., 2019).

Variation in year class strength and changes in selection pattern over time may distort length indicators and thus perception of stock status. The impacts of such proceses are likely to vary across indicators, i.e. affect tails ($L_{95\%}$ and $L_{25\%}$) and central tendencies (L_{mean} and L_c) differently. A way to assess these problems is to examine the series of annual length frequency distributions to look for evidence of shift in modes, it is important that these data are not prescreened to remove "outliers" for example without a good reason.

The total number of indicators should be minimised and be complementary and non-redundant (Shin et al. 2010, Kershner et al. 2011) and be robust proxies for corresponding ecosystem attributes or pressures (Fulton et al. 2005). They therefore need to be screened using appropriate selection criteria. In addition reference points for management are required as targets, limits, cautionary zones or thresholds (FAO 1996).

Screening potential indicators and reference levels can be performed using Receiver Operating Characteristic or ROC curves (Green and Swets, 1966). A ROC analysis compares the true positive rate (TPR) with the false positive rate (FPR) for different reference levels. Distinguishing between TPR and FPR is important since risks are asymmetric, i.e. gains and losses due to failing to act when management action is required are not the same as taking action unnecessarily.

The ROC curve can be thought of as a plot of power as a function of the Type 1 Error of the decision rule. When the probability distributions for both detection and false alarm are known, the ROC curve is generated by plotting the cumulative distribution function (area under the probability distribution from to the discrimination threshold) of the detection probability in the y-axis versus the cumulative distribution function of the false-alarm probability on the x-axis. ROC analysis therefore provides a tool to select the best candidate indicators.

An example of a ROC curve is shown in Figure 1, and demonstrates several things: namely

- It shows the tradeoff between TPR (or sensitivity) and FPR (or specificity), as any increase in TPR will be accompanied by a decrease in FPR.
- The closer the curve is to the left-hand border and then the top border of the ROC space, the more accurate the test.
- The closer the curve comes to the y=x line of the ROC space, the less accurate is the test.
- The area under the curve is a measure of a test's accuracy. An area of 1 represents a perfect test; an area of .5 represents a worthless test.
- The slope of the tangent line at a cutpoint gives the likelihood ratio (LR) for that value of the test.

To construct the ROC curves, as examples ICCAT stock assessments conducted using Stock Synthesis were used: namely the 2018 Atlantic bigeye tuna base case (ICCAT, 2018a), 2019 Atlantic yellowfin tuna run 1 (ICCAT, 2019a), 2018 Atlantic blue marlin base case (ICCAT, 2018b), 2019 Atlantic white marlin run 6 (ICCAT, 2019b), 2017 North Atlantic swordfish run 1 (ICCAT 2017b), and the updated 2019 north shortfin mako base case (ICCAT, 2019c). LBIs were constructed using the Stock Synthesis length compositions and compared to estimates of F/F_{MSY}. This allowed the cumulative true positive and false positive rates to be calculated.

Results

Time series of FF_{MSY} are shown in **Figure 2**, the red zones corresponds to $F > F_{MSY}$ and green to $F \leq F_{MSY}$, the corresponding indicators (combined over all fleets) are plotted in **Figure 3**. Examples indicators are plotted for mean length in **Figure 4** (where the horizontal reference line is L_{opt}) and in **Figure 5** for 50% of modal abundance (L_c) where the horizontal reference line is length at maturity L_{mat}. The correlations between indicators and FF_{MSY} are shown in **Figure 6**. A negative slope indicates that as F increases the value of the indicators decreases. Indicator behave different across the stocks, showing that it is important to screen indicators on a stock by stock basis. F

Indicators can also be based on different fleets, e.g. fleet with a flat selection pattern, fishes on adults or target a given species may be preferred. Therefore **Figure 6** shows time series of indicators by fleet for blue marlin, as an example.

Figure 7 shows ROC curves for all stocks, indicators and fleets). A indicator with good accuracy should have a high TPR and a Low FPR, i.e. the ROC curve should pass as close as possible to the top lefthand corner (TPR=1 and FPR=0). The value of the reference level at the "best" point , e.g. where the euclidian distance from (TPR=1 and FPR=0) is minimised, could be used to trigger management. In some cases the ROC curves are below the y=x line, in which case there is a positive relationship between the LBI and F.

Discussion and Conclusions

The example of blue marlin highlights the importance of visualising the data at the fleet level. Particularly as opposing trends by fleet result in an uninformative indicator when aggregated over fleets so there is no relationship to F/F_{MSY}. At the fleet level, the trends in the indicator for fleet 2 correspond with the changes in status. This raised the question is it fleet 2 that is driving the assessment and determines whether the stock is experiencing overfishing or not? R_0 likelihood component profiles relative to the data likelihood components for length compositions and CPUEs would be a useful diagnostic to address this issue and to help identify which data sources were informative and which were in conflict.

It is interesting to see how the indicators relate to the species. L_c is an important indicator for bigeye tuna, which makes sense as it represents the conservation of immatures. The ROC curves for Lc differ by fleet, however, and may indicate which fleets are determining status with respect to overfishing.

Even for data rich stocks not all LBIs were accurate, i.e. the area under the ROC curves was close to or less than 50%. The performance of the LBIs are variable even for the data rich stocks, this implies that some length distributions are not informing the integrated assessments or are potentially in conflict.

Given that the length compositions were used in a model that provides estimates of F/F_{MSY}, interpreting indicator performance using the ROC curves should be treated with caution. The analysis could be rerun configuring SS as an Aged Structure Production Model.

The results are promising and should be used with data moderate and poor species at the fleet level. A next step could be to compare model based approaches (e.g. Pons et al., 2020).

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Figures

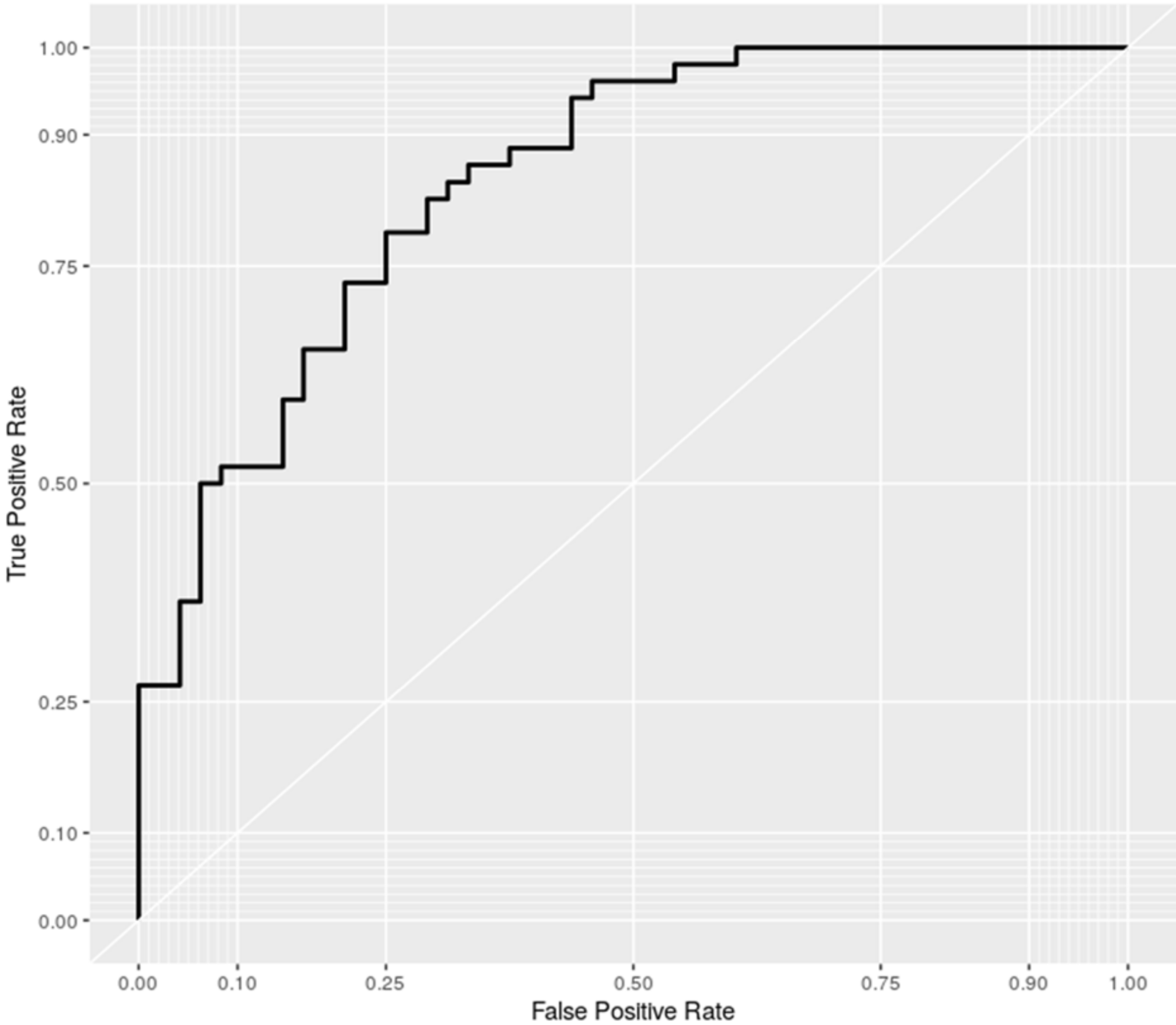

Figure 1. Receiver Operator Characteristic curve, showing an example of a classifier, the y=x line represents a model with no skill.

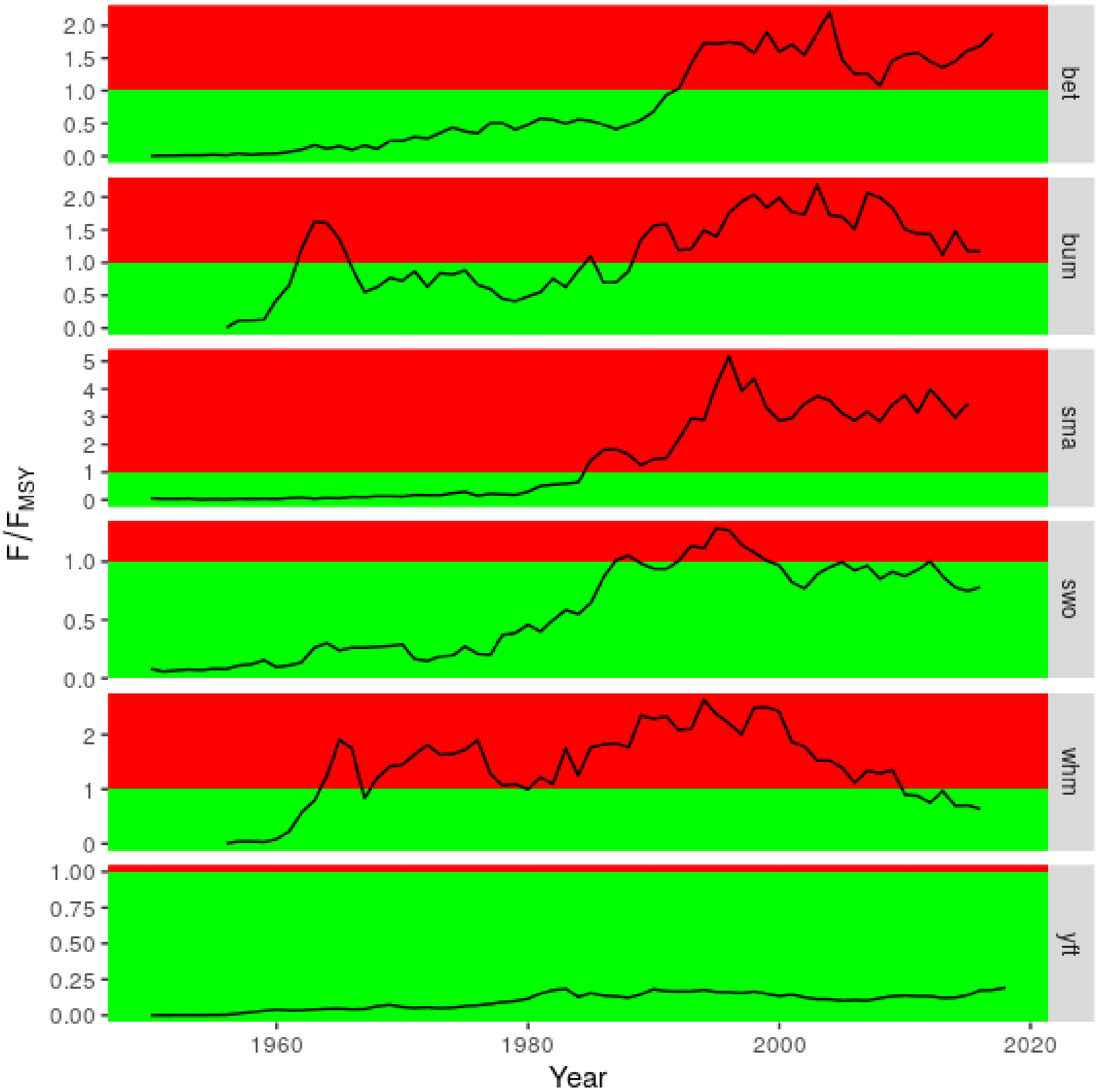

Figure 2. Time series of FF_{MSY}; red zone corresponds to $F > F_{MSY}$. (bet: bigeye tuna, bum: blue marlin, sma: shortfin mako, swo: swordfish, whm: white marlin, and yft: yellowfin tuna)

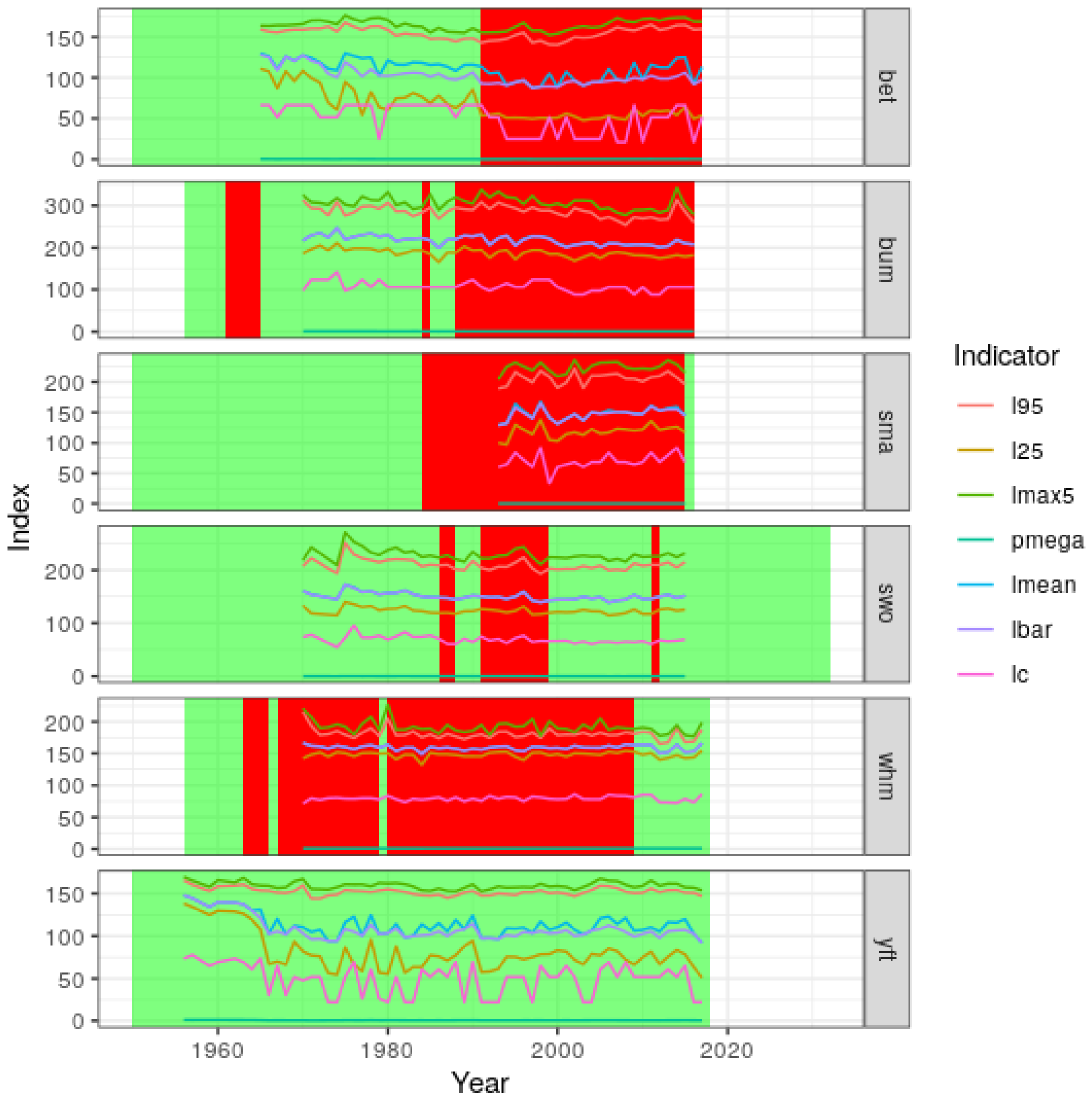

Figure 3. Time series of indicators; red zone corresponds to $F > F_{MSY}$.

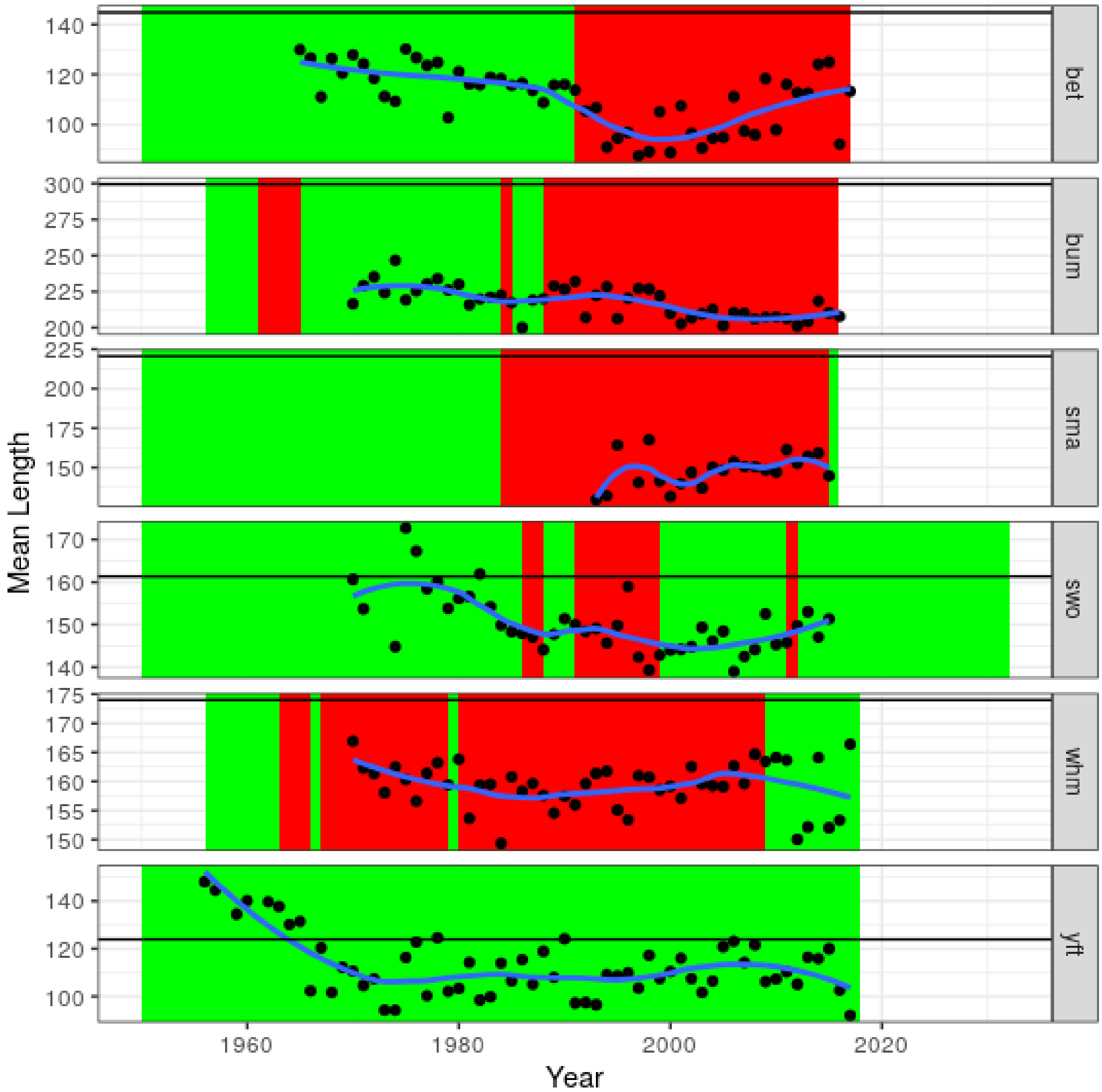

Figure 4. Time series of mean length, horizontal reference line is L_{opt}; red zone corresponds to $F > F_{MSY}$.

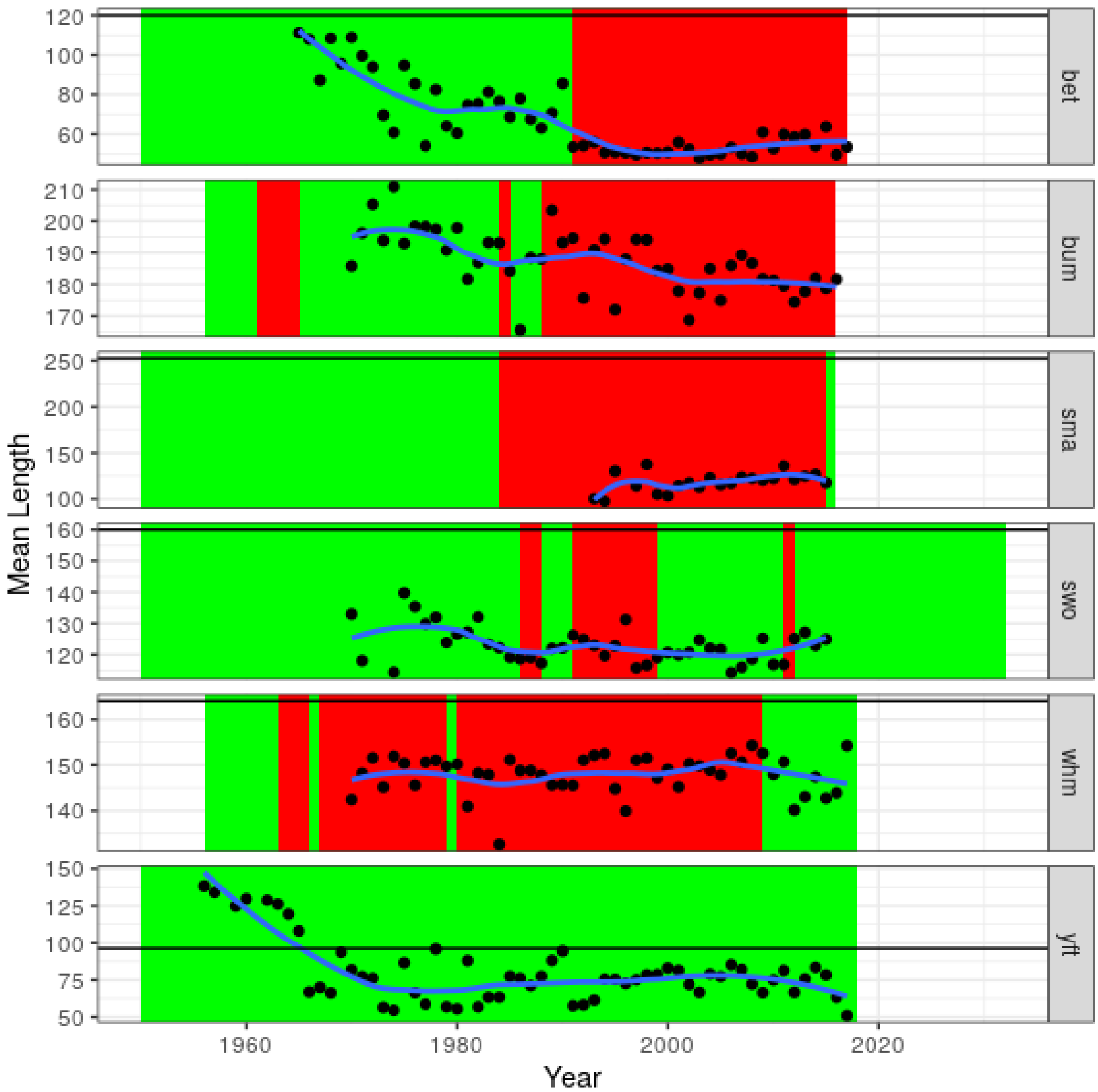

Figure 4 Time series of 50% of modal abundance (L_c), horizontal reference line is length at maturity L_{mat}; red zone corresponds to $F > F_{MSY}$.

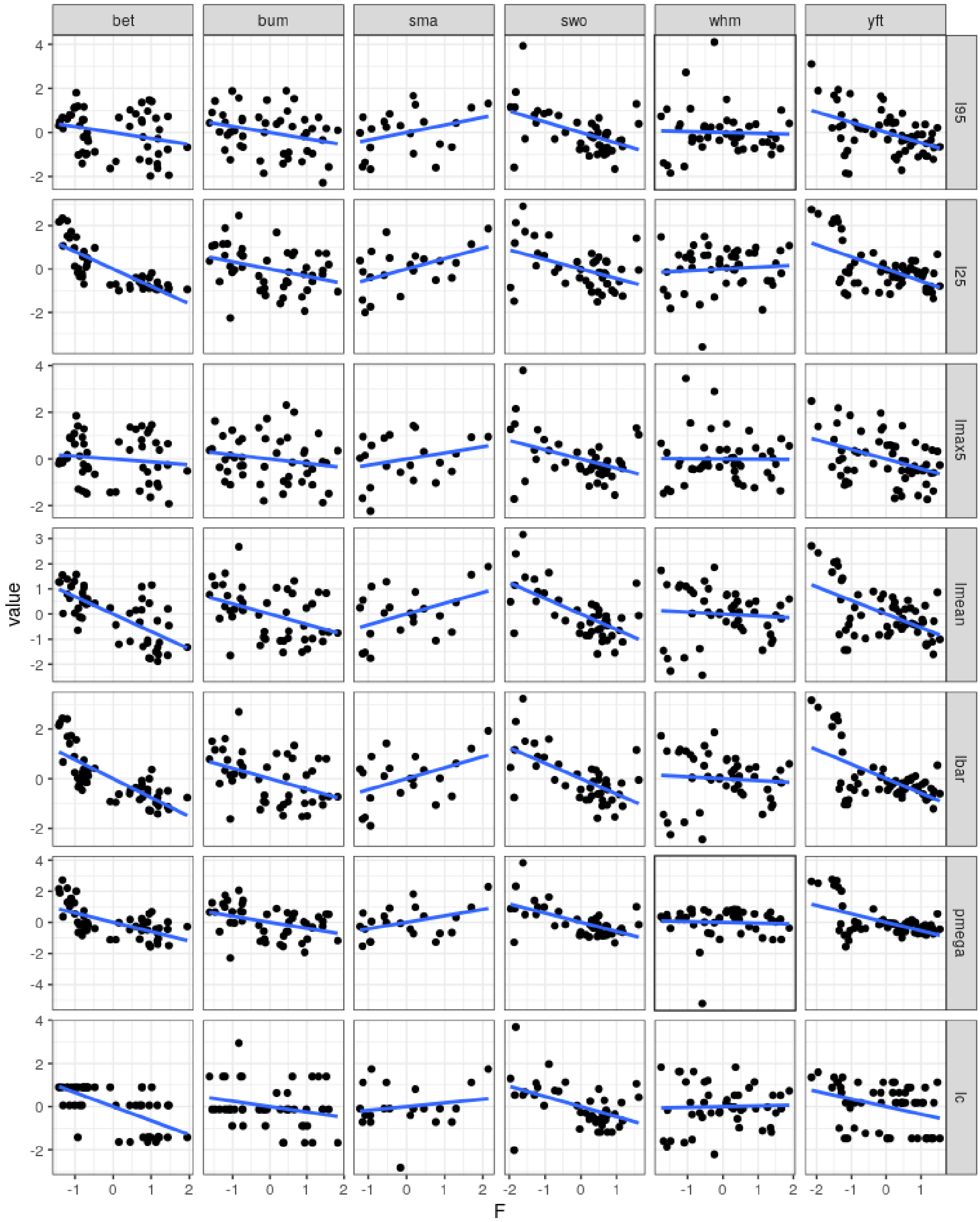

Figure 5 Correlations between indicators combined over all fleets and FF_{MSY}.

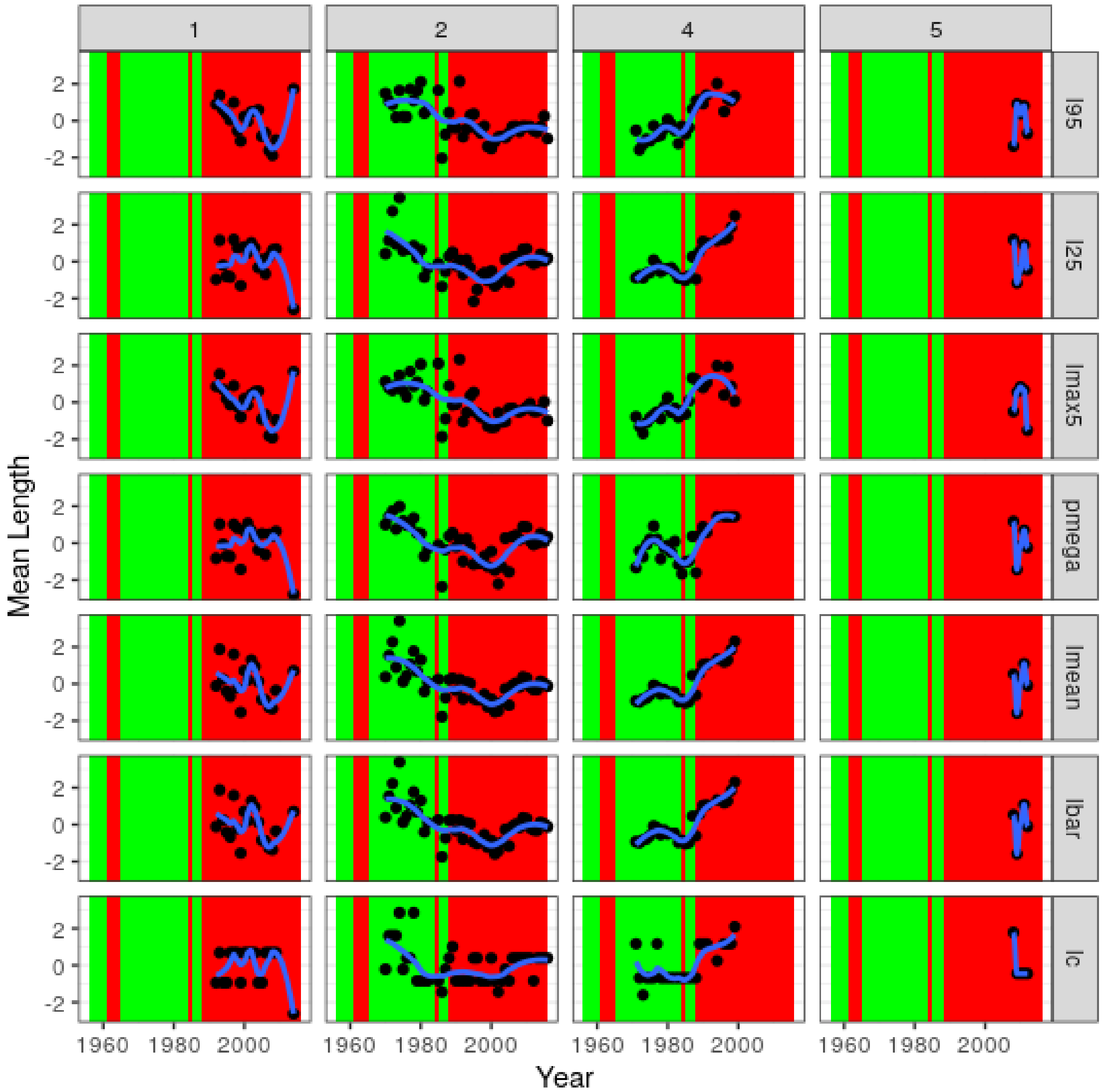

Figure 6 Time series of indicators for blue marlin by fleet.

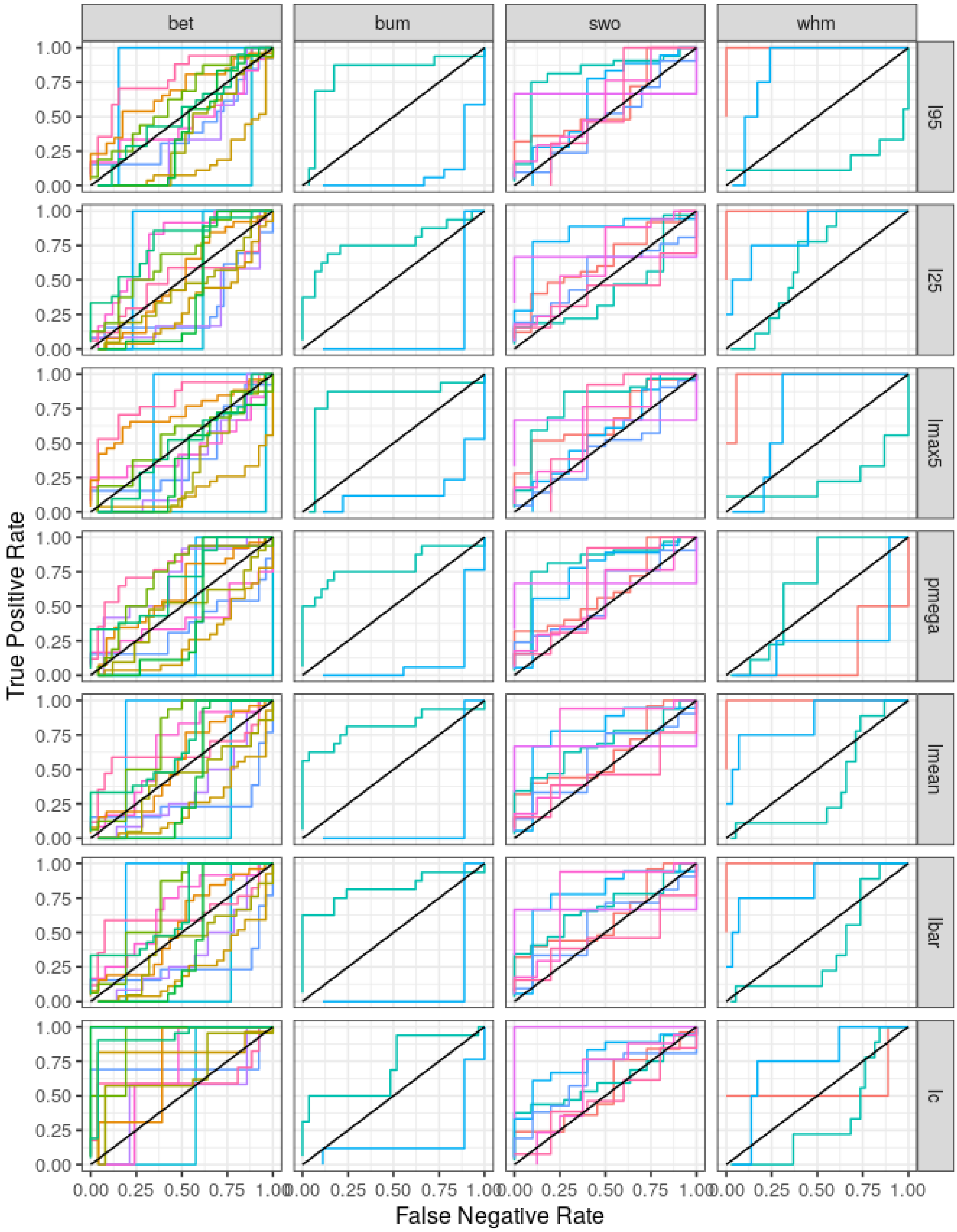

Figure 7. ROC curves, colours correspond to fleets.