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Re-conditioning of the CCSBT Operating Model: impacts of revised natural mortality schedule and interaction with steepness

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Table of Contents

Abstract

In 2009, the CCSBT will consider advice from the ESC on the current status of the SBT stock and the potential implications of different future catch levels. This advice will be based on constant catch projections using a "re-conditioned" CCSBT Operating Model (OM) and an analysis of fisheries indicators (Anon 2008). A workshop of the CCBST Management Procedure Working Group (MPWG) was held in Seattle (13-17 July 2009) to "re-condition" the OM (Anon 2009). Outcomes of the OMMP workshop included a revised natural mortality (M) schedule. It was not possible at the workshop to fully consider interactions between this revised M schedule and other axes of uncertainty in the OM grid, in particular the steepness parameter of the stock-recruitment relationship. We present results and further consideration from analysis of model diagnostics for the base model (as agreed at the MPWG workshop) and a number of model variations used to explore these interactions. The results suggest that steepness and natural mortality at young ages (<age 10) are positively correlated in the OM. There is a slight negative correlation between M at age 30 and steepness, but this correlation appears to be fairly weak. The highest steepness level (0.73) is preferred using the revised M schedule, consistent with the outcomes of the Seattle workshop. However, this is in part driven by the fact that the new M schedule, which is linear between ages 1 and 4, does not allow for low M at ages 2-4. When a more flexible M function is used (such as the original "power" functional form), M declines quickly after age 1 and results in the, the medium steepness level (0.55) gaining a higher preference, as indicated by the posterior likelihoods.

Introduction

In 2009, the CCSBT will consider advice from the ESC on the current status of the SBT stock and the potential implications of different future catch levels. This advice will be based on constant catch projections using a "re-conditioned" CCSBT Operating Model (OM) and an analysis of fisheries indicators (Anon 2008).

A workshop of the CCSBT Operating Model and Management Procedure (OMMP) Technical Working Group (WG) was held in Seattle (13-17 July 2009) to "re-condition" the OM (Anon 2009). This involved reviewing aspects of the model structure and data inputs, in particular the natural mortality schedule, selectivity schedules, the form of the likelihood function for the 1990's tagging data, a revised CPUE series, and the addition of the aerial survey index to the model. This workshop was the first opportunity to review in detail the interaction between the unreported catch scenarios, model formulation and the OM grid used for future catch projections.

Outcomes of the OMMP workshop included a revised natural mortality (M) schedule. It was not possible at the workshop to fully consider the interaction between this revised M schedule and other axis of uncertainty in the OM grid, in particular steepness of the stock-recruitment relationship. The OMMP WG requested that further detailed exploration of this interaction and related aspects of the OM conditioning be examined for consideration by the ESC at the 2009 meeting (Anon 2009). Here we present results and further consideration from analysis of model diagnostics for the reference, or base, model (as agreed at the OMMP workshop) and a number of variations used to explore the influence of the revised M schedule on steepness.

Methods

One of the more significant changes made to the OM at the OMMP workshop was a revised schedule for natural mortality (M). Prior to this workshop, M was modelled with a power function between ages 0 and 10, after which it remained at a constant value. Mathematically, this schedule can be expressed as:

$$M_a = \begin{cases} M_0 + \left(M_{10} - M_0\right)\left(\dfrac{a}{10}\right)^{0.7} & \text{for } 0 \le a \le 10 \\ M_{10} & \text{for } a > 10 \end{cases}$$

Parameters M_0 and M_{10} were included in the grid, with values of 0.3, 0.4, and 0.5 for M_0 and 0.07, 0.10 and 0.14 for M_{10}.

Further evaluation and consideration of this schedule resulted in the OMMP WG making several revisions (Anon 2009). In brief, the M-schedule specified above, led to the model predicting an over-abundance of fish in the plus group (age 30+). A number of options for reconciling “over-abundance” of 30 + fish were considered, including increasing M at older ages. Following examination of a range of alternatives, a linear increase from M_{10}, between ages 25 and 30 was adopted (Anon 2009). In addition, the functional form of the M-schedule between ages 1 and 10 was considered to be to restrictive to allow for the lower M values at intermediate ages indicated by the data. One option considered was to make the power parameter, which was fixed at 0.7, an estimable parameter; however, an alternative two-part linear function between ages 1 to 4 and ages 4 to 10 was adopted (Anon 2009).

Mathematically, the revised M schedule can be expressed as:

$$M_a = \begin{cases} M_1 & \text{for } a = 0 \\ M_1 + \dfrac{M_4 - M_1}{3}(a-1) & \text{for } 1 \le a < 4 \\ M_4 + \dfrac{M_{10} - M_4}{6}(a-4) & \text{for } 4 \le a \le 10 \\ M_{10} & \text{for } 10 < a < 25 \\ M_{10} + \dfrac{M_{30} - M_{10}}{5}(a-25) & \text{for } 25 \le a < 30 \\ M_{30} & \text{for } a \ge 30 \end{cases}$$

where,

M_1 and M_{10} are fixed parameters included in the grid, and
M_4 and M_{30} are parameters estimated in the model, with M_4 bounded between M_1 and M_{10}.

After considering model fits using various values for M_1 and M_{10}, the grid values chosen for M_{10} remained the same as for the previous schedule (0.07, 0.1 and 0.14), and the grid values chosen for M_1 were 0.3 and 0.35 (note, for comparison, that the grid values of 0.3, 0.4 and 0.5 for M_0 for the previous M-schedule equated to average values of 0.26, 0.34 and 0.42 for M_1).

In this paper, we consider results from the base model as agreed upon by the OMMP WG (Anon 2009), as well the following 4 model variations:

- **tag_H_factor:** This was a sensitivity trial suggested by the OMMP WG, in which harvest rates (H) for the season 1 (i.e. surface) fishery in the tagging likelihood are replaced by k*H. This trial was designed with the intention of allowing for only a fraction of the overall population being available to tagging operations. This was a sensitivity analysis for incomplete mixing of 1+ cohorts resulting in biased estimates of H in the surface fishery (Anon 2009). Rather than selecting essentially arbitrary values for k, we allowed the model to estimate this factor, with an upper bound set of 2.5.

- **M30_equal_M10:** To examine the effect of allowing M to increase from age 25 to 30, we ran a model with M kept constant from ages 10 to 30 as it was in the sbtmod 21 M-schedule, while retaining the revised schedule for fish under age 10.

- **powerM:** In this variation, we replaced the current M schedule between ages 1 and 10 with a power function, as for sbtmod 21 with the exception that the power parameter was estimated in the model, rather than fixed at 0.7, and parameterized in terms of M_0 instead of $M_{1,}$ for consistency with the new schedule.

Specifically:

$$M_a = \begin{cases} M_1 & \text{for } a = 0 \\ M_1 + \left(M_{10} - M_1\right)\left(\dfrac{a-1}{9}\right)^{\alpha} & \text{for } 1 \le a \le 10 \\ M_{10} & \text{for } 10 < a < 25 \\ M_{25} + \dfrac{M_{30} - M_{25}}{5}(a-25) & \text{for } 25 \le a < 30 \\ M_{30} & \text{for } a \ge 30 \end{cases}$$

Where, α is estimated in the model, and M1 and M10 are kept as part of the grid with the same values as for the revised M-schedule.

The rationale for this model variation was that the two-part linear M function can result in a “kink” at M_4 that does not appear consistent with conventional life history theory; furthermore, it does not allow M at the youngest ages (i.e., ages 1 to 4), for which the tag data are most informative, to be very flexible in fitting the various data inputs.

- **no_tag:** In this variation, we set the tagging likelihood to 0. Since the tag data contain the most information on M at young ages, we were interested to examine the effect of removing this data set on the model estimates of M and, consequently, on model preference for gird values of steepness and other parameters.

These model variations were chosen for their potential to affect the estimates of M, either by directly altering the functional form assumed for M, or by changing the way that the tag data are fitted in the OM (since the tagging data has the greatest influence on the estimation of M).

All runs with the above models were made using the conditioning code and data input files provided on 21 July 2009 or 10 August 2009 (note that the only difference in the more recent version is that it allows for the option of running the sensitivity trials using alternative CPUE series 3 and 6, as defined in item 11 and Attachment 5 of the Report of the OMMP Technical Meeting, Seattle 2009, Anon 2009).

Results and Discussion

The output files and a number of diagnostic plots for all models considered in this paper are provided on a data CD. Here we attempt to summarize the key results, and have included the most relevant figures for more convenient reference.

We focus on the results pertaining to steepness and natural mortality. For all of the models except "no_tag", higher steepness is generally associated with higher M at young ages (i.e., with a higher M_4 estimate); for the "no_tag" model, this trend actually switches (Figure 1).

The M_{30} estimates are similar across all the models, and they tend to be slightly higher when steepness is lower, however the relationship is not strong (average M_{30} values of 0.44, 0.43 and 0.41 for steepness levels 1, 2 and 3, respectively). In all of the models except "M30_equal_M10", selectivity on the older age classes (ages 20+) in the Indonesian fishery tends to be low when steepness is low, presumably to 'counterbalance' the high M estimates on these age classes. For the "M30_equal_M10" model, the relationship is more complicated (Figure 4).

We now consider each of the models in more detail, and especially how the model variations compare with the base model (refer to Figures 1 and 2).

Base

- With the base model, high steepness is preferred, and correspondingly, higher M_4 values are also preferred.
- There is no real preference between the two M_1 values of 0.3 and 0.35, however there is a preference for lower M_{10} value.

Tag_H_factor

- The mean estimate of k over all grid runs was 2.3 (min=1.8, median=2.4, max=2.5), and it hit the upper bound of 2.5 in 16 out of the 72 runs.
- This suggests that the tagging data estimates the surface fishery harvest rates (age classes 1 to 5) to be about 2.3 times higher than the other data sources.
- This result was expected because of the contradictory preferences between the tagging data and other data sets (such as the surface age frequency data) were observed at the OMMP technical meeting and led to this sensitivity trial being developed (See Davies et al., 2009).
- However, the implications are:
  - The highest M_1 level is strongly preferred (compared to almost equal preference for the base case).
  - The lowest M_{10} level is even more strongly preferred than in the base case.
  - M_4, and consequently all M's between ages 1 and 4, are estimated to be much higher under this robustness test than under the base model, that is, from 0.24 and 0.32 in comparison to 0.14 and 0.24, and; as a result,
  - F's at young ages are estimated to be lower than in the base model.

- There is an increased preference for the medium steepness level than in the base model.

M30_equal_M10

- With M kept low for all the oldest age classes, high steepness is almost exclusively preferred.
- Not surprisingly, when M is constrained to stay at a constant level after age 10, the highest M_{10} level is exclusively preferred.
- The positive correlation between steepness and M_4 is not as strong as in the models with the new, increasing M schedule for old fish.

PowerM

- With this model, a higher M_1 value is much preferred compared to the base.
- There is a corresponding drop in M at age 2, which cannot be achieved with a linear function between M_1 and M_4.
- Also, the base model prefers the lowest M_{10} value, whereas the "powerM" model has no overall preference for M_{10}.
- There is greater preference for the medium steepness level with this model than with the base model, similar to the tag_H_factor model, but even more pronounced.

No_tag

- Without tag data, the estimate of M_4 often hits the upper bound of M_1 (this is almost always true for the two lowest steepness levels), meaning that M remains high from M_1 to M_4.
- As noted above, unlike the models where tag data are included, lower steepness is now associated with higher M_4 (which translates to higher M’s at ages 1 to 10).

The table 1 summarizes the preferred value for each grid factor for each model based on the posterior (likelihood-based) ‘shade plots’ in Figure 2.

Table 1: Summary of results from different models based on posterior likelihood values.

	Steepness (.385,.55,.73)	M_1 (.3, .35)	M_{10} (.07, .1, .14)	CPUE series (w5, w8)	q age range (4-18, 8-12)
base	.73, then .55	Equal	low to high	w8	8-12
tag_H_factor	.55, then .73	.35	.07	w8	4-18
M30_equal_M10	.73	roughly equal	.14	w8	4-18
powerM	.55	.35	high to low	w8	8-12
no_tag	.55	Equal	.07, then .10	w8	4-18

The steepness, M_0 and M_{10} results have been discussed above. The w8 CPUE series is preferred by all models; however, the preferred age range for standardizing *q* differs between models.

When considering Figure 2 and this table, it is important to keep in mind that:

1. The results are based on posterior weightings, which update the prior weightings based on the likelihood values. Not all factors have flat priors—the 3 steepness levels have prior weightings of (.2, .6, .2), and the 2 *q* age range options have prior weightings of (.67, .33), so even if a model has a strong preference for, say, the

highest steepness level, the medium steepness level can still end up with the most posterior weight.

2. The posterior weightings take into consideration the total likelihood values, so they may be driven by a particular likelihood component. Thus, we also want to consider the preferred grid values for individual components; ideally they would all be in agreement, but unfortunately this is most often not the case, as seen below.

Figure 3 shows the likelihood profiles for a number of model parameters broken down by the nine likelihood components for the base model. Clearly, there are contradictions in the various data sets as to which parameter values are preferred; for example:

- high steepness is strongly preferred by the LL3 and Indonesia components, but low steepness is preferred by LL4 and, to a lesser extent, the surface, LL1 and aerial components;
- low M_1 is strongly preferred by the LL1 and surface components, but high M_1 is strongly preferred by the tagging component.

Only the results for the base model are provided here, but similar tensions between likelihood components are seen for all models (see figures included on CD). These contradictory preferences among components make interpretation of the results and evaluation of model assumptions and appropriate grid values challenging and will require further detailed examination of diagnostics by the ESC.

Establishing a clearer understanding of the underlying source of these tensions is clearly a priority for interpreting the relative robustness of the results for stock status and constant catch projections presented to date and for deciding on the model structure and data refinements that may be required for development and evaluation of alternative management procedures.

Acknowledgements

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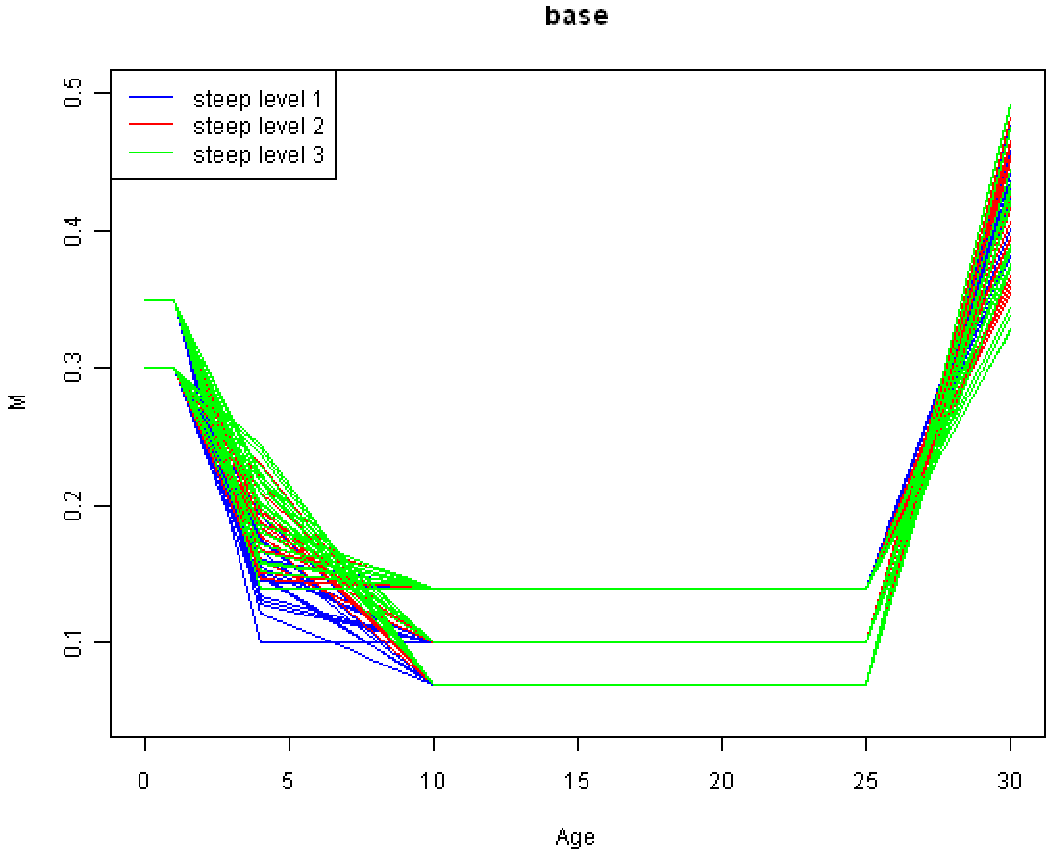
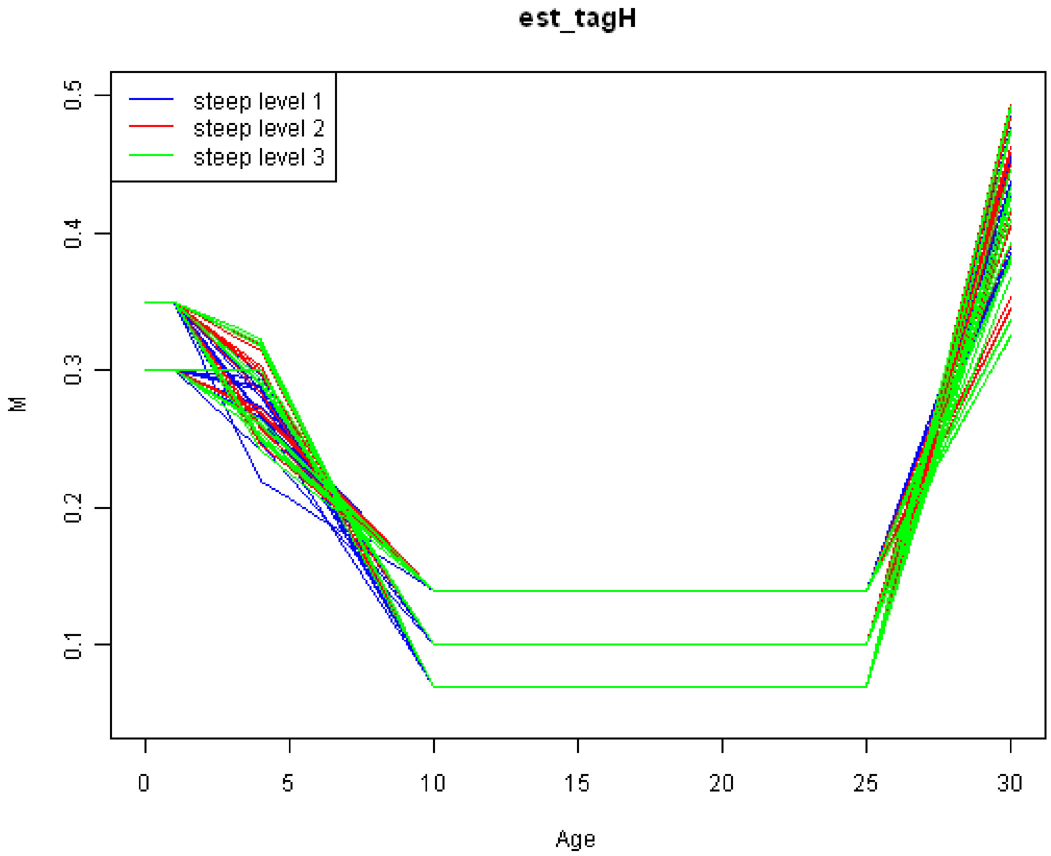
Literature Cited

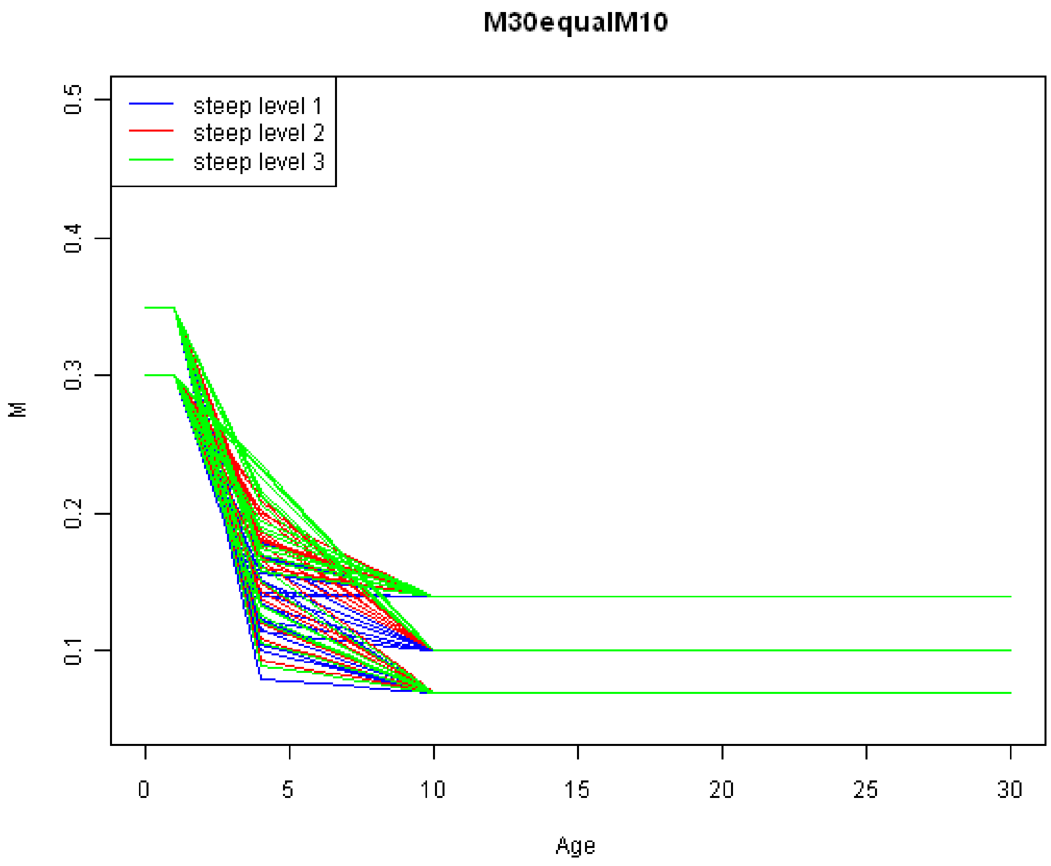
Anon 2009 Report of the CCSBT Operating Model and Management Procedure workshop. 13-17 July 2009, Seattle, USA.

Davies, C., Gianni, F., Barnes, B., Eveson, P., and Begg, G. 2009. Conditioning of the Southern Bluefin Tuna Operating Model and constant catch projections. Working Paper (CCSBT-ESC/0909/10) presented to the 14th Meeting of the CCSBT Extended Scientific Committee, 5-11 September 2009, Busan, Korea.

Figure 1. Estimated M schedules over all grid runs, broken down by steepness levels. (Note that ‘est_tagH’ refers to the tag_H_factor model variation.)






M30equalM10
steep level 1
steep level 2
steep level 3
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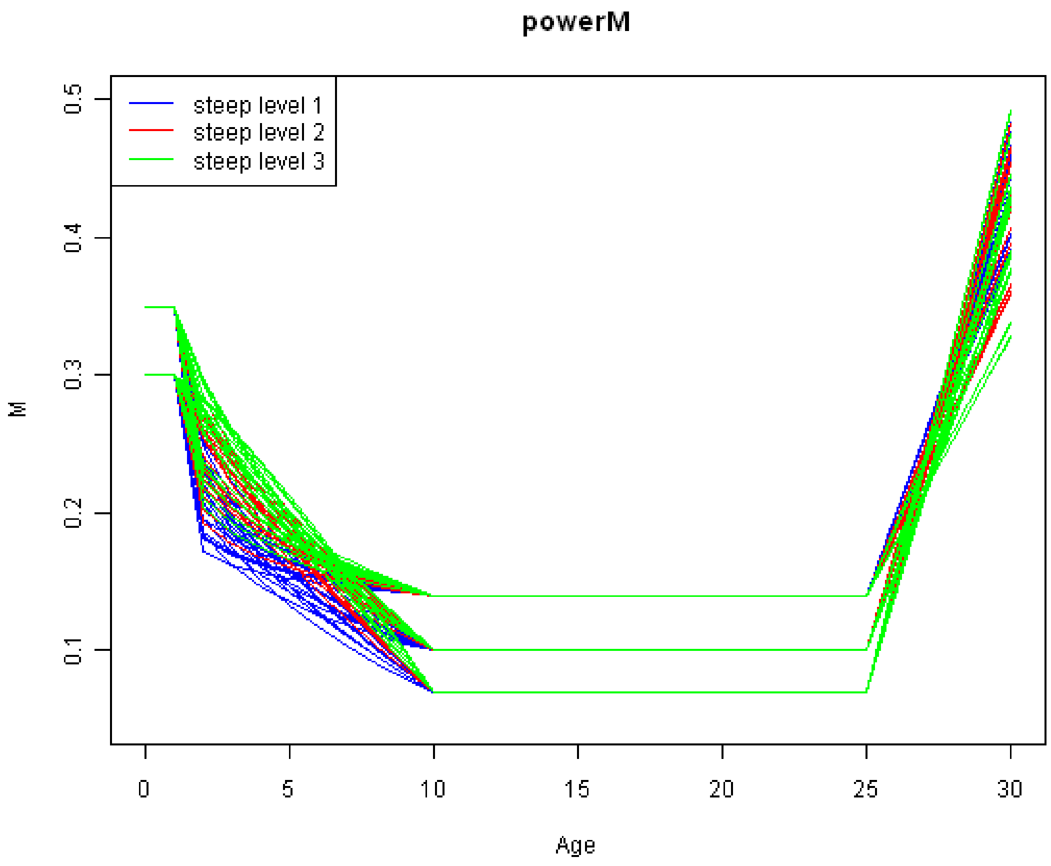
0.2
0.3
0.4
0.5
0
5
10
15
20
25
30
Age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steep level 2
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10
15
20
25
30
Age

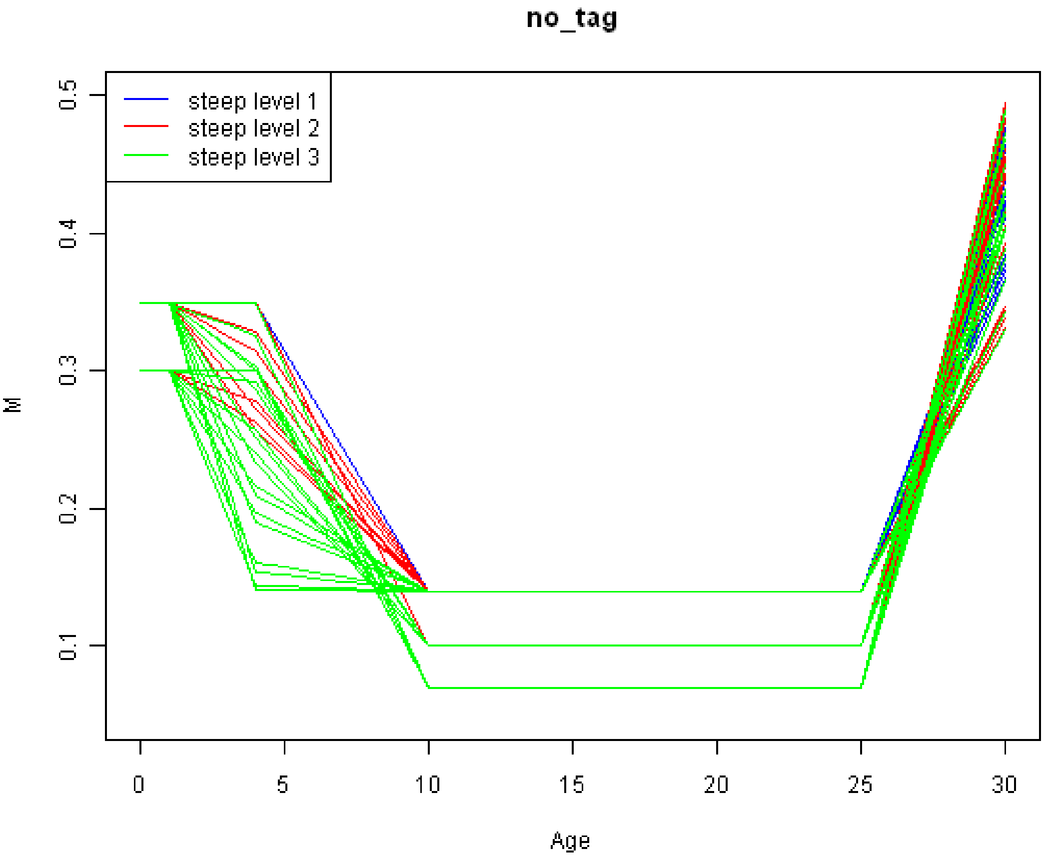
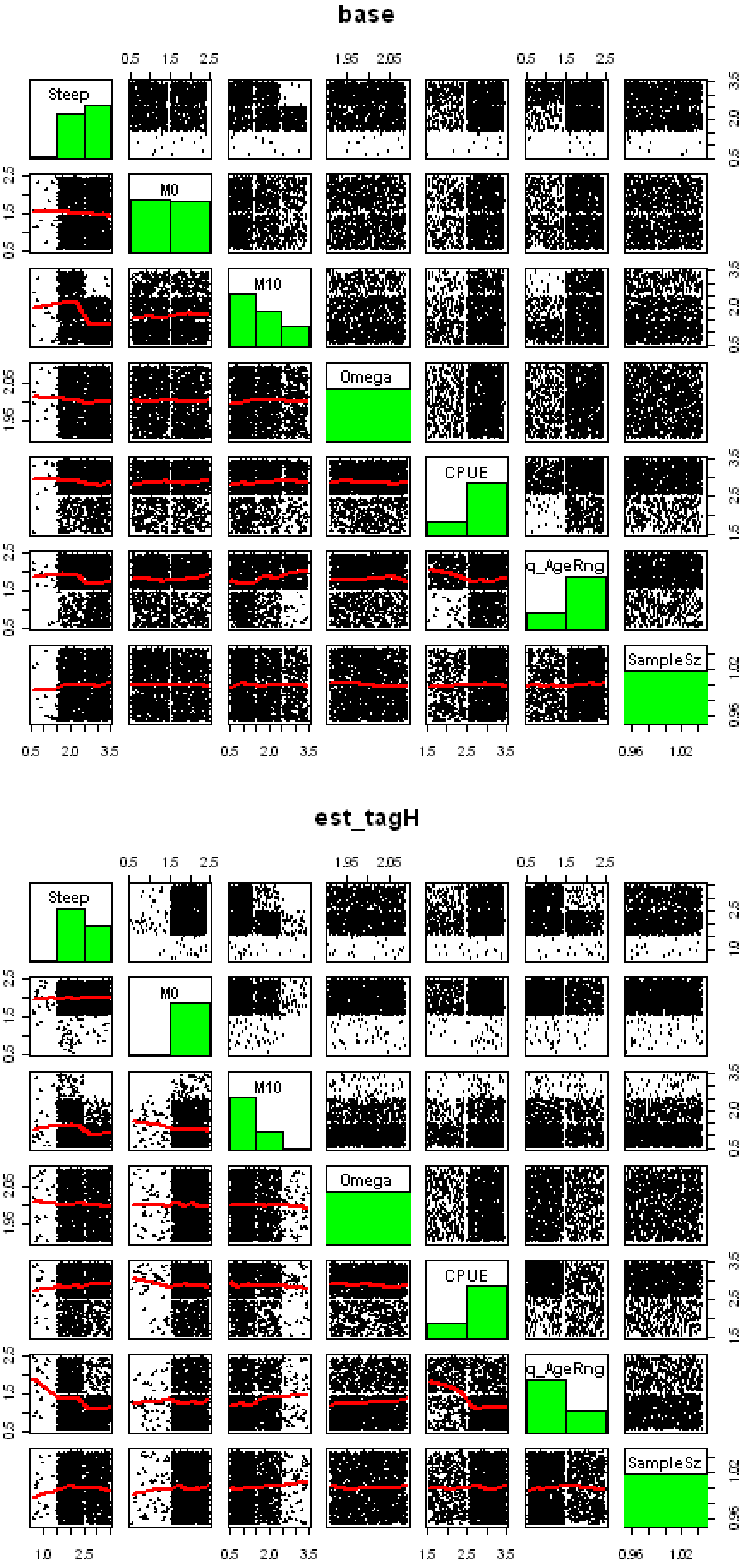

no_tag
steep level 1
steep level 2
steep level 3
M
0.1
0.2
0.3
0.4
0.5
Age
0
5
10
15
20
25
30

Figure 2: Shade plots using posterior (likelihood-based) weights for all grid factors. (Note that ‘est_tagH’ refers to the tag_H_factor model variation.)



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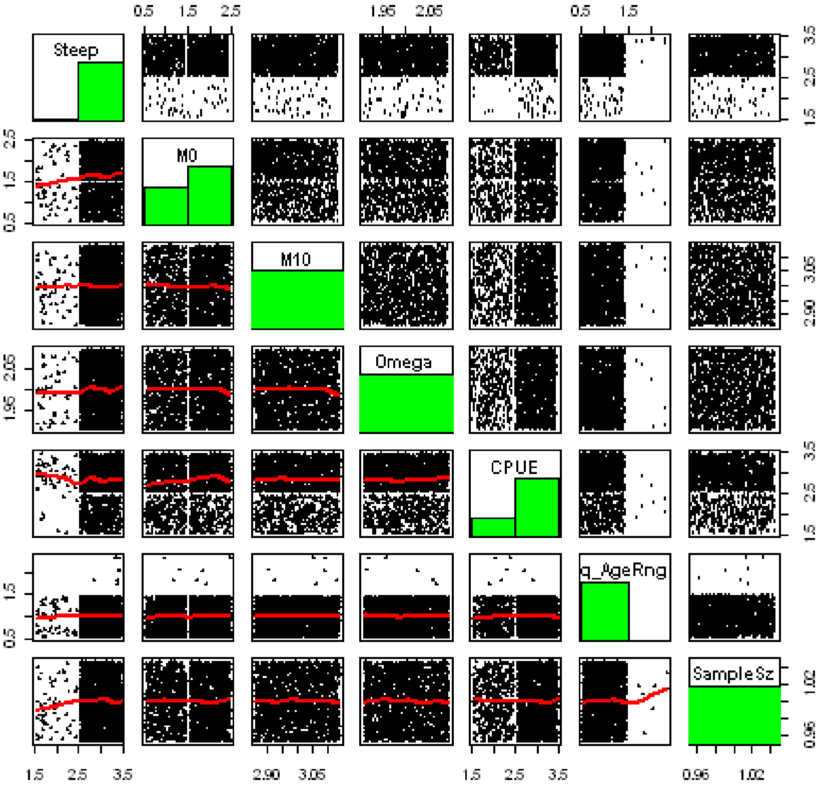
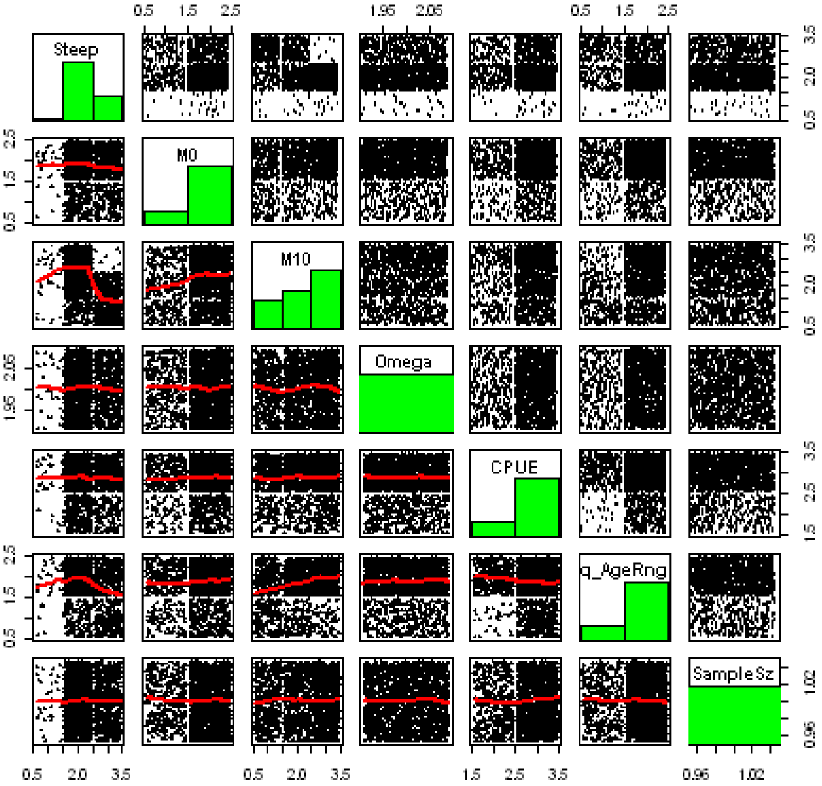
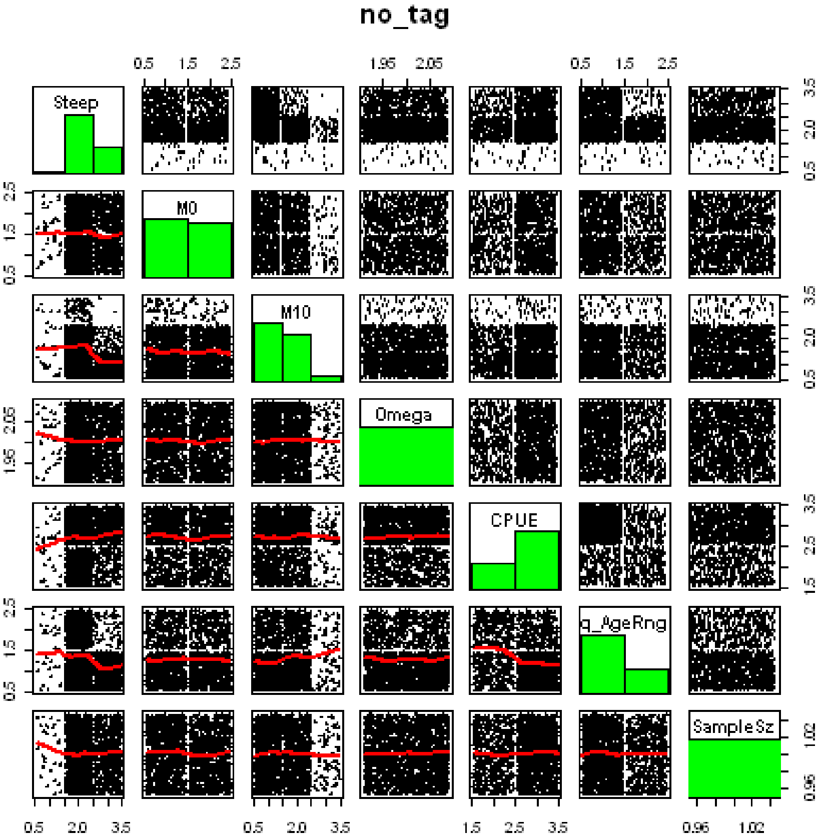


powerM

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Steep
M0
M10
Omega
CPUE
q_AgeRng
SampleSz
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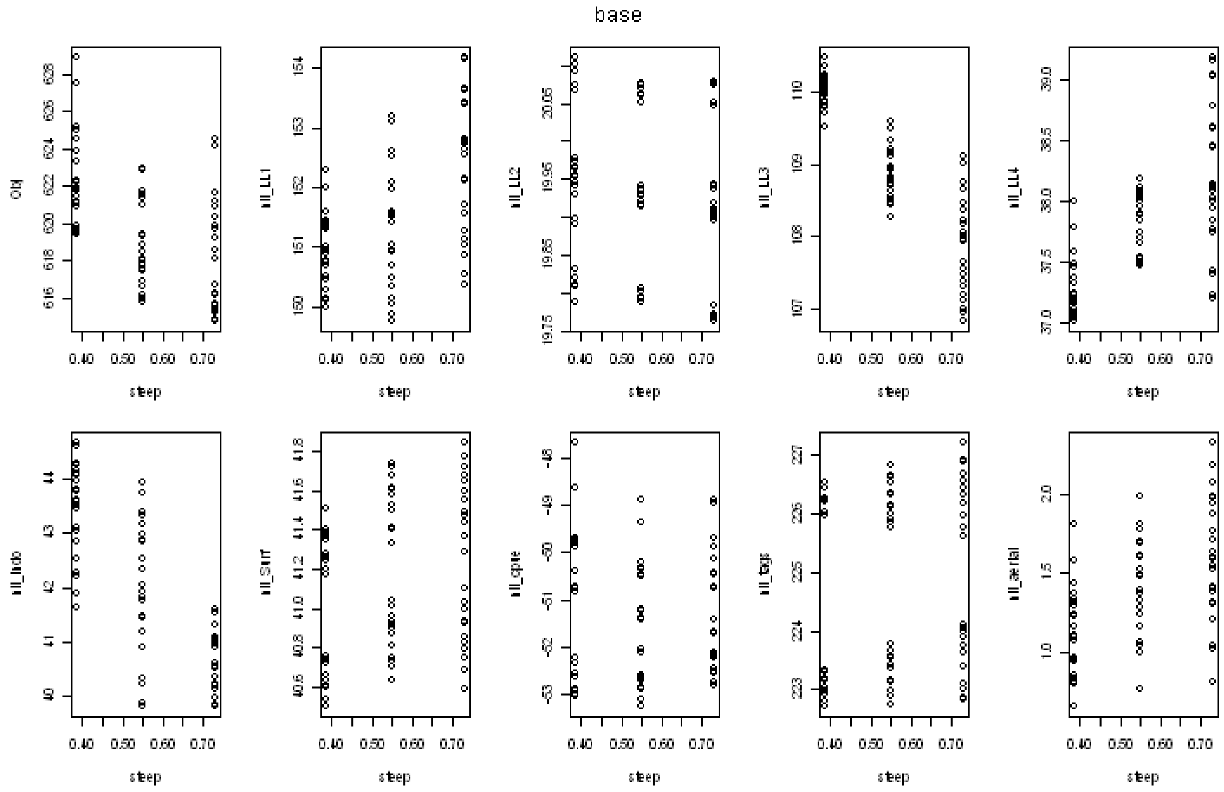
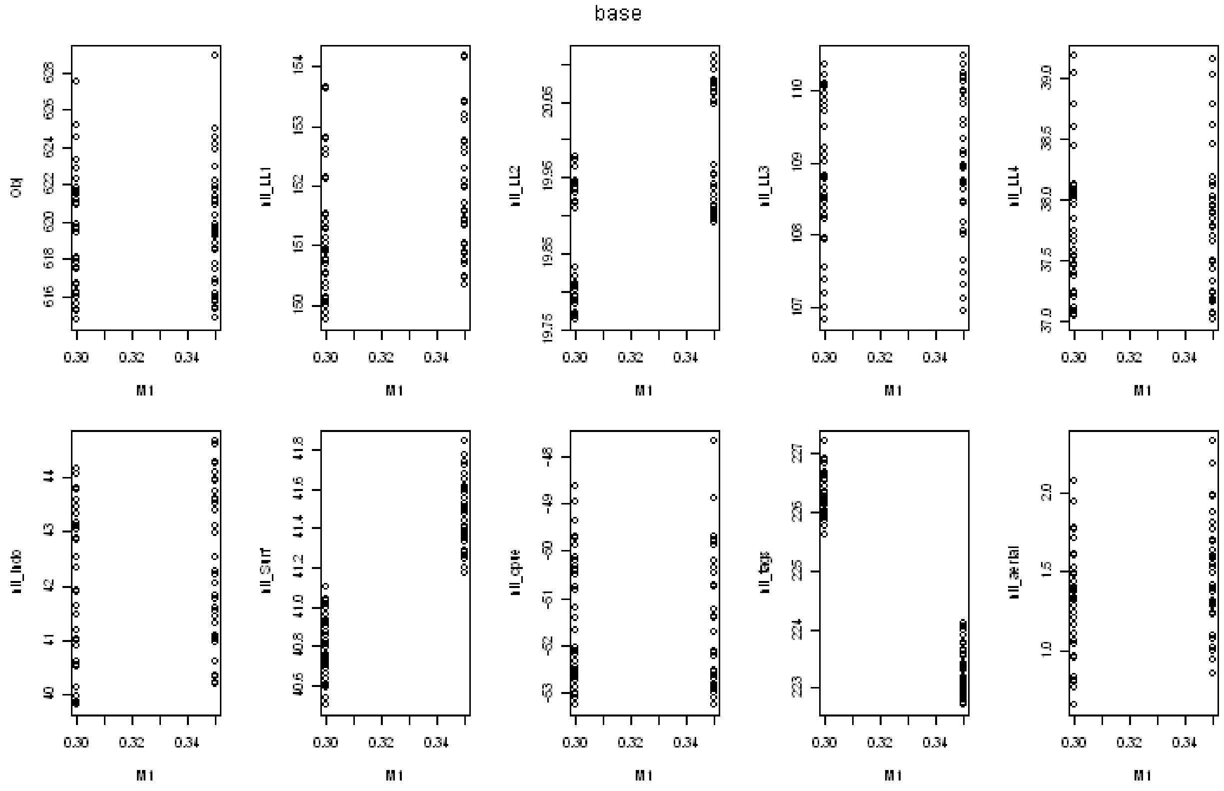
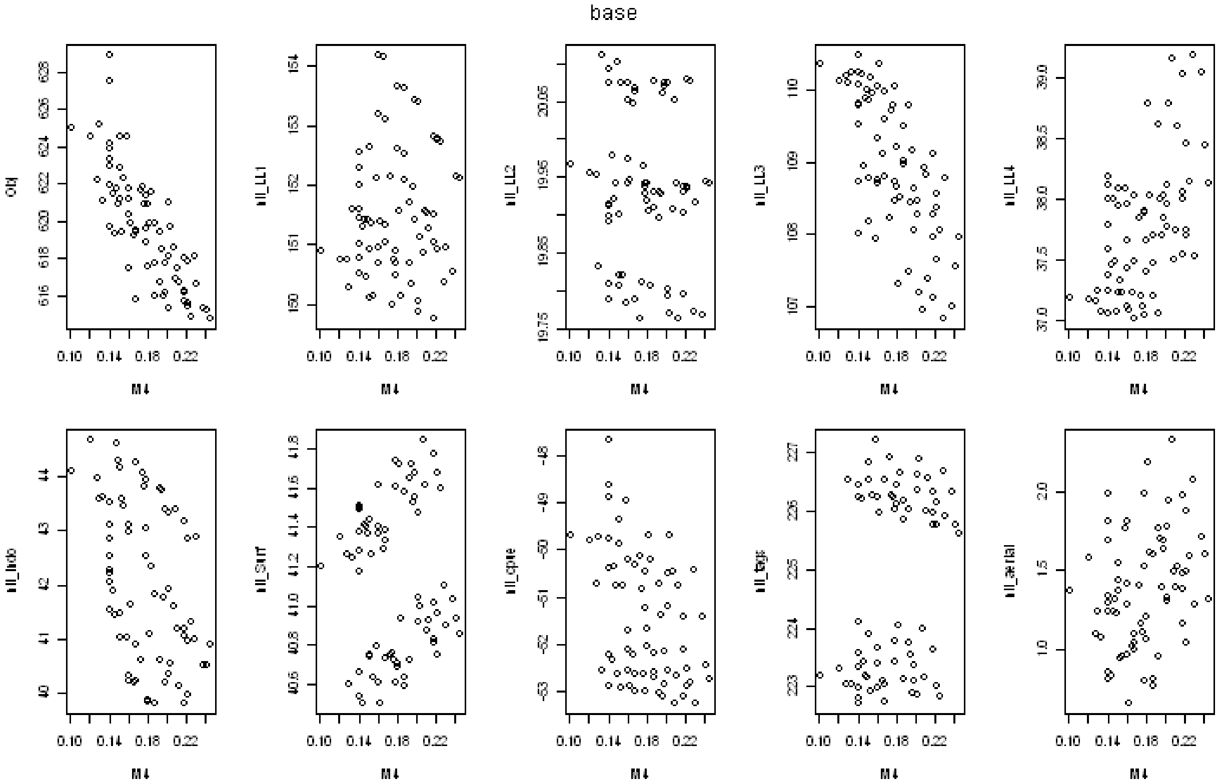
1.5
2.5
1.95
2.05
2.0
3.5
0.96
1.02

Figure 3. Likelihood profiles for various model parameters (steepness, M1, M4, M10, M30, C = cpue option, a = q age-range option) for the base model, broken down by the 9 likelihood components.



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nll_LL3
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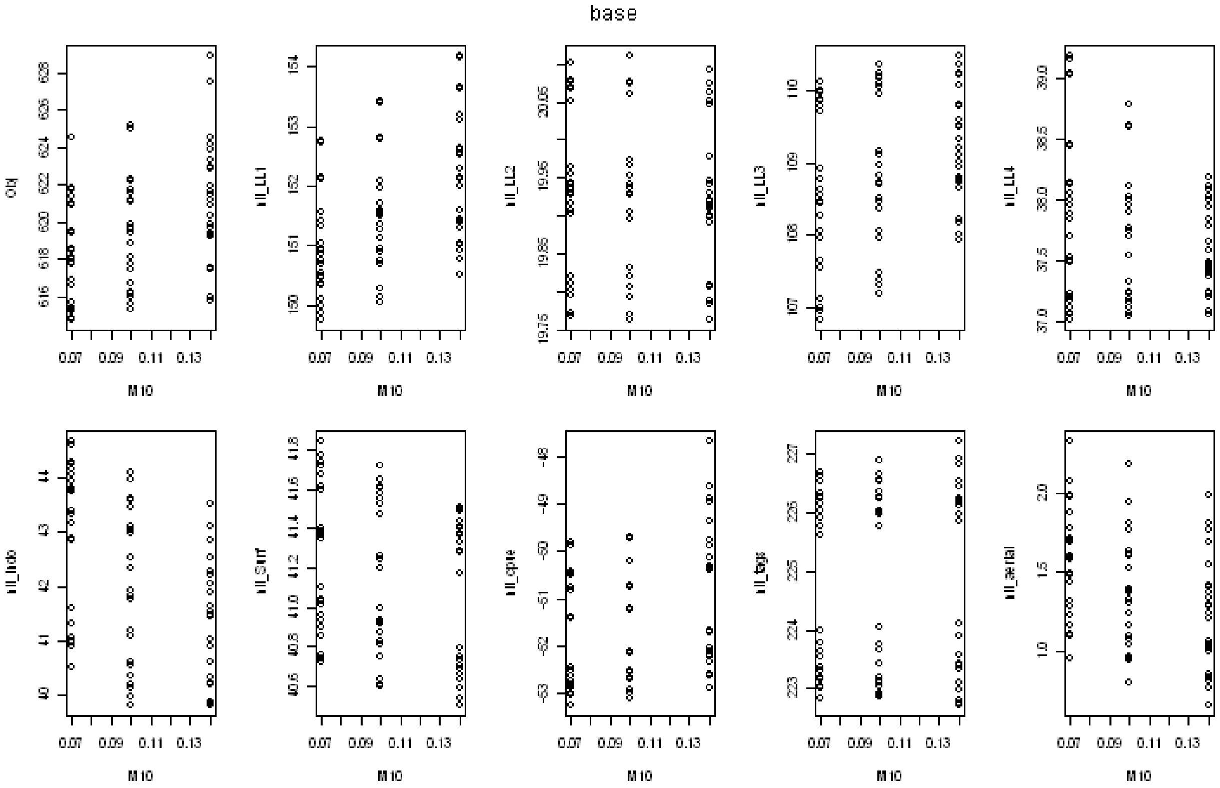
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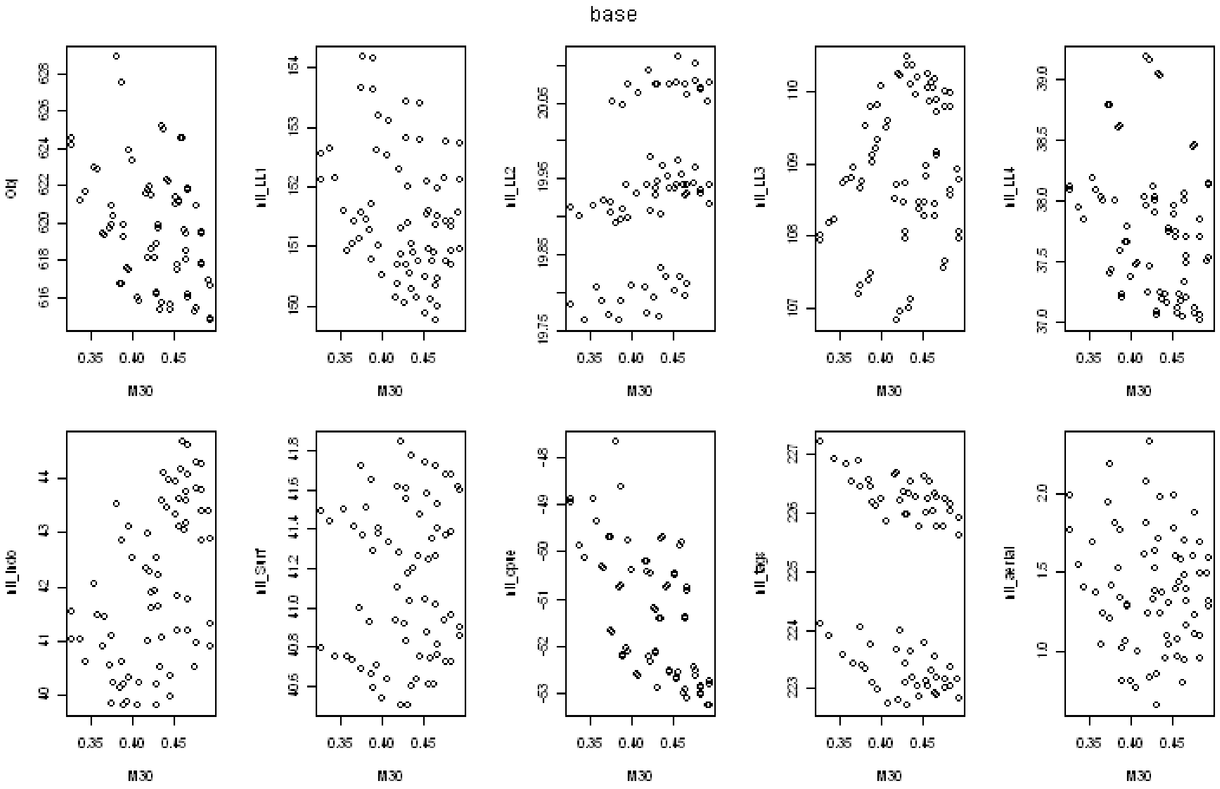
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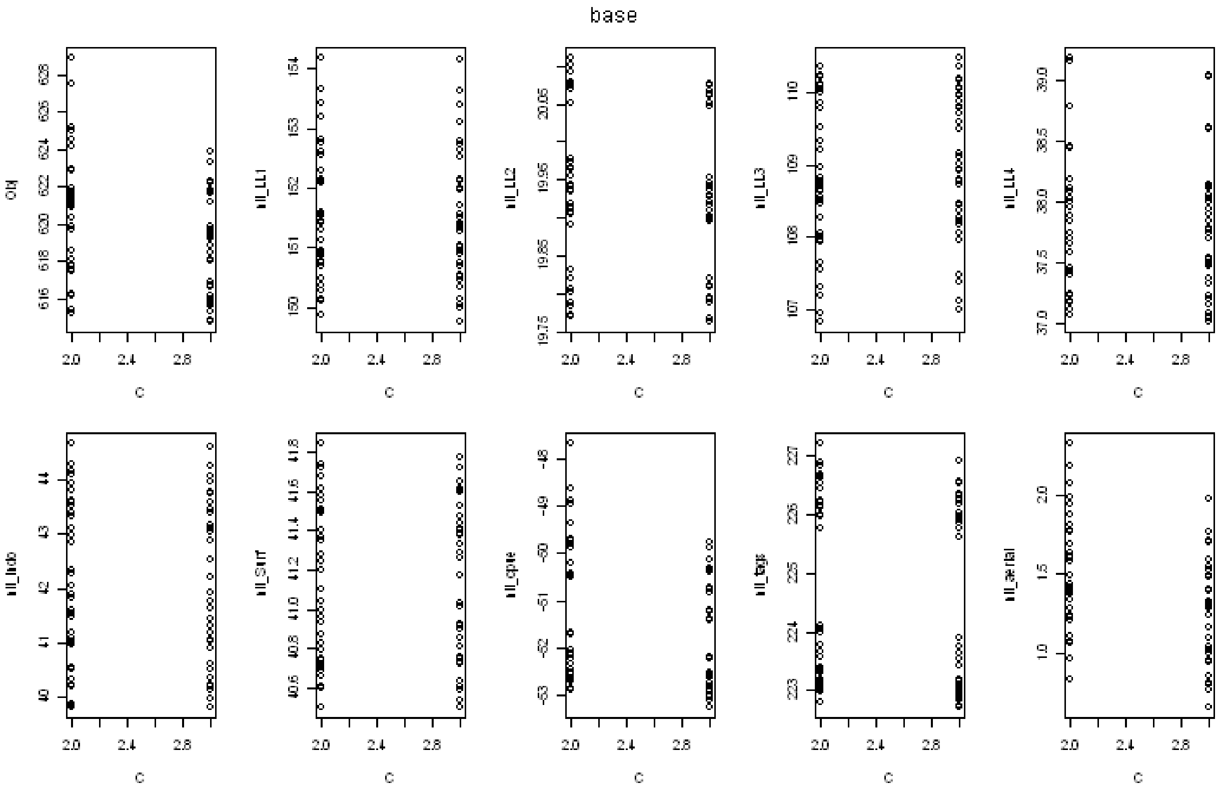
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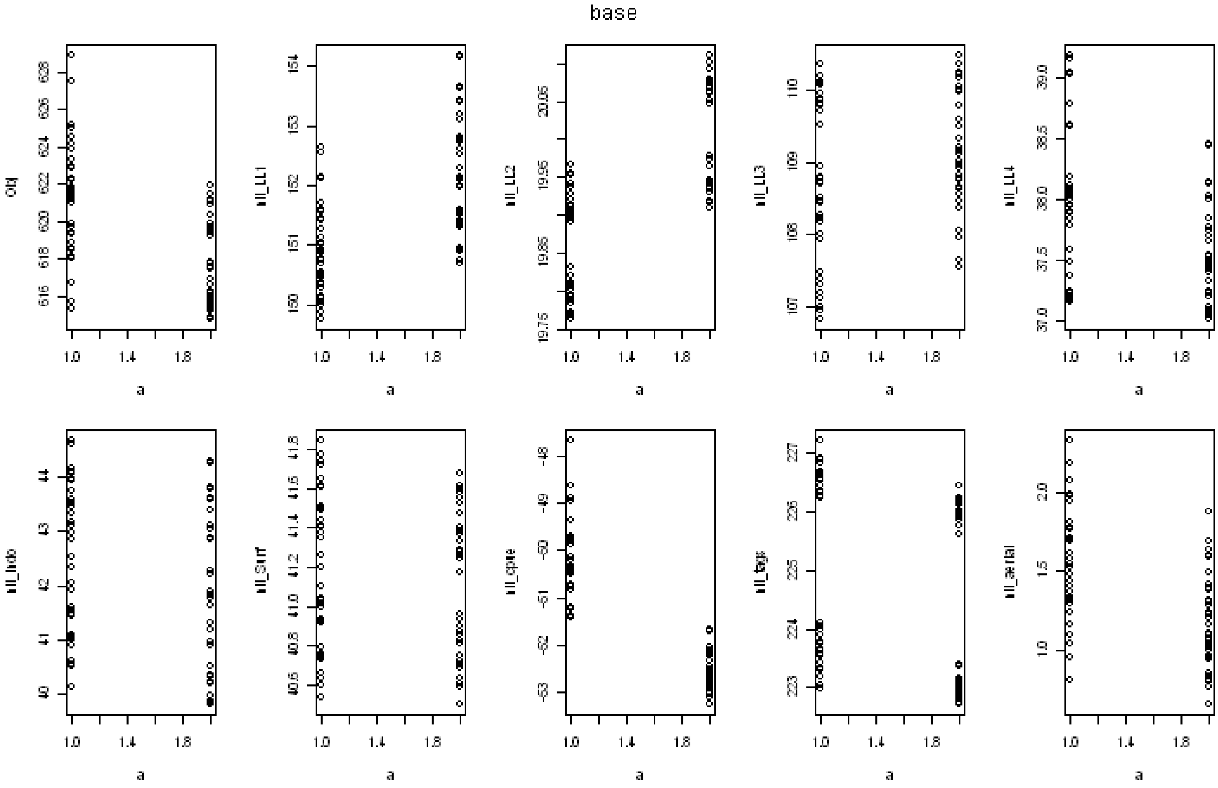
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43
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nll_Surf
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nll_tags
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225
226
227
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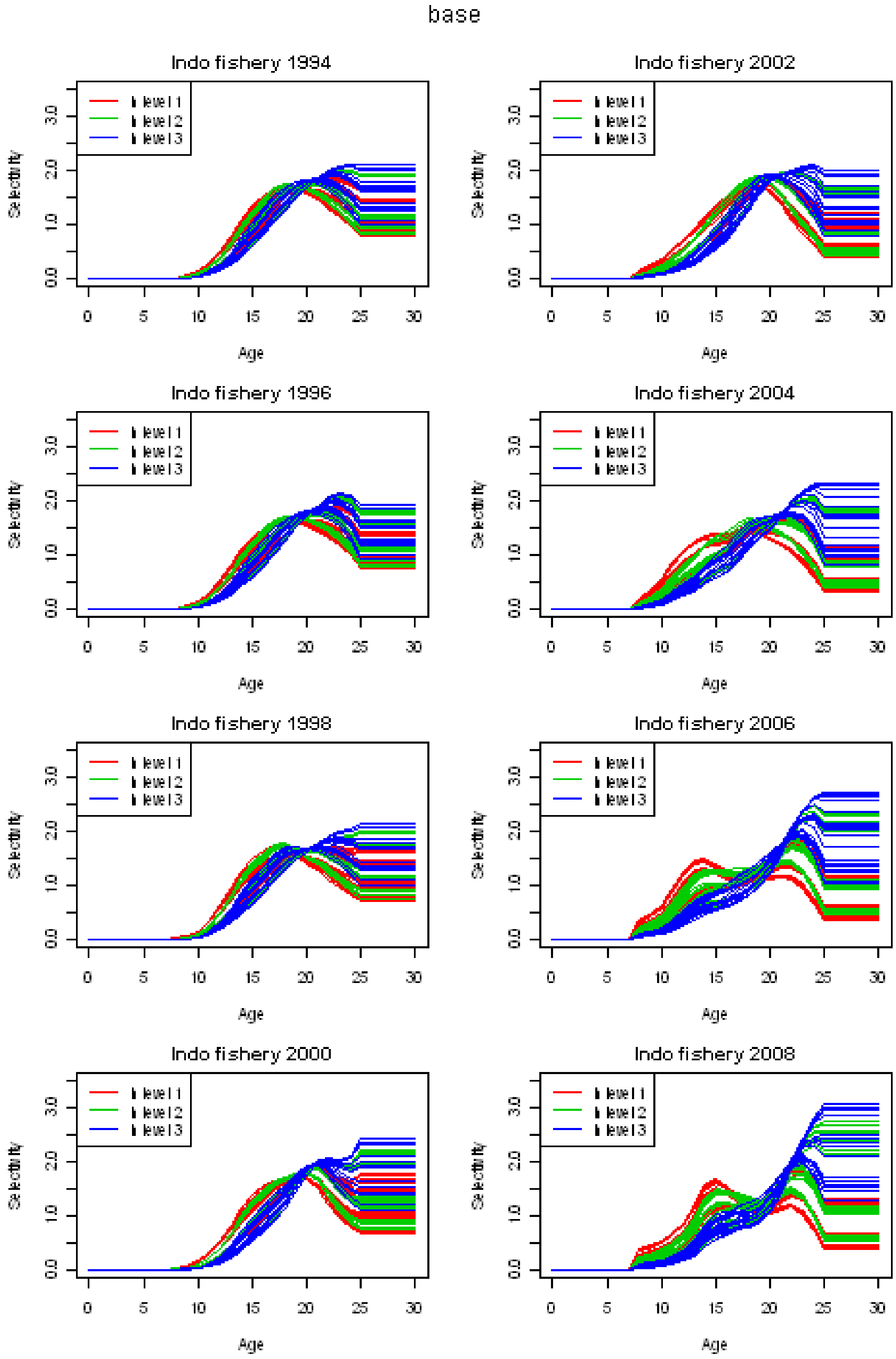
1.5
2.0
1.0
1.4
1.8
a

Figure 4. Selectivity estimates for the Indonesian fishery over all grid runs, broken down by steepness. Selectivity is plotted for each year the model allows a change. (Note that only the base and "M30_equal_M10" models are included here; refer to CD for other models).



M30equalM10