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THE USE OF LIFE HISTORY THEORY FOR STOCK ASSSESSMENT: AN ALBACORE EXAMPLE

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SUMMARY

The adoption of the Precautionary Approach (FAO, 1996) requires a formal consideration of uncertainty, for example in the quality of the available data and knowledge of the stocks and fisheries. An important principle is that the level of precaution should increase with uncertainty about stock status, so that the level of risk is approximately constant across stocks. However, even when data are limited empirical studies of teleosts have shown that there is significant correlation between the life history parameters such as age at first reproduction, natural mortality, and growth rate. This may mean that from something that is easily observable like the maximum size it is possible to infer other life history parameters, such as natural mortality. In this study we show how life history theory can be used to derive parameters for use in stock assessments where data and knowledge are limited and to validate the assumptions used in data-rich stock assessments. We do this for an example based on North Atlantic Albacore.

RÉSUMÉ

L'adoption de l'approche de précaution (FAO, 1996) nécessite un examen formel de l'incertitude, telle que l'incertitude entourant la qualité des données disponibles et les connaissances des stocks et des pêcheries. Un principe clé consiste à ce que le niveau de précaution soit augmenté en fonction de l'incertitude entourant l'état du stock afin que le niveau de risque demeure à peu près constant d'un stock à l'autre. Cependant, même lorsque les données sont limitées, les études empiriques sur les téléostéens ont indiqué qu'il existait une corrélation importante entre les paramètres du cycle vital, tels que l'âge de la première reproduction, la mortalité naturelle, et le taux de croissance. Cela peut vouloir dire qu'à partir d'un fait qui est facilement observable, tel que la taille maximale, il est possible de déduire d'autres paramètres du cycle vital, comme la mortalité naturelle. Dans cette étude, nous présentons la façon dont la théorie du cycle vital peut être utilisée pour obtenir des paramètres aux fins de leur utilisation dans les évaluations de stock lorsque les données et les connaissances sont limitées et aux fins de la validation des postulats utilisés dans les évaluations des stocks pour lesquels de grandes quantités d'informations sont disponibles. Nous appliquons ce principe au germon de l'Atlantique Nord à titre d'exemple.

RESUMEN

La adopción del enfoque precautorio (FAO, 1996) requiere una consideración formal de la incertidumbre, por ejemplo en la calidad de los datos disponibles y en los conocimientos de las pesquerías y de los stocks. Un principio importante es que el nivel de precaución debería aumentar con la incertidumbre acerca del estado del stock, para que el nivel de riesgo sea aproximadamente constante en los diferentes stocks. Sin embargo, incluso cuando los datos son limitados, estudios empíricos de los teleósteos han demostrado que existe una correlación significativa entre los parámetros del ciclo vital como la edad de primera reproducción, la mortalidad natural y la tasa de crecimiento. Esto podría significar que a partir de algo fácilmente observable como la talla máxima es posible inferir otros parámetros del ciclo vital, como la mortalidad natural. Este estudio mostraba cómo puede utilizarse la teoría sobre el ciclo vital para derivar parámetros con el fin de utilizarlos en evaluaciones de stock cuando los datos y los conocimientos son limitados, así como para validar los supuestos utilizados en las

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evaluaciones de stock ricas en datos. Se desarrolló un ejemplo basado en el atún blanco del Atlántico norte.

KEYWORDS

Albacore, data-poor, data-rich, FLR, life history relationships, Reference points, Thunnus alalunga

1. Introduction

There is an increasing need to provide stock assessment advice for more stocks, even those data and knowledge are limited. To address this in Australia a management advice framework based on a hierachical approach has been used **?**, where a species or stock is assigned to a tier depending on the amount and type of information and data available. **?** point out an important principle of such an approach is that the level of precaution should increase with uncertainty about stock status, so that the level of risk is approximately constant across the tiers. The highest information-rich tier is when a robust quantitative assessment based on catch-at-age and standardized CPUE or research survey is available and the lowest information-poor tier is when only life history and limited fishery data are available. There is therefore an incentive to reduce uncertainty through improved management, science and data collection. Although the terms data rich and poor are often used interchangeably with information rich and poor, a large quantity of fisheries dependent data does not necessarily provide a better understanding of population dynamics.

The adoption of the Precautionary Approach Garcia (1996) for fisheries management requires a formal consideration of uncertainty and the reconciliation of risk and uncertainty when providing scientific advice, For example, in the quality of the available data and knowledge of the stocks and fisheries.

Even when data are limited empirical studies have shown that in teleosts there is significant correlation between the life history parameters such as age at first reproduction, natural mortality, and growth rate Roff (1984). This may mean that from something that is easily observable like the maximum size it is possible to infer other life history parameters, such as natural mortality that are less easy to observe. The biologically plausible parameter space is also restricted since size-spectrum theory and multispecies models suggest that natural mortality scales with body size Andersen and Beyer (2006), Pope et al. (2006) and Gislason et al. (2008b).

In this paper we adapt the life history relationships of Gislason et al. (2008a) using the life history data in Fromentin and Fonteneau (2001) on the main ICCAT stocks. We use these data to simulate an example based on albacore. We use a stock simulator based on the life history relationships which allows a stock to be simulated based on life history assumptions. We then compare the predicted dynamics to that of Atlantic albacore derived from the 2009 stock assessment. This allows us to evaluate the utility of life history relationships for validating the assumptions of both data-rich assessments and to evaluate their usefulness for data poor stock assessments.

2. Material and Methods

Albacore was selected as a case study since the Northern and Southern Atlantic and Mediterranean albacore stocks present a wide range of levels of data and knowledge. North Atlantic albacore is currently assessed using Multifan-CL, which requires detailed data on catch, catch-at-size and effort by fishery, knowledge of growth and other biological parameters, and provides estimates for around 3000 parameters. In contrast, South Atlantic albacore is assessed using a biomass dynamic model, requiring only catch and effort data, while the whole stock dynamics are represented by only four parameters r (the intrinsic rate of growth), K (the carrying capacity) B0 (the initial stock size) and p the shape parameter of the surplus production function. Meanwhile, only very limited data are available for Mediterranean albacore and so a formal assessment was only first performed in 2011.

Life history relationships were used to parameterize an age-structured equilibrium model, where spawning stock biomass-per-recruit, yield-per-recruit and stock recruitment analyses are combined, using fishing mortality (F), natural mortality (M), proportion mature (Q) and mass (W) -at-age with a stock.-recruitment relationship.
SSB-per-recruit (*S/R*) is given by:

$$\frac{S}{R} = \sum_{a=r}^{n-1} e^{\sum_{i=r}^{a-1} -F_t - M_t} W_a Q_a + e^{\sum_{i=r}^{n-1} -F_n - M_n} W_n \frac{F_n}{F_n + M_n}$$

where a is age, n is the oldest age, and r the age at recruitment. The second term is the plus-group (i.e. the summation of all ages from the last age to infinity).

Similarly for yield per recruit (Y/R)

$$\frac{Y}{R} = \sum_{a=r}^{n-1} e^{\sum_{i=r}^{a-1} -F_t - M_t} W_a \frac{F_a}{F_a + M_a} (1 - e^{-F_t - M_t}) + e^{\sum_{i=r}^{n-1} -F_n - M_n} W_n \frac{F_n}{F_n + M_n}$$

The stock recruitment relationship can then be reparameterised so that recruitment R is a function of S/R e.g., for a Beverton and Holt Beverton and Holt (1993)

$$\frac{S}{R} = (b + S)/a$$

S can then be derived from F by combining equation 3 or 4 with equation 1.

2.1 2.1 Life History Relationship

There are various models to describe growth, maturation and natural mortality and the relationships between them.
Here we model growth by applying (Von Bertalanffy, 1957)

$$L_t = L_\infty - L_\infty \exp(-kt)$$

where L∞ is the asymptotic length attainable, K is the rate at which the rate of growth in length declines as length approaches L∞ , and t0 is the time at which an individual is of zero length.

Mass-at-age can be derived from length using a scaling exponent (a) and the condition factor (b).

$$W_t = a \times W_t^b \quad t$$

Natural mortality (M) at-age can then be derived from the life history relationship Gislason et al. (2008a).

$$\log(M) = a - b \times \log(L_\infty) + c \times \log(L) + d \times \log(k) - \frac{e}{T}$$

where L is the average length of the fish (in cm) for which the M estimate applies.

While maturity (Q) can be derived as in Williams and Shetzer (2003) from the theoretical relation- ship between M, K, and age at maturity a Q based on the dimensionless ratio of length at maturity to asymptotic length (Beverton, 1992).

$$a_Q = a \times L_\infty - b$$

2.2 Stock Recruitment Relationships

Stock recruitment relationships are needed to formulate management advice, e.g. when estimating reference points such as MSY and Fcrash and making stock projections. Often stock recruitment relationships are reparameterized in terms of steepness and virgin biomass, where steepness is the ratio of recruitment at 40% of virgin biomass to recruitment at virgin biomass. However, steepness is difficult to estimate from stock assessment data sets: there is often insufficient range in biomass levels to allow the estimation of steepness (Anon. 2011).

We use a Beverton and Holt stock recruitment relationship reformulated in terms of steepness (h), virgin biomass (v) and S/R_F =0.

Where steepness is the proportion of the expected recruitment produced at 20% of virgin biomass relative to virgin recruitment (R0). For the Beverton & Holt stock-recruit formulation, this equals

$$R = \frac{0.8 \times R_o \times h \times s}{0.2 \times S/_{R_{F=0}} \times R_o(1-h) + (h-0.2)S}$$

2.3 Selection Pattern

To estimate reference points from an aged based model requires a selection pattern. The selectivity of the fishery can be represented by a double normal, which allows the peak selectivity age and either a flat topped or dome shaped selection pattern to be selected. This allows knowledge of factors such as gear selectivity, availability and post-capture mortality to be modeled.

F_{MSY}, the level of exploitation that would provide the maximum sustainable yield depends upon the selection pattern. Since not all ages are equally vulnerable to a fishery and if there is a refuge for older fish a higher level of fishing effort will be sustainable.

2.4 Scenarios

Calculating reference points and performing projections within an age based framework requires a variety of parameters. Some like growth and maturity are relatively easy to observe, while others such as natural mortality and stock recruitment parameters cannot be observed directly and are difficult to estimate even within a data rich assessment.

Life history relationships can be used to parameterize reference points and projections calculations, if only the maximum size of L∞ of a stock is known. To evaluate the performance using life history relationship we compare MSY reference points and the expected yields and SSB at a range of fishing mortalities.

We considered three sources of uncertainty, model, process and estimation. Uncertainty Model relates to the ability of the model structure to capture the core of the system dynamics. It can be due to inadequate models, incomplete or competing conceptual frameworks, or where significant processes or relationships are wrongly specified or not considered. Such situations tend to be underestimated by experts (Morganand Henrion, 1990). Or value uncertainty due to missing or inaccurate data or poorly known parameters. Uncertainty in processes is caused by disregarding variability in dynamic population and fisheries processes, while estimation error arises when estimating parameters of the models used in the assessment procedure. Two other forms of uncertainty result from sampling and measurement error (i.e., due to observations) and Implementation where the effects of management actions may differ from those intended.

We consider the following factors and levels for the population dynamics based on the assumed biological parameters and stock recruitment relationship.

1. Biological Parameters

(a) M from the stock assessment base case, i.e. constant for all ages

(b) M from based on life history relationship, i.e. varies by age

(c) Maturity from the stock assessment base case

(d) Maturity based on life history relationship

2. Steepness

(a) 0.9 (b) 0.75

3. Age at recruitment to fishery

(a) 2 (b) 4

Growth was assumed to be the same as in the stock assessment base case, i.e. Von Bertalanffy.

The stock recruitment relationship was assumed to be of a Beverton and Holt functional form, reparameterised as steepness and virgin biomass. For ease of comparison virgin biomass was fixed at 1000 and to reflect uncertainty about recruitment at low spawning stock sizes steepness is either 0.9 or 0.75. Such a reparameterisation is a three parameter model since the the value of S/R at zero fishing mortality is also required; this of varies depending on the biological parameters and so the stock recruitment parameters were re-estimated for the four levels of the biological parameters.

For process error we modeled the variability in recruitment as a lognormal random error with CVs of either 10, 20 or 30%. While for estimation error we assumed that current stock status was estimated with a CV of either 0, 10, 20 or 39%

3. Results

The biological processes of growth, maturation and natural mortality as assumed by the North Atlantic albacore species group (ref) are plotted by age in **Figure 1** These correspond to the nine scenarios considered by the stock assessment group. The scenarios were chosen to conducted sensitivity tests and did not attempt to reflect the plausibility of different hypotheses.

The life history parameters for all teleosts are plotted as co-plots on the log scale in figure 2, along with their distributions (diagonal panels) and the linear regressions fitted for demersal and pelagic stocks separately. For demersal stocks M is negatively correlated with maximum L and $L\infty$ and positively correlated with K. For pelagic stocks the relationships between M and the other parameters are less pronounced, with no apparent relationship between M and $L\infty$. There is a negative correlation between K and maximum L and $L\infty$, again the relationships are stronger for demersal stocks.

The relationships for demersal and pelagic species, is explored further in **Figure 2** for between log(K) and log($L\infty$) and in **Figure 4** for log(M) and log($L\infty$). K is plotted against maximum length and $L\infty$ in **Figure 3**. There are multiple values of maximum length for three values of K but only three values of $L\infty$. This is because for *Thunnus spp*. the same growth model has been used for multiple stocks. M verses maximum length and $L\infty$ is shown in **Figure 4**; there is a negative relationship for demersal spp. (as length increases M decreases) but no relationship for pelagic species.

The relationships for the main ICCAT stock are shown in **Figure 5**; These were used to estimate natural mortality and proportion mature-at-age derived based upon life history relationship and the albacore growth curve, the values obtained are compared in **Figure 5.**

We then estimated the equilibrium dynamics for different values of steepness (0.9 and 0.75) and different values of age at recruitment to the fishery, i.e., either a fishery on mature fish where age at maximum selectivity was age 4 or where juveniles were also caught in the fishery, i.e. recruitment at age 2. The Equilibrium values of yield against fishing mortality and SSB in **Figures 6 and 7**; along with the MSY reference points (**Figure 7**). The population growth rates of the different stocks are plotted in **Figure 9.**

4. Discussion

A main objective of this study was to show how life history relationships could be used within ICCAT stock assessments. Both for the main stocks where long time series of fisheries catch, effort and size data and biological studies are available and for stocks where data are incomplete or missing and studies lacking, i.e., data or information rich and poor stocks.

We used life history data from to model the process of growth, natural mortality, maturation and spawning reproductive potential. However these relationships were mainly derived based on demersal and small pelagic stocks, therefore we used the life history data in From & Font derived from the main ICCAT stocks. We used the life history framework described in SCRS/2012/034 to simulate an albacore stock. Then expected dynamics of the simulated stocks were compared. This allowed us to evaluate the utility of life history relationships for validating the assumptions of both data-rich assessments and to evaluate their usefulness for data poor stock assessments.

There are clear correlations between parameters such as $L\infty$, K, size and age at maturity and natural mortality. The relationships varied however by demersal and pelagic stocks. It will be worthwhile therefore to collate such data from other tuna stock, i.e. from other tuna RFMO assessments and explore these relationships further. The processes derived from life history assumptions for albacore were similar to those used in the stock assessment working group base case with the exception of natural mortality. While the maturity ogive derived from life history relationships predicted that fish mature at a slightly earlier age. The sensitivity of the stock assessment to both maturity and natural mortality had been considered by the stock assessment working group. The maturity ogive used for the base case was altered, dropping the age at 50% maturity from age class 5 to age class 4 with full maturity assumed from age class 5 onwards (as opposed to age class 6 in the base case) Instead of assuming a constant mortality of 0.3.y-1 across all age groups, an age-specific natural mortality ogive was included in the model run. However, the advice was made on the base case alone. Sensitivity analyses being limited to the assessment alone. In the assessments the historical dynamics did not change much, the main effect was to increase recruitment when M was higher at younger ages. Changing maturity simply rescaled the SSB.

The effect on the expected dynamics (with respect to the biological assumptions made by the stock assessment working group) were evaluated for the different life history assumptions, two values of steepness (i.e. 0.75 and 0.95) and two selectivity patterns (i.e. corresponding to a fishery on mature fish and one on immature and mature fish). Steepness had little effect compared to selectivity. Of the assumed biological processes M had the largest effect increasing B_{MSY} and F_{crash} (the level of F that would cause stock collapse). Using life history relationships in all cases reduced M SY.

We also compared the population growth rates using either the working group assumptions or those based on life histories gave similar growth rates at all stock sizes. However, using the working group assumptions and modify M increased growth rate while modifying maturity alone reduced growth rate.

The analysis showed unsurprisingly that the assumed biological parameters have a large affect on the dynamics, i.e. large changes were seen in the estimate of target and limit reference points and the rate at which a stock will rebuild. Process such as natural mortality and maturity (and hence spawning reproductive potential), having a larger impact than the steepness of the stock recruitment relationship.

This form of sensitivity analysis could be used to prioritize research, i.e., it appears that both M and maturity are more important than steepness. Since maturity is easier to measure than M, it is likely that studies on SRP are more likely to be cost effective.

When providing stock assessment advice the main sensitivity analyses are conducted on the assessment of historical stock status. However this study showed that the assumed biological parameters can have a bigger effect on the projections and hence advice based upon them. The Commission has recommended that a statement characterizing the robustness of methods applied to assess stock status and to develop the scientific advice must be included in SCRS assessment reports. This statement should focus on modeling approaches, assumptions and the reliability of long term projections period. This study has shown that the biological assumptions are important when providing such advice and that life history relationships are a useful tool for validating those assumptions and potentially developing priors or weights for both assessments and projections.

5. Conclusions

Life History Relationships mean that biological parameters are correlated, e.g. species that reach a large maximum size, growth more slowly, mature later and experience lower natural mortality. These relationships mean that from something that is easily observable such as size, parameters that are more difficult to observe such as M can be inferred. Use of life history theory also allows the transfer of knowledge between species, stocks and populations.

Tuna differ in some of their life history relationships from other species. Most of the published relation- ships are based on demersal and small pelagic species, therefore it is important to collate data on tuna and other species (e.g., sharks, billfish and turtles) management by and of interest to ICCAT.

Biological parameters are often inconsistent between stock and even within species, life history relationships can be used to both provide consistent hypotheses and to identify where research and data collection should be focused.

Data poor stock assessments are often hampered by lack of reliable estimates for key biological parameters, life history relationships can be used to help parameterize these assessments.

Data rich stock assessments are often hampered by lack of reliable estimates for key biological parameters, life history relationships can be used to help evaluate the assumptions made in these assessments.

Kobe 2 Strategy Matrices are important tools for communication of advice and uncertainty. Life history relationships can be used to evaluate the robustness of advice based on the K2SM assumptions made about biological process.

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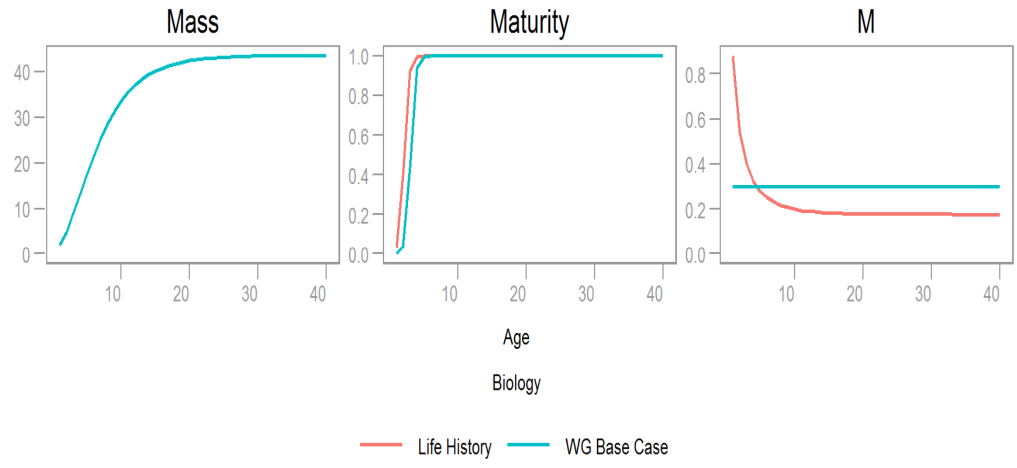

Figure 1. Mass, proportion mature and natural mortality-at-age from the stock assessment scenarios.

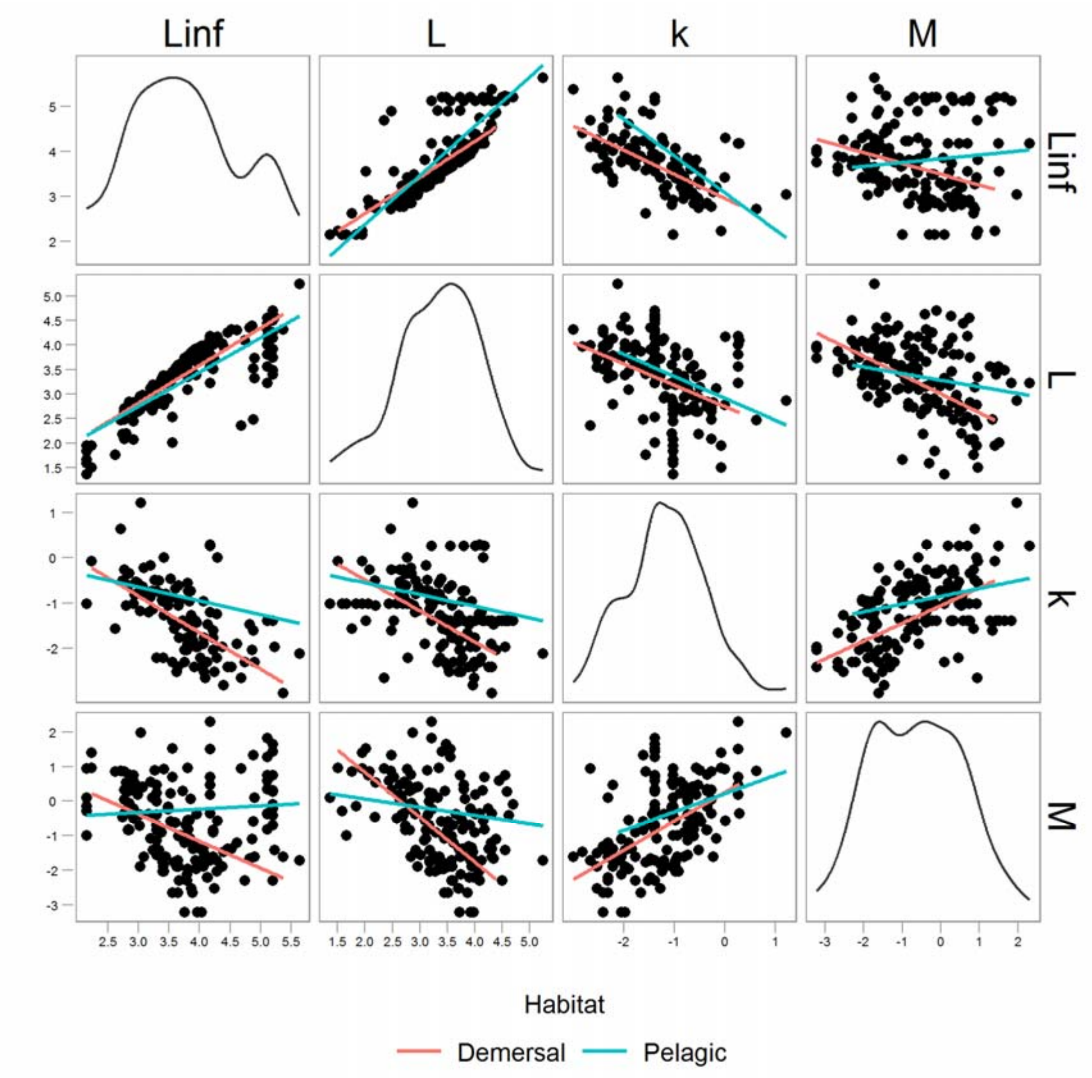

Figure 2. Scatter plots of life history characteristics L∞ , maximum length, K and M; fitted lines are regressions for demersal (blue) and pelagic (pink) species. Diagonal panels show the distributions of the parameters.

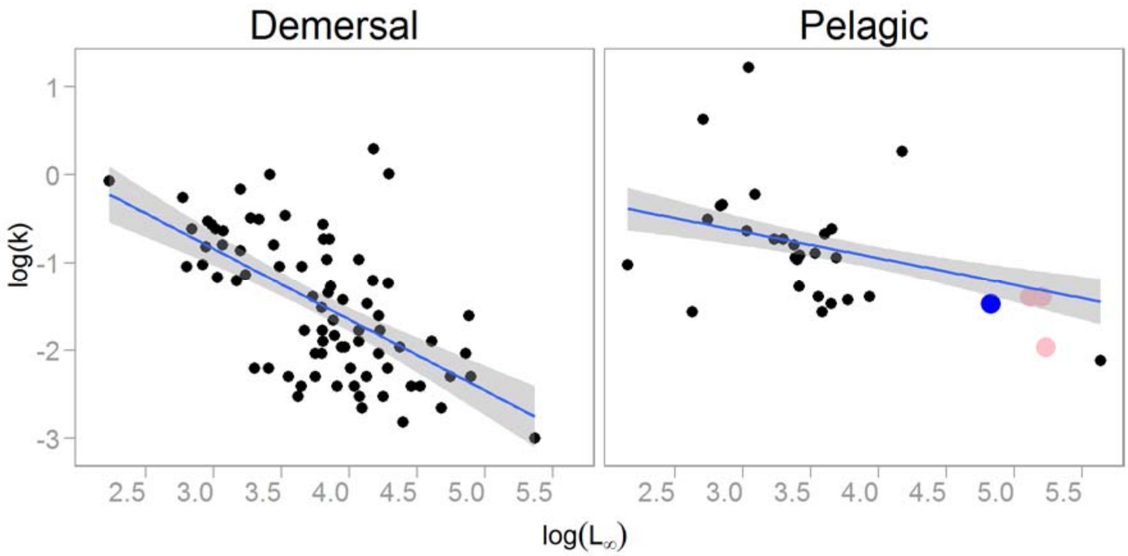

Figure 3. Plot of K against L∞ on the log scale for demersal and pelagic stocks, pink points correspond to Thunnus genera and blue to albacore.

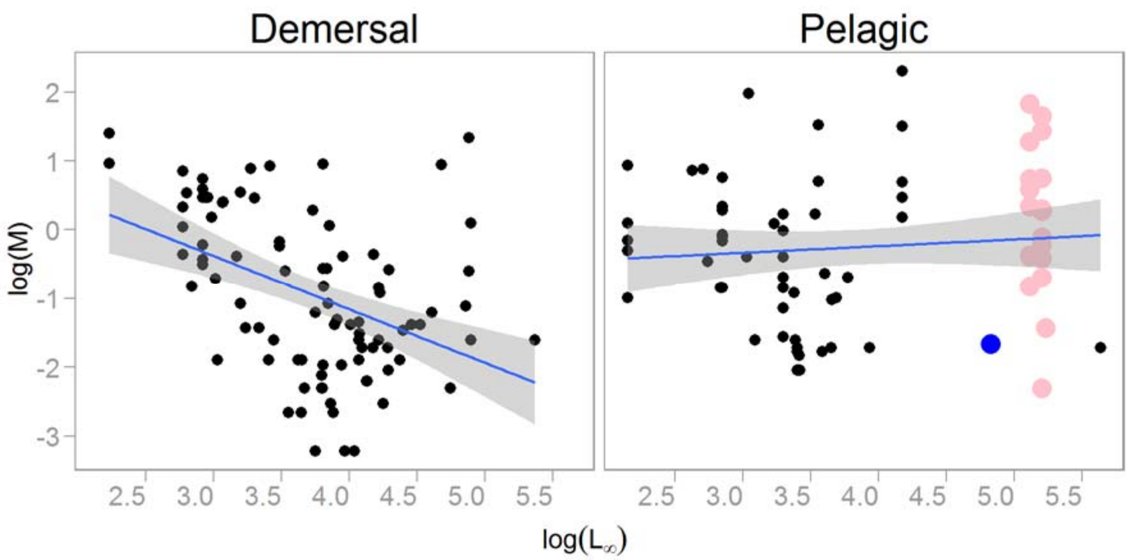

Figure 4. Plot of M against L∞ on the log scale for demersal and pelagic stocks, pink points correspond to Thunnus genera and blue to albacore.

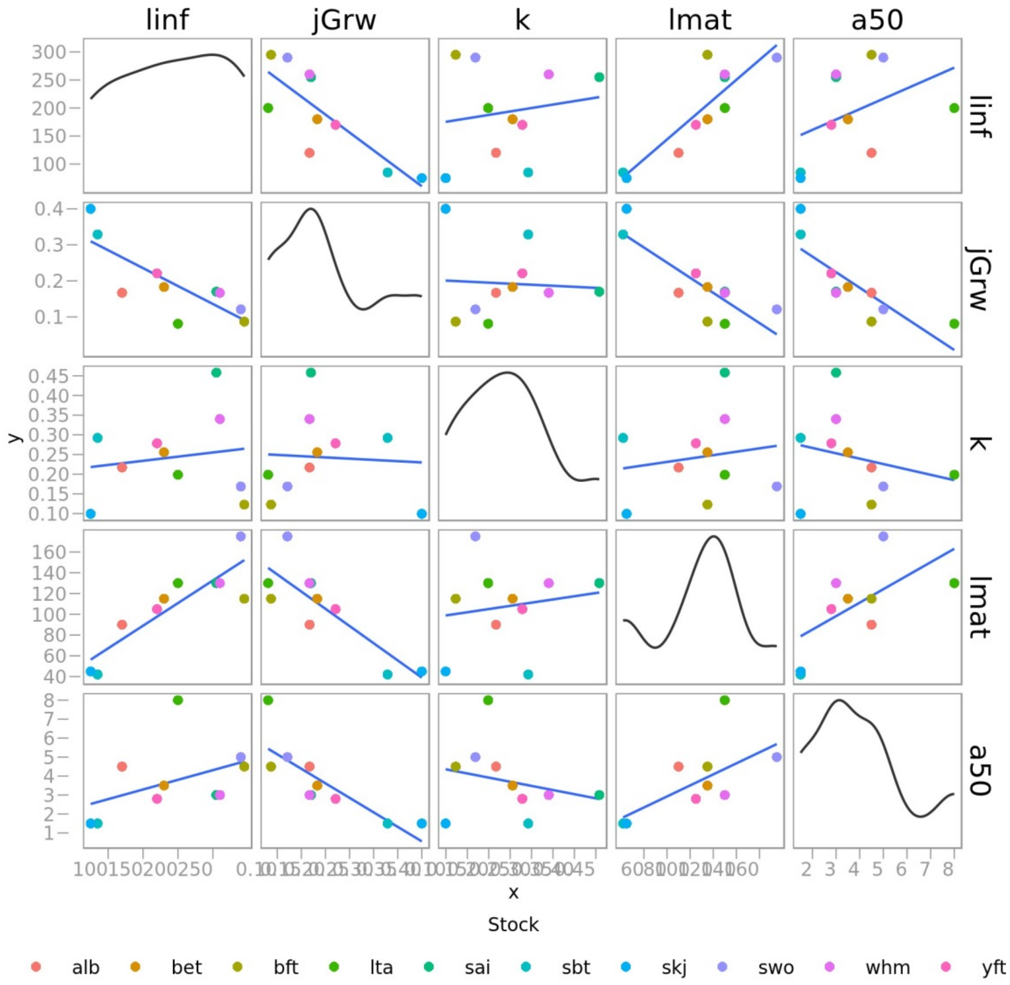

Figure 5. Scatter plots of life history characteristics L∞ , juvenile growth rate, length and age at maturity from Fromentin and Fonteneau for ICCAT stocks; fitted lines are regressions. Diagonal panels show the distributions of the parameters.

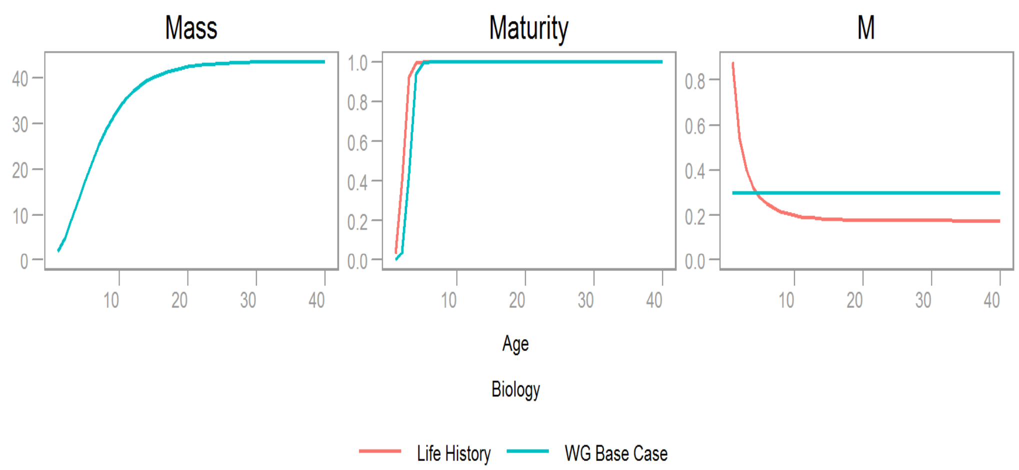

Figure 6. Mass, proportion mature and natural mortality-at-age from the stock assessment base case and the life history relationships.

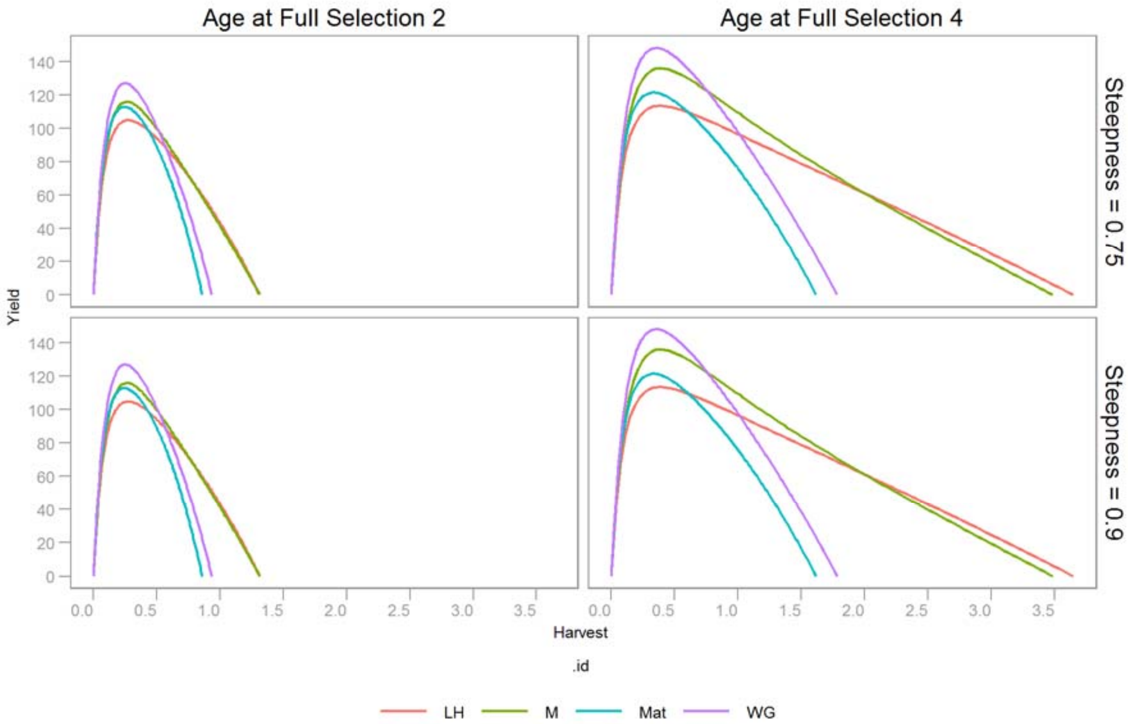

Figure 7. A comparison of the equilibrium or expected values of fishing mortality and yield by scenario;points correspond to MSY.

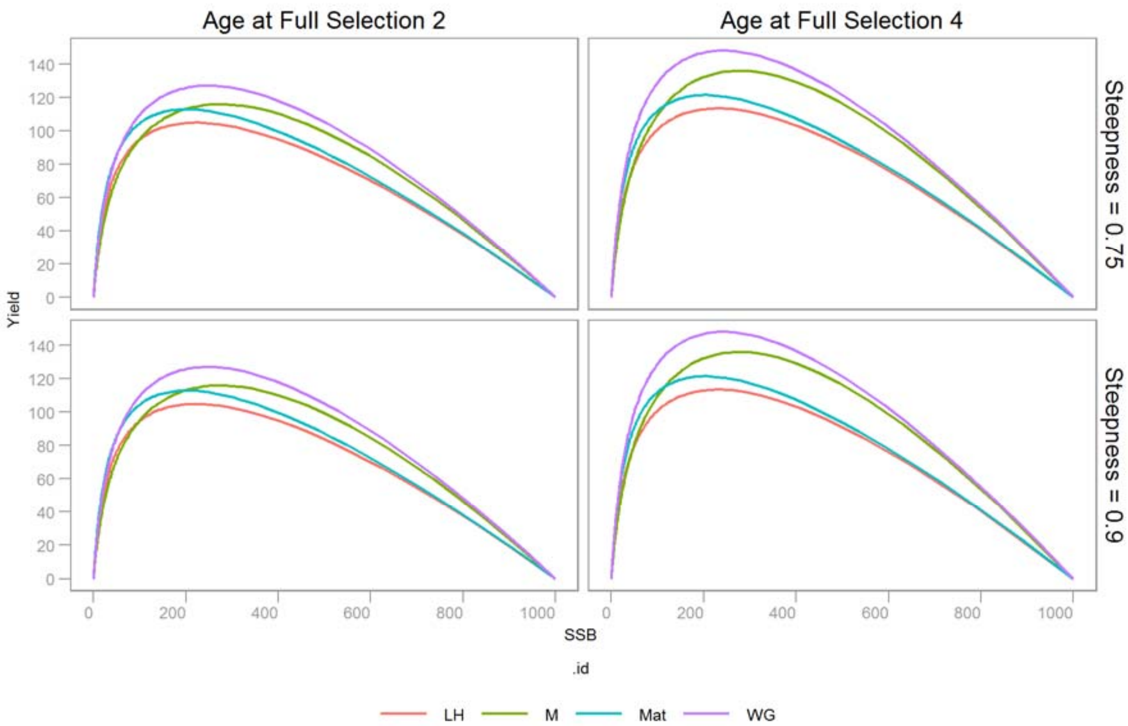

Figure 8. A comparison of the surplus production curves, i.e., equilibrium or expected values of SSB and yield by scenario; points correspond to MSY.

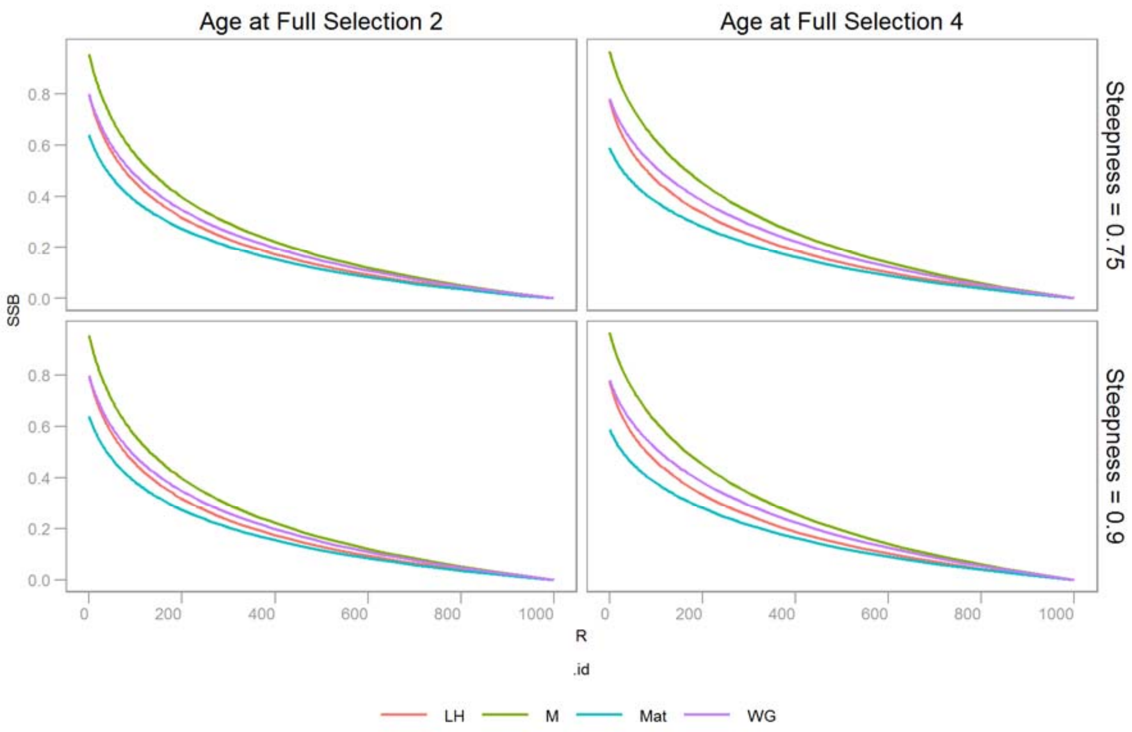

Figure 9. Population growth rate by scenario.