Report of the 2011 ISSF Stock Assessment Workshop

Rome, Italy, March 14-17, 2011

Summary. A workshop was held to examine two issues that significantly affect scientific management advice and which are not always being treated consistently in tuna stock assessments: (1) Assumptions about the stock-recruitment relationship, and (2) evaluating the implications of changing mortality on juvenile and small tunas. The workshop reviewed available information and conducted several preliminary analyses. With regards to the first issue, many assessments either estimate or fix the value of "steepness", a parameter that determines the degree to which average recruitment depends on parental stock biomass. The Workshop concluded that estimated steepness values from individual assessments should be treated with considerable caution and that meta-analyses of the available data for all tuna stocks be continued in order to provide further advice for the estimation of steepness. In addition, the Workshop made recommendations for scientists to better characterize uncertainty in steepness in their stock status determinations, and for managers to consider Harvest Control Rules that are robust to this uncertainty. With regards to the second issue, the Workshop concluded that tuna stocks that have a high fishing mortality rate on juveniles relative to adults tend to have lower spawner-per-recruit levels. However, in terms of absolute spawning biomass relative to SSB_{MSY}, those stocks that have experienced high juvenile fishing mortality are not necessarily more overfished in comparison to stocks that have not. The Workshop recommended that stock assessment reports routinely include Fishery Impact plots so that the effect that gears with different selectivity have on spawning biomass can be readily evaluated. Finally, the Workshop recommended that future meetings be held to compare the basic life history parameters being used in the tuna stock assessments, with a view to reconcile differences or improve consistency.

1. Background, objectives and organization

Tuna population dynamics are complex. There are a number of uncertainties related to this complexity, which, together with the relatively limited information on fisheries and the lack of direct (fishery-independent) information on most of the tuna stocks, require stock assessment scientists to make a number of assumptions. The International Seafood Sustainability Foundation (ISSF) hosted a workshop to examine primarily two issues that significantly affect scientific management advice and which are not always being treated consistently in Tuna RFMO assessments: (1) Assumptions about the stock-recruitment relationship, and (2) evaluating the implications of changing mortality on juvenile and small tunas.

The workshop was held at the Hotel Capo d'Africa. Participants included members of the ISSF Scientific Advisory Committee, staff from the Tuna RFMO Secretariats, scientists that actively participate in the RFMO scientific committees, and several invited external experts: Robin Allen, Craig Brown, Shui-Kai Chang, Paul de Bruyn, Alain Fonteneau, Francesca Forrestal, Jean-Marc Fromentin, John Hampton, Shelton Harley, Jim Ianelli, Laurie Kell, Dale Kolody, Jacek Majkowski, Mark Maunder, Carolina Minte-Vera, Julio Morón, Iago Mosqueira, Ana Parma, Joseph Powers, Victor Restrepo (Chair), Keith Sainsbury , Gerry Scott, and Meryl Williams.

A number of participants made background presentations intended to inform the discussions. In addition, a number of scientific publications were made available, and data from the last assessment for each stock were compiled.

The workshop agreed to focus the report on a series of recommendations that could be made to the scientists and RFMOs, as opposed to a detailed record of the meeting. These are provided below. Acronyms are explained in the **Glossary**.

2. The stock-recruitment relationship

Many of the estimates of MSY-related benchmarks are calculated by combining (a) yield-per-recruit and spawner-per-recruit values, and (b) a stock-recruitment relationship (SRR). In most stock assessments, the SRR is notoriously difficult to estimate, and scientists end up using assumed values of the "steepness" parameter, h, which defines the degree of dependence of average recruitment on spawning biomass. The estimates of current stock status (F/F_{MSY} or B/B_{MSY}) are therefore dependent on an assumption.

Simulation studies also confirm that steepness is difficult to estimate from a single stock assessment data set, and is often overestimated. Furthermore, most tuna stock assessments result in estimates of stock-recruitment data that are highly variable and that lack sufficient range in biomass levels (including very low ones) that would allow for the estimation of steepness.

A review of the most recent stock assessments (including sensitivity runs) for 22 tuna stocks examined confirm that higher values of steepness are associated with more optimistic views of the status of the stock in terms of the ratios B/B_{MSY} and F/F_{MSY} (**Figure 1**). Values assumed for steepness across these stocks do not seem to be based on life history considerations or follow any obvious pattern (see **Figure 2**).

The Workshop recommended that estimated values of steepness from individual assessments be treated with considerable caution. Analysts should evaluate the extent to which the stock-recruitment estimation or assumptions influence the estimates of recruitment.

2.1 Advice for values of (or Priors for) steepness

The Workshop first considered the question of whether life history characteristics alone could provide more informative guidance about values for steepness, or at least a relative ranking by species. Two of the background documents dealt at least partly with this subject. The approach by Brooks et al. (2010) could be used, but it would require knowledge about survival ratios as the population approaches zero (i.e., the slope at the origin of the SRR). This would be a feasible thing to do for species like some sharks that have low reproductive rates, but not for tunas with very high ones. The approach by Mangel et al. (2010) was also considered, but it requires knowledge about the distribution of natural mortality at age 0 (pre-recruitment; refer to Mangel 2010, equation 41), which would also be difficult to ascertain for tunas.

Example evaluation of steepness by meta-analyses

A presentation comparing the implied stock-recruitment curve when proxies are used for F_{MSY} provided a means of determining (in a general sense) where the proxies tended to be precautionary relative to the actual model outputs of stock-recruitment data. Specifically, in some situations the F levels that result in a given level of SPR are used as a proxy for F_{MSY} following the work of Clark (2002). Such reference points have the advantage in that issues about fitting the stock-recruitment curve are avoided and estimates depend only on age-specific fishery selectivity, natural mortality, mean weight, and maturation. The Workshop discussed the pros and cons of doing something similar with tuna stocks and suggested also evaluating $F_{0.1}$ as a proxy for F_{MSY}. The Workshop encouraged setting up a meta-analysis framework to pursue these questions and this was done preliminarily during the meeting. The compiled assessment results were formatted so that they could be evaluated simultaneously. This allowed a set of evaluations including the ability to link stocks hierarchically in a type of meta-analysis. With these preliminary data, a set comparing unconstrained estimates of the Beverton-Holt SRR (without linkage between stocks), estimates assuming F_{MSY} is equal to $F_{35\%}$ and assuming a prior distribution on F_{MSY} (with mean=$F_{35\%}$ and CV=20%), and finally with unconstrained estimates but linked with a common mean among stocks. Results of the available SRR data and Beverton-Holt fits from the four cases are shown in **Figures 3a** to **3c**.

For further explorations, an approach was used to solving the problem (often encountered with Beverton-Holt curves) that steepness tends towards the upper bound of 1.0, using MCMC to integrate over the random effects (here treated as the variability in steepness over different stocks). An MCMC chain of length 5 million was done saving every 1000th draw so that a posterior was approximated from the remaining 5 thousand. Stock-specific estimates of steepness (h) and recruitment variability (σ_R) are given in **Figures 4** and **5**.

It should be noted that these explorations conducted during the Workshop are very preliminary and require further verification and validation of the data sets. Nonetheless, the results suggest the following:

- Steepness for the tropical tuna species is likely to be higher than 0.6;
- There is no obvious relationship between steepness and life history groupings (although steepness among the tropical tunas seem to be more homogeneous relative to the temperate ones). Subsequent analyses should treat tropical and temperate tunas differently, e.g. by linking them as separate groups;
- Future analyses should define data sets in recognition of possible regime shifts;
- Overall, estimated recruitment variability (σ_R) was low. However, stocks with continuous spawning throughout the year tended to show lower inter-annual recruitment variability than stocks with restricted spawning seasons. Further work is needed to corroborate these results (for example, by incorporating estimation errors for recruitment values used in the analyses).

Another type of meta-analysis was initiated during the Workshop (**Figure 6**). Using the available stock assessment and biological data, an updated analysis using the approach of Myers et al. (1999) was conducted. The analysis requires the conversion of recruitment estimates to replacement spawning biomass under no fishing mortality. This conversion allows useful interpretation of the data and may be useful for all stock assessments. In these analyses, estimates of the slope at the origin of the SRR were obtained for both the Ricker and Beverton-Holt SRR functions. Likelihood profiles for steepness were undertaken and were also informative. The results of these analyses are also very preliminary but consistent with those of the other meta-analysis (compare

Figures 4 and **6**). Once the assessment data are finalized for more stocks, a full random-effects meta-analysis will be undertaken including incorporation of covariates relating to the biological characteristics of the individual stocks.

Participants agreed that the analyses initiated during the Workshop would be very useful in providing further guidance for handling steepness in stock assessments.

RFMOs should collaborate towards undertaking a meta-analysis of spawner-recruitment data as initiated during this Workshop. It was recommended that analysts continue to develop this work with a view to provide further advice for the estimation of steepness in tuna assessments.

2.2 Advice on model-averaging as a method to address uncertainties in steepness (among other things)

All of the tuna RFMOs investigate multiple models (or runs of the same model with different parameter values) during each stock assessment. In some cases, the argument has been made that a single model can be selected to provide an adequate description of the stock status. In other cases, a single model is not sufficient, because: (a) the uncertainty in key parameters cannot be adequately encompassed (such that the assessment is unrealistically precise), and (b) structurally different models may be plausibly consistent with the data and represent considerably different management implications. The workshop recognized that some form of model averaging represented a useful tool for representing the uncertainty encompassed by multiple models, and provided the following guidelines:

- When resources allow, the application of multiple models with different structural assumptions should be encouraged, to ensure a more diverse and robust assessment process. If different models result in different management implications, this should be described in the management advice.
- A range of steepness uncertainty should be reflected in the assessment advice for all tuna species. If the estimates of statistical uncertainty on steepness conditional on a single model specification are dubiously narrow (e.g., CV <15% or some value derived from simulations), then efforts should be made to expand the uncertainty. This can be achieved by integrating the results of several models with a range of fixed steepness values. Where there is evidence for a recruitment regime shift, this should be admitted as one of the structural options.
- Variability in the magnitude and functional form of M_{age} should be admitted into the analysis and the corresponding uncertainties carried through the management advice.
- Whenever possible, relative plausibility weighting should be assigned to each model (rather than the default of all models weighted equally). The weighting should consider issues of model fit to the data, biological plausibility, and recognized limits for fisheries data to estimate some important parameters. Inappropriate models should be omitted from the management advice. A Delphi approach may be helpful to reach consensus if opinions about weightings are widely divergent.
- Model averaging can lead to polymodal distributions, and the management advice should be clear about whether this is the real perception (e.g. non-

overlapping distributions due to different structural assumptions) or an artifact (e.g. due to a coarse grid of steepness values).

The Workshop recommended that stock status advice incorporate stock assessment structural and parameter uncertainty including a range of plausible steepness values.

2.3 Advice for improving the presentation of tradeoffs to managers

Decision tables provide information to managers about the tradeoffs of different management actions in the face of uncertainty. Decision tables present quantities of interest (e.g. catch and depletion levels) estimated under alternative states of nature (e.g. steepness) based on different management strategies. The probabilities of the states of nature are presented if available and can be used to determine expected values of the quantities of interest. Decision tables can be used to present the tradeoffs implied by mis-specifying the steepness of the stock-recruitment relationship. **Figure 7** shows how a F_{MSY} based harvest strategy based on mis-specified steepness performs under alternative values for the true value of steepness (states of nature). In the top panel the true state is *h* = 1.00 and the lost yield based on fishing at F_{MSY} calculated assuming steepness is 0.75 is [A-B]. In the bottom panel the true state is *h* = 0.75 and the lost yield based on fishing at F_{MSY} calculated assuming steepness is 1.00 is [B-A]. It is clear in this example that due to the flat yield curve when *h*=1, under-specifying h results in less lost catch than over-specifying *h*. In addition, fishing at F_{MSY} based on *h*=0.75 maintains the biomass at a higher level. This information can be presented in a decision table (**Table 1**). The example presented here is rather simplistic. In addition to the expected equilibrium quantities, managers would be interested in transitional quantities as well.

Table 1. Hypothetical decision table used to show potential tradeoffs associated with mis-specifying steepness. In this simplistic and idealized example, quantities are only approximate and probabilities are only for illustrative purposes. The top table presents tradeoffs in terms of equilibrium yield; the bottom table presents tradeoffs in terms of depletion (B/B_0).

	Catch at Fmsy estimated with h=1.0	**Catch at Fmsy estimated with h=0.75**
True h=1.0 (Prob = 0.6)	270,000	240,000
True h=0.75 (Prob = 0.4)	240,000	290,000
Expected catch:	**258000**	**260000**

	Depletion at Fmsy estimated with h=1.0	**Depletion at Fmsy estimated with h=0.75**
True h=1.0 (prob = 0.6)	0.25	0.45
True h=0.75 (prob = 0.4)	0.20	0.40
Expected depletion:	**0.23**	**0.43**

2.4. Advice on management and using Harvest Control Rules (HCRs)

It is recommended that options to present management advice in the form of harvest control rules be developed, scientifically evaluated and considered by the relevant decision-making body. HCRs relate the recommended catch, or other fishery control measure, to the current value of selected control variables. HCRs can be empirical in which the control variables are directly measurable quantities (e.g., catch rate, size composition, tag recovery rate, survey estimates of abundance and species composition). For instance, empirical algorithms have been proposed for southern bluefin tuna to determine Total Allowable Catches using information solely from CPUE indices and fisheries independent index (aerial surveys). HCRs for making management decisions are thus based on a relative procedure that uses year-to-year changes and trends in the empirical indicators. Such procedure will require choosing appropriate reference levels (e.g. an absolute value to initiate the process) that may be based on historical catch and or effort and be tuned to meet management objectives. HCRs can also be model based in which the control variables are quantities estimated from stock assessment or other models (e.g., F, SSB, $B_{current}/B_0$, $B_{current}/B_{MSY}$).

In both cases, it is necessary to test the performance of the HCRs across the plausible range of uncertainty in steepness and other aspects of the population dynamics and observations relevant to the fishery. The performance of different HCRs should be tested for their ability to robustly deliver against a relevant range of desired fishery outcomes (e.g. high catch, high catch rate, low variability in catches, high fishery and population resilience to environmental and other 'shocks', low catches of nominated by-catch or by-product species). Simulation studies should help in determining the performances and the robustness of the different HCRs, especially in a multi-species context (e.g. tropical tunas) or in data-poor situations.

Tuna RFMOs should consider the ability of different tested HCRs to deliver across that range of management outcomes and chose the HCR that they would prefer to be the basis of future 'bases case' management advice. There should be periodic review of the HCR that is used, including proactive identification of 'exceptional circumstances' that would trigger an in-depth review.

The Workshop recommended that RFMO decision-makers consider management measures and/or HCRs that are robust to uncertainty in steepness, noting the precautionary approach and the economic benefits of maintaining stocks at higher stock sizes. RFMOs should collaborate on methods for the incorporation of uncertainty of steepness into stock assessment advice, including approaches such as management strategy evaluation.

3. Issue 2: Small fish

The juvenile (immature) component of several tuna stocks has been subjected to particularly high levels of fishing mortality in recent and/or past times. The Workshop reviewed per-recruit calculations presented for the various stocks and noted that, the two bigeye stocks that have SPR (Spawning Potential Ratio) values lower than 15% of the maximum are those for which the ratio of juvenile to adult mortality in the last generation is higher than 1. The same pattern is observed for the longest lived species

(Pacific bluefin and eastern Atlantic bluefin) for which SPR is low and the ratio of juvenile:adult F is greater than 1.0 (**Figure 8**). These results suggest that, in general, stocks that have a current small equilibrium spawning potential, at least for BET, PBT and BFT, have also experienced higher rates of fishing mortality of juveniles compared to adults.

In absolute terms, it was noted that some stocks that have experienced high F on juveniles in recent years are not necessarily more overfished in comparison to stocks that have not. **Table 2** arranges the stocks for which estimates of $SSB_{current}/SSB_{MSY}$ are available, depending on whether or not the ratio of juveline:adult F is greater than 1.0. This ranking is somewhat subjective in the sense that the magnitude of estimated F is related to the magnitude of assumed M.

Table 2. Classification of various tuna stocks according to their current spawning stock size relative to the MSY level, and the magnitude of fishing mortality on juveniles (j) relative to that on adults (a) experienced during the last generation time.

	$F_j>F_a$	$F_j<F_a$
$SSB<SSB_{MSY}$	BFT-EA SBT	ALB-NA ALB-SA BFT-WA YFT-AO
$SSB>SSB_{MSY}$	BET-EPO BET-WPO YFT-EPO YFT-WPO	ALB-NP ALB-SP BET-AO BET-IO SKJ-EA SKJ-EPO SKJ-WA SKJ-WPO YFT-IO

One question that comes up when the F on juvenile fish is high and the species can grow to larger sizes targeted by other gears is: Can overall yields and economic rent increase substantially if F is lowered for the gears that catch small fish so that the surviving fish can become available to other gears that catch larger ones? The Workshop examined work that addressed this question, looking in particular at tradeoffs between purse seine and longline fisheries catching bigeye tuna (Sun *et al.*, 2010). The results indicate that large gains in yield could be achieved in theory by lowering purse seine fishing effort, but that in practice such gains could only be realized if longliners would actually be able to catch the fish that survive. The lack of impact on the longline CPUE by the rapid expansion of the purse seine fishery in this study puts doubt into the assumption that bigeye released from the purse seine fishery being available to the longline fishery. In addition to this question, the potential gain would be highly dependent on the level of natural mortality of the fish that survive the purse seine fishery: Higher M levels would result in fewer fish becoming available to the longline fishery. Furthermore, it was noted that the purse seine fisheries for tropical tunas are largely multi-specific such that actions aimed at controlling F on bigeye could have undesirable consequences for skipjack catches (note that FAD-based purse seine fisheries are the major source of fishing mortality on small bigeye, but they mostly target skipjack).

The Workshop noted that one useful way to visualize the effect on the stock of fisheries that target different size groups is to conduct a "fishery impact analysis" such as those shown for various Pacific Ocean stocks (e.g. **Figure 9**). Fishery impact plots automatically take both the level of fishing mortality and the size of the fish caught into consideration when determining the impact on biomass.

The Workshop recommended that Fishery Impact plots be included routinely in tuna RFMO stock assessment reports.

4. Other matters: Life history parameters and future workshops

Participants examined the life-history parameters (growth, M, maturity) that were compiled in preparation for the workshop. It was noted that in some cases the differences in parameters assumed or estimated in the different assessments are quite large (**Figure 10** shows age-specific M vectors as an example). The Workshop agreed that it would be a good initiative for assessment scientists and other experts to get together to examine these differences and determine the degree to which they are real, and whether or not it would be useful to reconcile values that are purely assumed.

It was suggested that this could be done through one or two workshops like the present one, and that RFMOs should fund them if possible. Other potential topics for a workshop in 2012 were discussed, as well. In terms of priorities, the following were mentioned:

- A workshop on growth and age determination (and possibly M as well).
- A workshop on purse seine CPUE standardization.
- A workshop on natural mortality of tunas, comparing estimates to theoretical studies such as Gislason (2010) or Lorenzen (1996).
- A workshop on bigeye tuna stock assessments.

The Workshop recommended that RFMOs facilitate meetings to compare the basic life history parameters being used in the tuna stock assessments, with a view to reconcile differences or improve consistency, if necessary.

5. Closure

A. Fonteneau, who chaired the 2010 Joint Tuna RFMO Meeting of Experts to Share Best Practices on the Provision of Scientific Advice (Barcelona, Spain), congratulated ISSF for taking the initiative to hold this Workshop and noted that it was a good follow-up to the actions recommended at the Barcelona meeting. He expressed hope that the RFMOs and/or ISSF will support similar workshops in the future.

The Chairman thanked participants for their hard work and the Workshop was closed.

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GLOSSARY OF TECHNICAL TERMS

B_0. Equilibrium biomass (or spawning biomass, SSB_0) expected when F=0 (also known as "virgin biomass").

B_{MSY}. Average biomass (or spawning biomass, SSB_{MSY}) that results from fishing at $F=F_{MSY}$.

CPUE. Catch-per-unit-effort (or "catch rate"). Stock assessments typically use CPUE as an index of abundance for a component of the population.

$F_{0.1}$. Fishing mortality for which the slope of the yield-per-recruit curve is 10% of the value as F approaches 0.0. $F_{0.1}$ is sometimes used as a proxy for F_{MSY}.

$F_{35\%}$. Fishing mortality that results in an SPR of 35%. $F_{35\%}$ is sometimes used as a proxy for F_{MSY}.

F_{MSY}. Fishing mortality that would produce MSY.

h. Steepness: the fraction of recruitment from an unfished population obtained when the spawning stock biomass is 20% of SSB_0.

HCR. Harvest Control Rule. The rule relates a variable over which management has some direct control as a function of some indicator of stock status (for example, how catch could be set depending on the level of SSB).

M. Natural mortality rate.

MCMC. Markov Chain Monte Carlo methods. These are a class of algorithms for sampling from probability distributions based on constructing a Markov chain that has the desired distribution as its equilibrium distribution.

MSY. Maximum Sustainable Yield. The largest amount of yield that could be produced by a stock, on average.

SPR. Spawning potential ratio: The expected value of spawners per recruit (SSB/R) at a given fishing mortality divided by the SSB/R with F=0.

SRR. Stock-recruitment relationship. The relationship predicts the average number of recruits that would be produced at different population sizes. Two functional forms are commonly used in fisheries: The Beverton-Holt and the Ricker models.

σ_R. "Sigma-R" measures the magnitude of recruitment variability around the SRR.

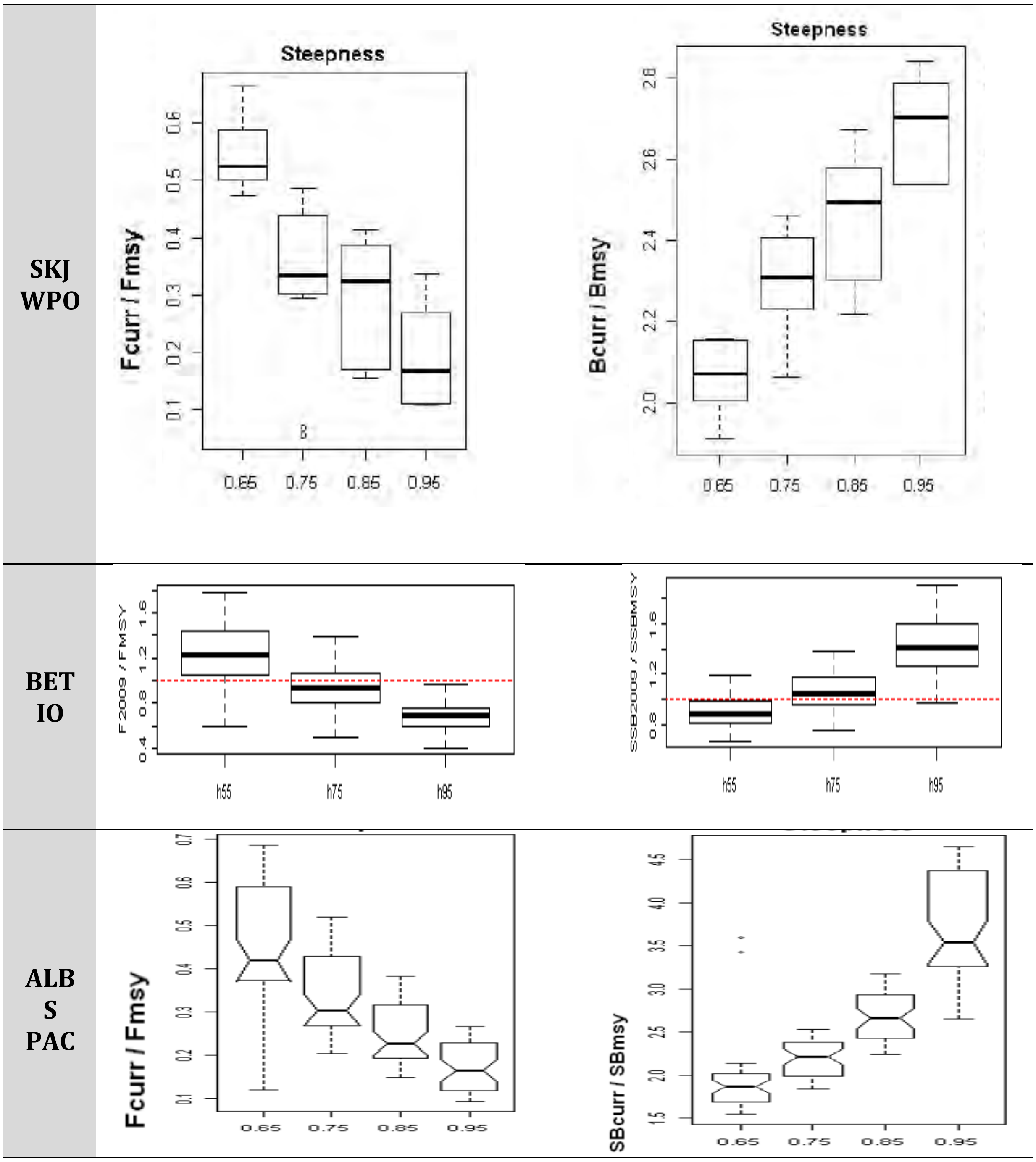
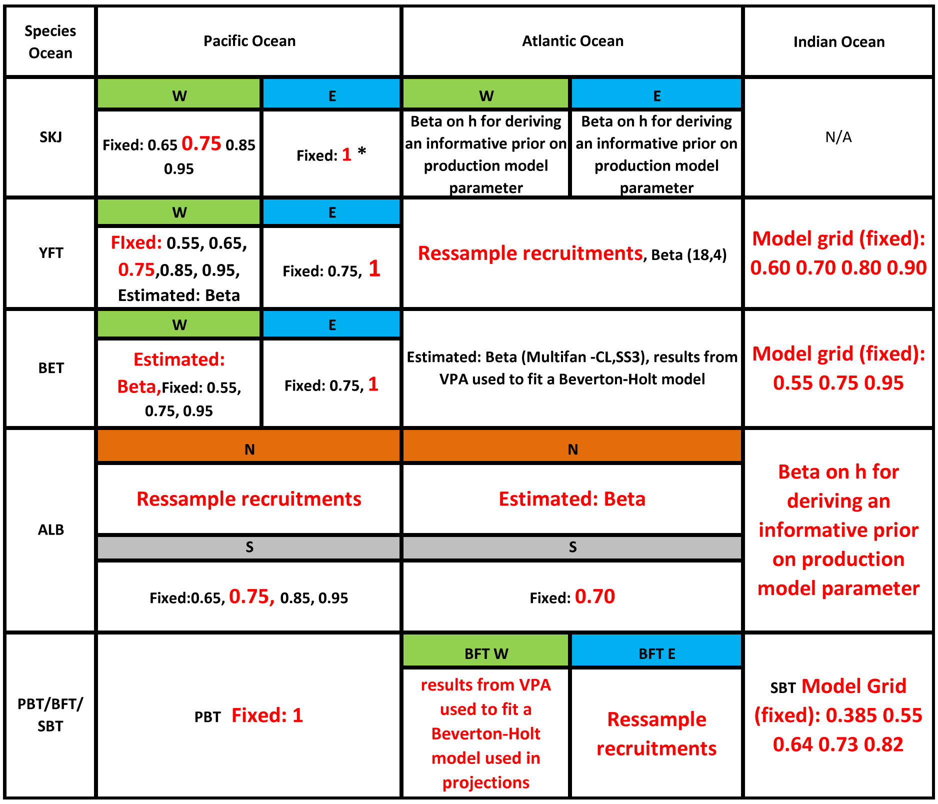


Figure 1. Box-plot showing the effect of assumptions of specific values of steepness on derived relative quantities for fishing mortality ($F_{current}/F_{MSY}$) and biomass (top panel – $B_{current}/B_{MSY}$, next two panels $SB_{current}/SB_{MSY}$) for three tuna stocks (SKJ-WPO, BET-IO, ALB-SPAC). The variability comes from a grid of model runs with different assumptions.



Species Ocean	Pacific Ocean		Atlantic Ocean		Indian Ocean
SKJ	W	E	W	E	N/A
	Fixed: 0.65 0.75 0.85 0.95	Fixed: 1 *	Beta on h for deriving an informative prior on production model parameter	Beta on h for deriving an informative prior on production model parameter	
YFT	W	E	Ressample recruitments, Beta (18,4)		Model grid (fixed): 0.60 0.70 0.80 0.90
	FIxed: 0.55, 0.65, 0.75,0.85, 0.95, Estimated: Beta	Fixed: 0.75, 1			
BET	W	E	Estimated: Beta (Multifan -CL,SS3), results from VPA used to fit a Beverton-Holt model		Model grid (fixed): 0.55 0.75 0.95
	Estimated: Beta,Fixed: 0.55, 0.75, 0.95	Fixed: 0.75, 1			
ALB	N		N		Beta on h for deriving an informative prior on production model parameter
	Ressample recruitments		Estimated: Beta		
	S		S		
	Fixed:0.65, 0.75, 0.85, 0.95		Fixed: 0.70		
PBT/BFT/SBT	PBT Fixed: 1		BFT W	BFT E	SBT Model Grid (fixed): 0.385 0.55 0.64 0.73 0.82
			results from VPA used to fit a Beverton-Holt model used in projections	Ressample recruitments	

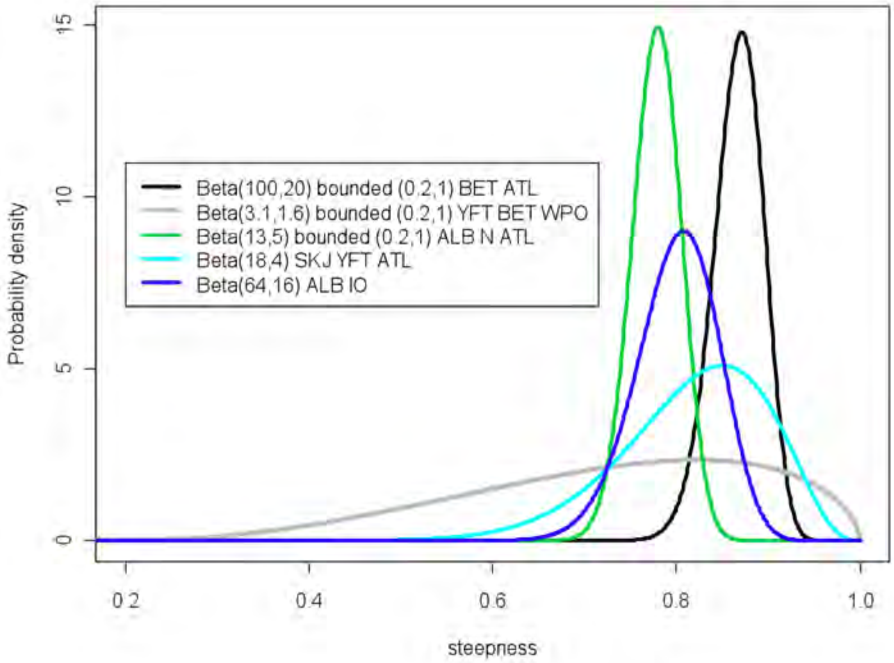


Figure 2. Top panel: Steepness values assumed for base-case (in red) and sensitivities (in black). The steepness may be either estimated or fixed in the base-case or sensitivity analyses. Resampled recruitments may be the approach used for future projections in some assessments, where no stock-recruitment function is assumed. Bottom panel: When steepness is estimated, the Beta distribution is used as a prior in most cases.

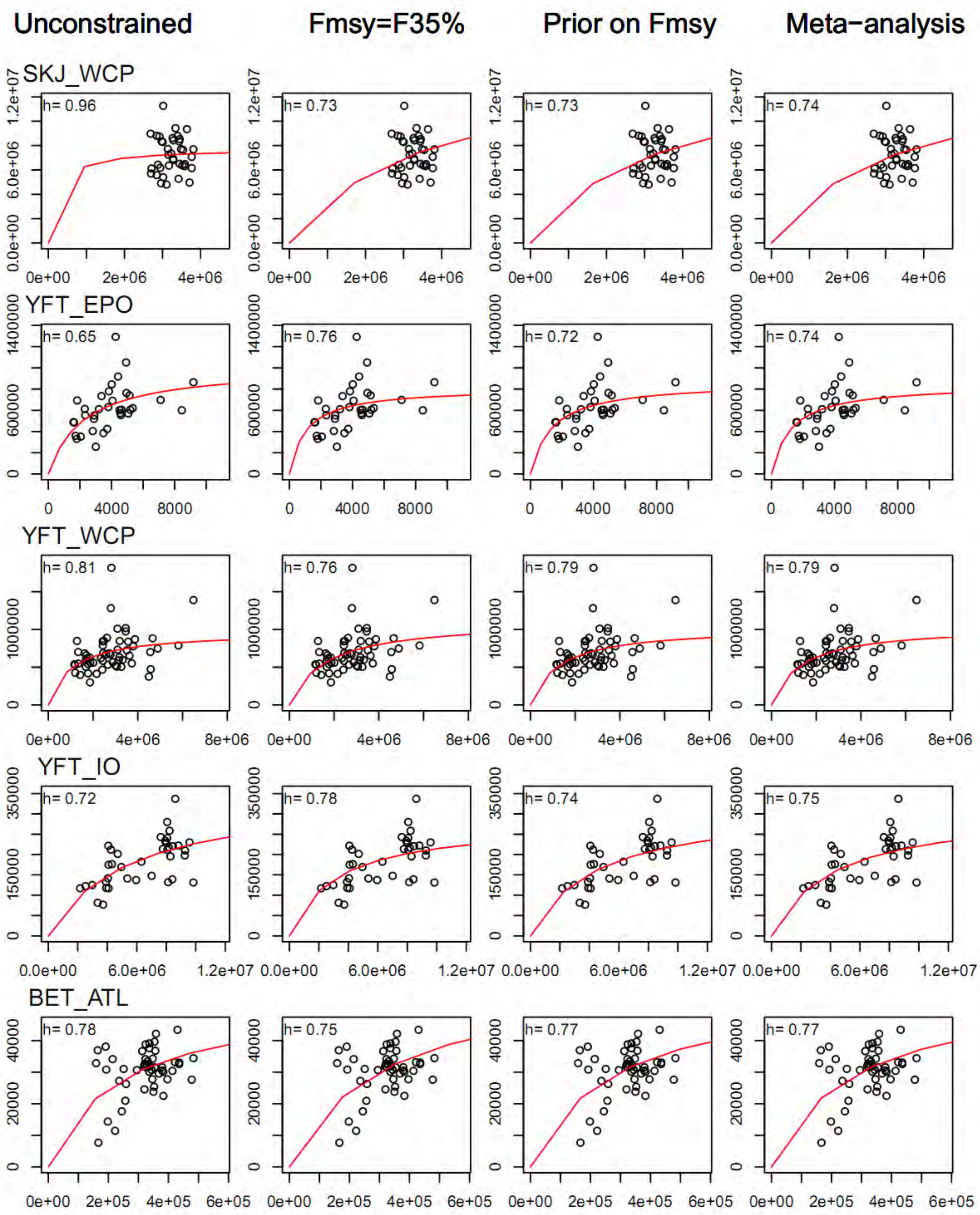


Figure 3a. Preliminary results comparing constraint configurations (columns) for different stocks of tunas (rows). NOTE: all data are preliminary.

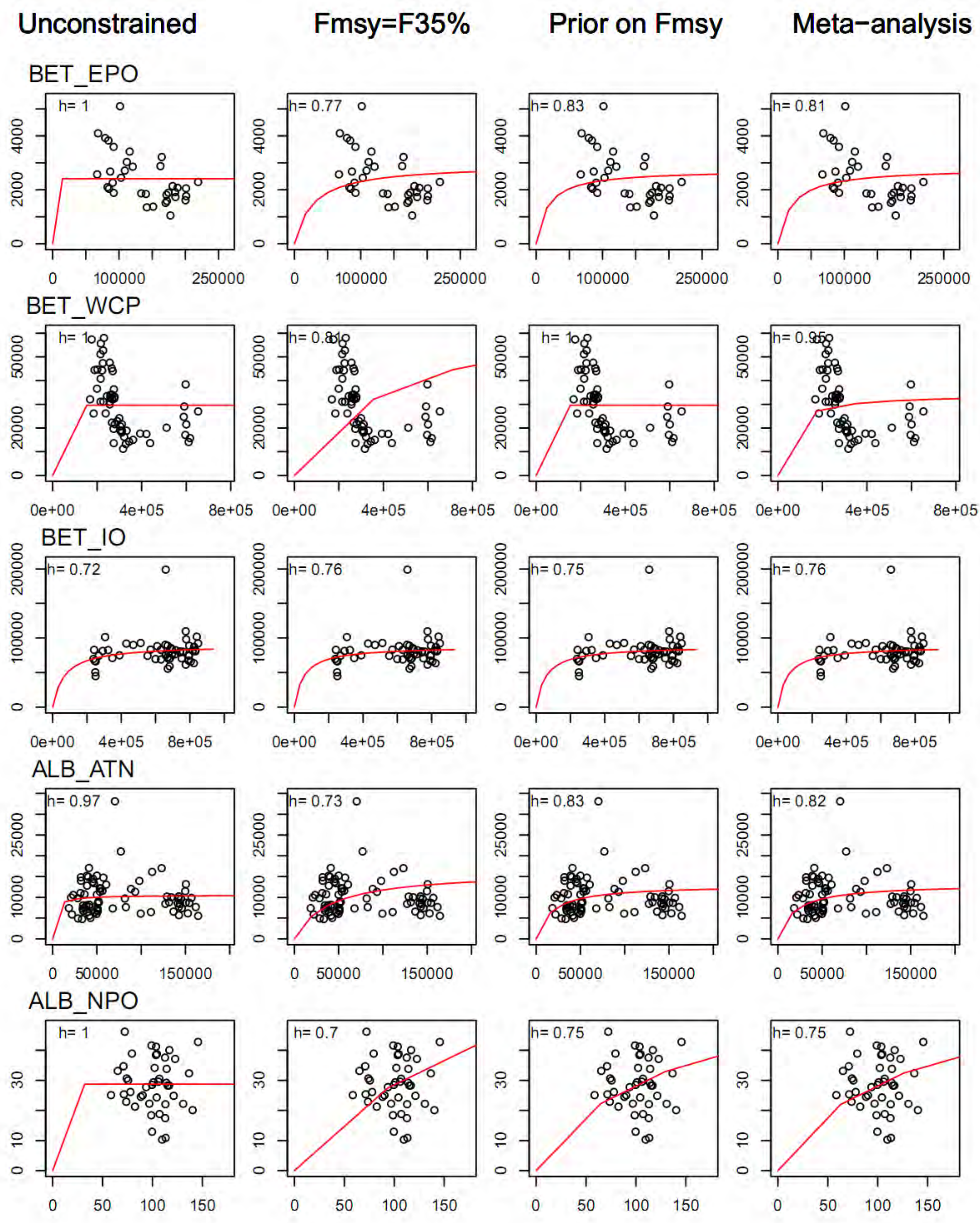


Figure 3b. Preliminary results comparing constraint configurations (columns) for different stocks of tunas (rows). NOTE: all data are preliminary.

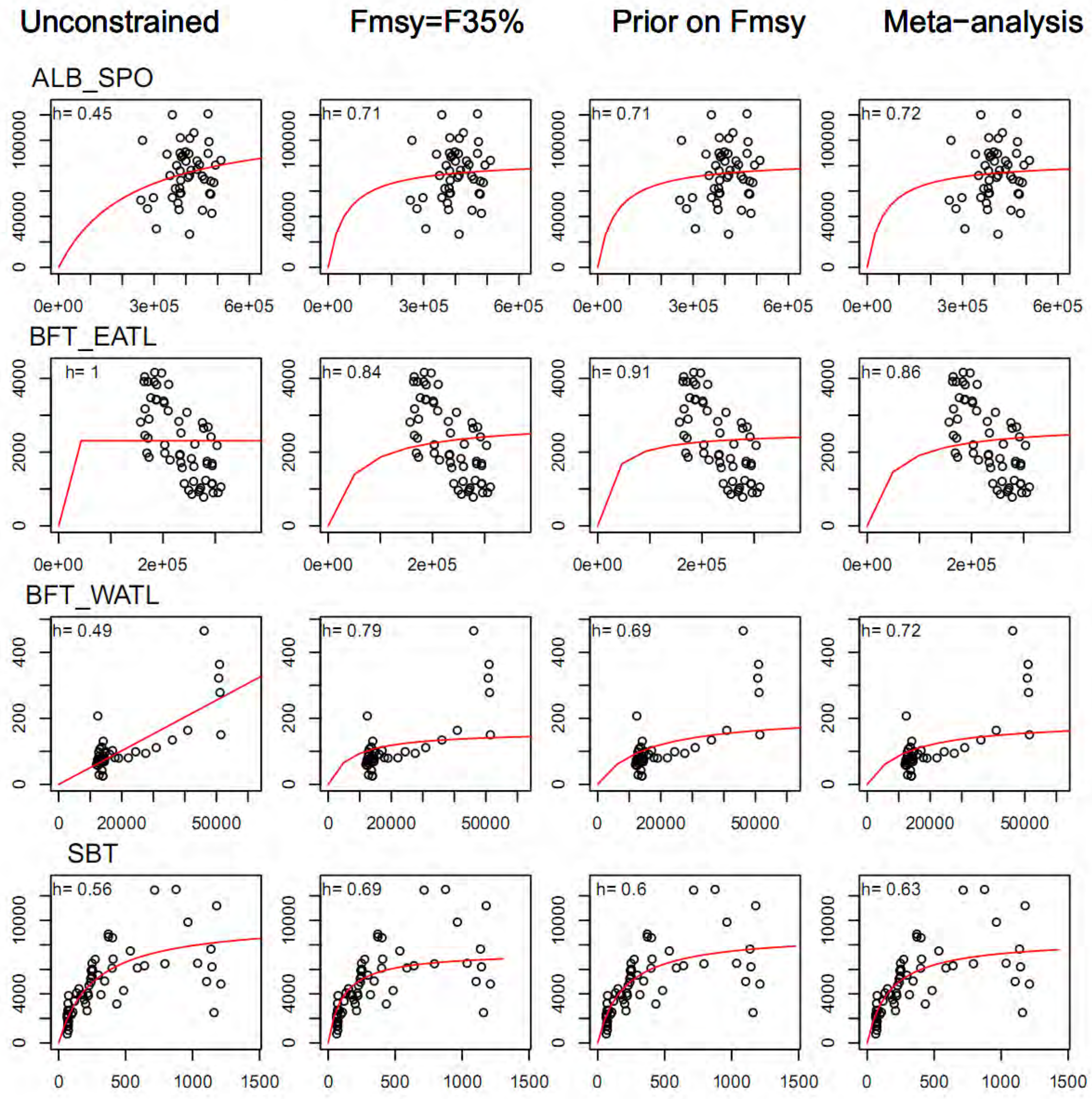


Figure 3c. Preliminary results comparing constraint configurations (columns) for different stocks of tunas (rows). NOTE: all data are preliminary.

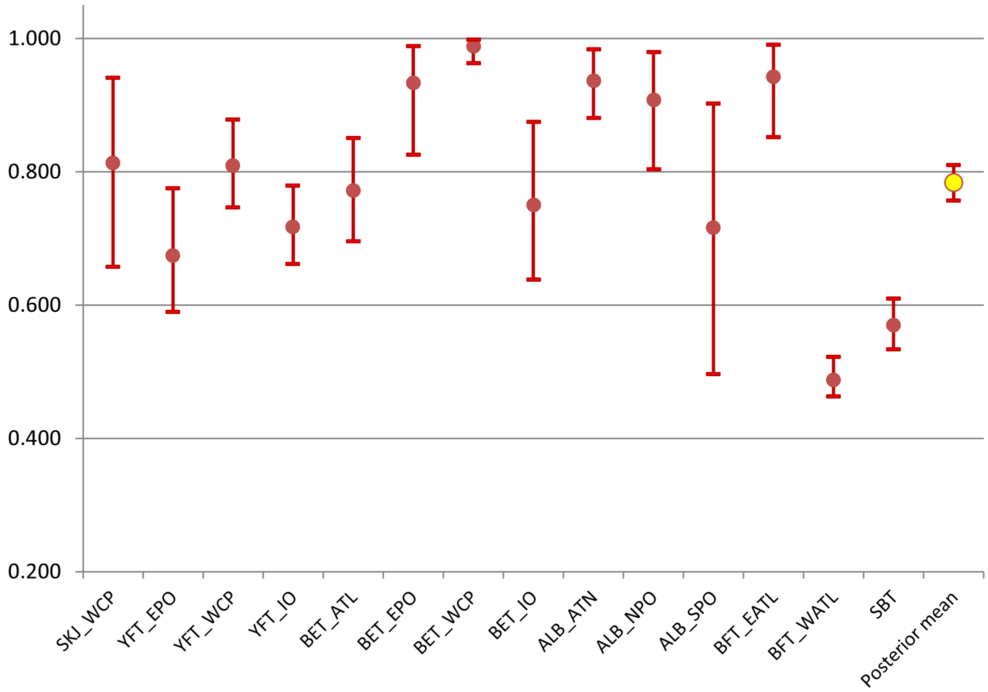


Figure 4. Preliminary results of the first meta-analysis showing steepness values for different stocks of tunas. The posterior mean is shown on the far right. NOTE: all data and analyses are preliminary.

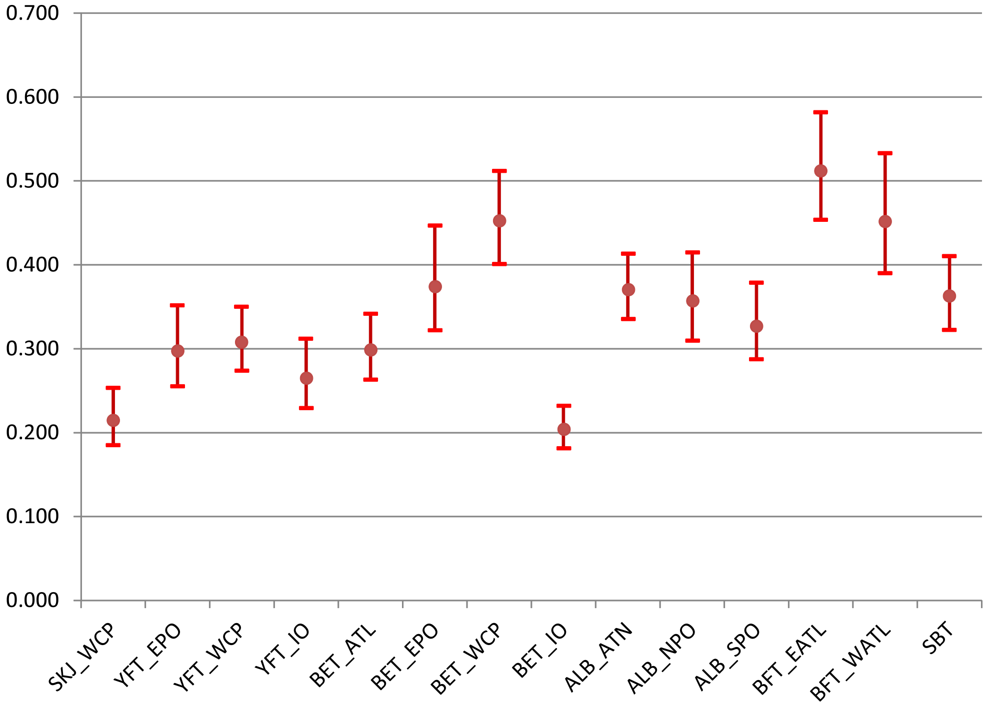


Figure 5. Preliminary results of the first meta-analysis showing σ_R for different stocks of tunas. NOTE: all data and analyses are preliminary.

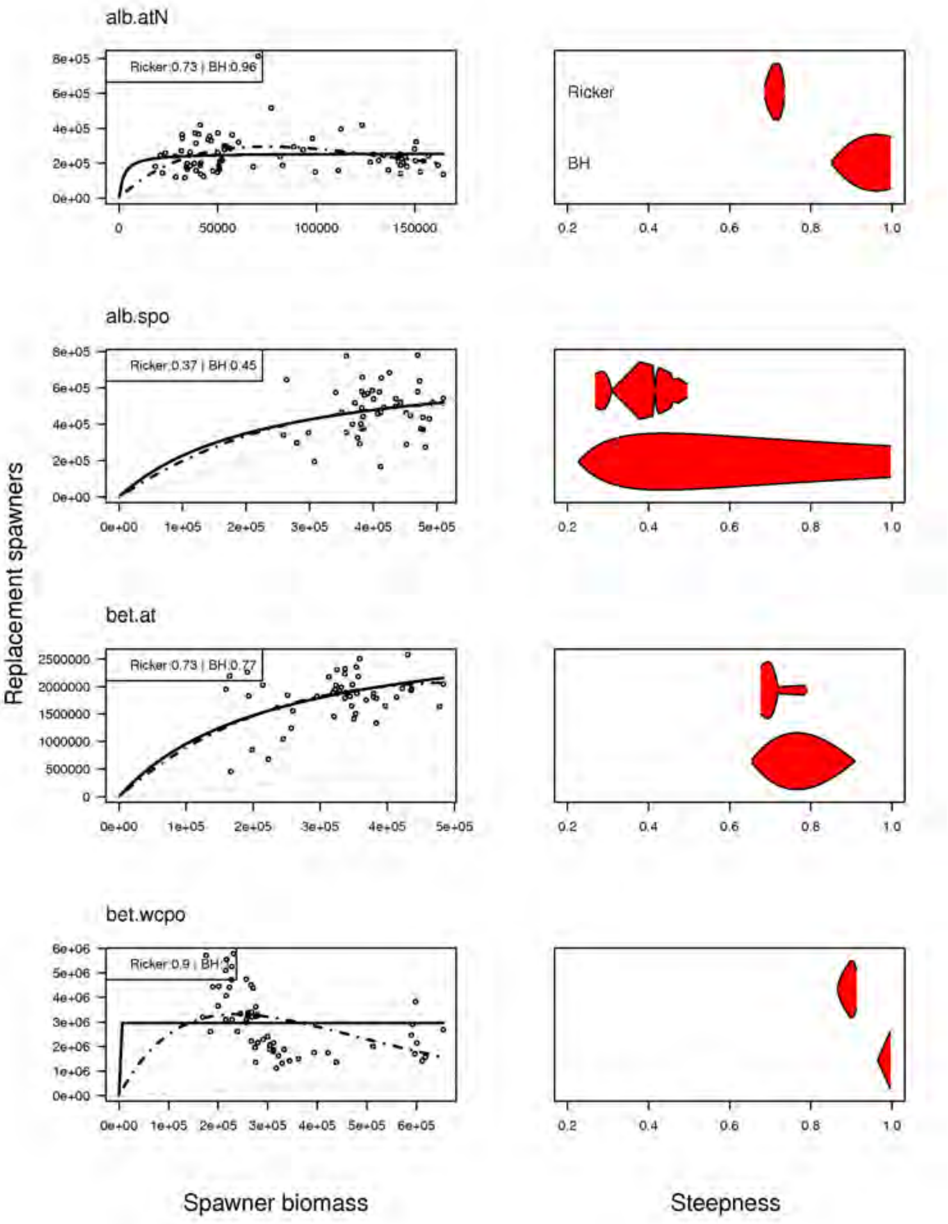


Figure 6. Preliminary results of the second meta-analysis. Left side: Spawner-recruitment data for each stock with recruits translated into replacement spawners. A Ricker (dashed) and Beverton-Holt (solid) curve is fitted to each data series and the implied value for steepness (estimated from the slope at the origin) for each model is provided; (right side) likelihood profiles for the implied level of steepness from the slope at the origin from each model. These curves can sometimes provide strange patterns - some might simply be the result of problems in the minimization.

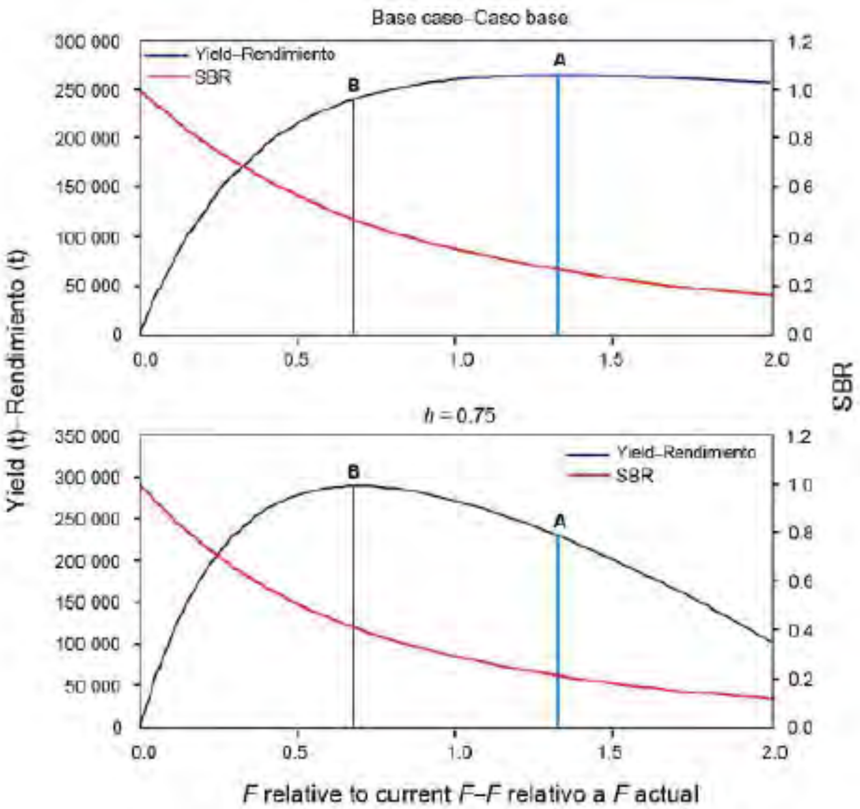


Figure 7. Hypothetical example showing yield and spawning biomass ratio (SBR) as a function of fishing mortality relative to the current level. The vertical lines represent F_{MSY} for a base case assessment (top, estimated *h*=1, F_{MSY}=line A) and a sensitivity run (bottom, assumed *h*=0.75, F_{MSY}=line B).

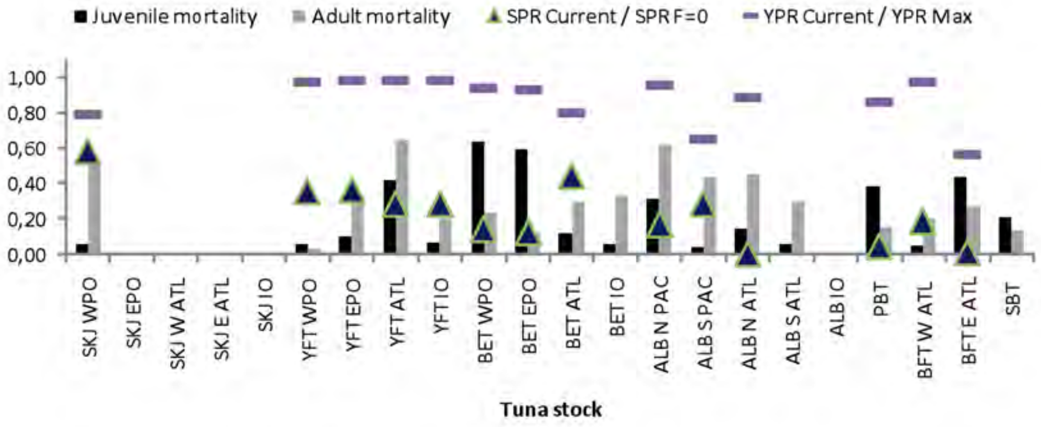


Figure 8. Average juvenile and adult fishing mortality at age ($year^{-1}$) in the last period of one generation in relation to current spawning-per-recruit ratio ($SPR_{current}/SPR_{F=0}$) and yield-per-recruit ratio ($YPR_{current}/YPR_{Maximum}$).

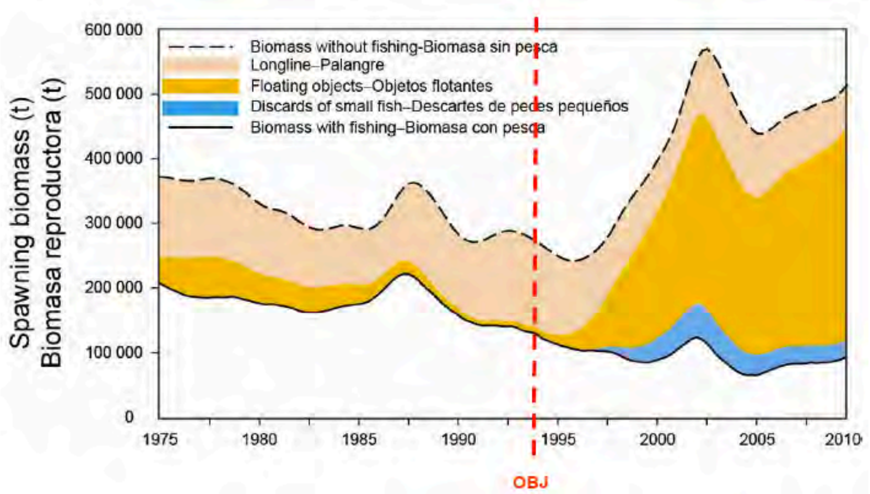


Figure 9. Example fishery impact analysis (from the 2010 assessment of EPO bigeye). The different lines show what the spawning biomass trajectory could have been like in the absence of different fisheries, assuming the same level of recruitment.

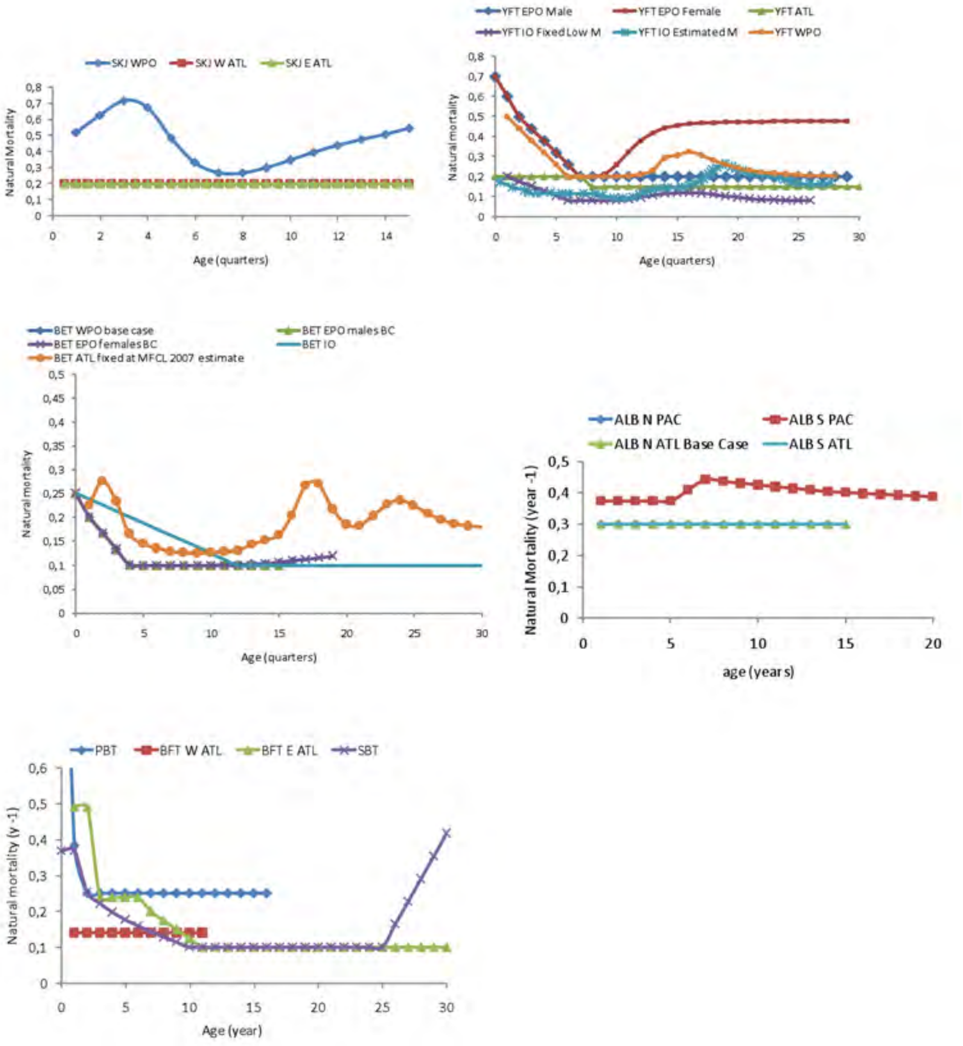


Figure 10. Age-specific vectors of natural mortality, M, assumed or estimated during the last tuna stock assessments.