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SENSITIVITY OF THE BIGEYE STOCK ASSESSMENT TO ALTERNATIVE STRUCTURAL ASSUMPTIONS

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1 Abstract

Many sources of uncertainty affect the results of stock assessment models. It is important to examine their influence, and to consider overall assessment results in the light of this uncertainty. Including structural uncertainty in the assessment, using multiple combinations of structural uncertainties, has advantages over the standard approach of using a base case and sensitivity runs. Integrating across these structural uncertainties can improve understanding of the overall level of uncertainty in the stock assessment. Interactions among sources of uncertainty can also be important. We examined the influence of 15 sources of structural uncertainty, using 2 options for each source (factor), and further examined interactions among 12 of these factors. However, this approach can be difficult to implement, given that each run of the bigeye model takes over 16 hours, and a full factorial design involves 2^12 = 4096 runs of the model. We dealt with this problem using a partially confounded factorial experimental design and a distributed computing system (Condor), which together reduced the expected runtime from 85 to 6 days.

Results indicated that uncertainty about the steepness parameter and effort creep contributed most structural uncertainty to the assessment results. Integrating across the chosen components of structural uncertainty, conditional on the equal weighting given to the options, and without including parameter uncertainty, provided conditional probability distributions on $F_{CURRENT}/F_{MSY}$, $B_{CURRENT}/B_{MSY}$, and $SB_{CURRENT}/SB_{MSY}$.

2 Introduction

Sensitivity analyses to aspects of model structure are regularly run as part of each stock assessment. For example, the 2006 yellowfin stock assessment considered the effects of lower effective sample size for size frequency data, higher effective sample size for size frequency data, and using seven regions instead of six (Hampton *et al.* 2006). The 2007 assessment carried out 13 structural sensitivity analyses relating to growth, size frequency data re-weighted by catch, Indonesian catch, longline effort penalty weights in region 3, newly defined fisheries, steepness, and modelling region 3 alone (Langley *et al.* 2007).

However, the complexity of the stock assessments means that many structural assumptions remain to be examined. In particular, interactions among structural assumptions are potentially important, but have not been examined in detail to date.

In this paper we develop a procedure for running multiple MFCL stock assessments to test a range of structural assumptions, and combining the assumptions to examine the effects of interactions.

The structural sensitivity analysis was based on the 2008 bigeye stock assessment (Langley *et al.* 2008). The base case version of this model involves 25 fisheries in 6 regions, and quarterly catch and effort from 1952 to 2007.

3 Methods

A series of 15 pairs of alternative hypotheses (each pair designated R, M, J, S, C, X, B, L, P, D, G, W, T, H, or I, see Table 1) was established about selected factors that may affect the results of the MFCL bigeye stock assessment. Each hypothesis was examined using a scenario established in the MFCL input files. Interactions among hypotheses are likely to be important, so multi-way interactions among 12 of these hypotheses were also tested by combining scenarios. Testing all possible combinations of scenarios (2^{12} or 4096 runs) was impractical, since a single bigeye tuna MFCL run can take between 16 and 30 hours to complete, depending on the scenario and the computer. Scenarios were therefore combined using a fractional factorial design (Montgomery 1991). This approach involves 'confounding' some variables with high order interactions, on the assumption that most of the information is in the main effects and the low order interactions. A partially confounded (11-5) design, designated 2_{IV}^{11-5}, was used, with a fold-over to include the 12th parameter. This resulted in 128 runs. The design generators were G=± CDE, H=±ABCD, J=±ABF, K=±BDEF, and L=±ADEF (Montgomery 1991, Table 11-12, page 359).

Running 128 MFCL jobs on a single fast machine would take, assuming sixteen hours per run, twelve weeks. However, this type of simulation can be run with many jobs in parallel, which we achieved by setting up a Condor cluster (Tannenbaum *et al.* 2001); http://www.cs.wisc.edu/condor) at the Secretariat of the Pacific Community. Once established, Condor clusters can be expanded relatively easily to include hundreds of computers. This cluster was limited by MFCL's requirement, when running under Condor, for computers to have more than 1GB of RAM. The jobs were submitted to 14 personal computers, running both Linux and Windows XP operating systems, and the entire set ran in approximately one week. The setup of files is described below in more detail. The condor submit script and related files are in the Appendix.

Setting up each of the 128 runs as a combination of 12 scenarios involved altering 4 MFCL input files: the batch script (doitall.bet), the data file (bet.frq), the tag data file (bet.tag), and the initial values file (bet.ini). To facilitate this process we wrote a program, MFCLCC.jar, which took an input matrix of all the jobs as a series of codes (e.g. R0M0J1S0C1X1B0L0P1D0G1W0T1H1I0), generated input files, set up the job directory, and submitted the job to condor.

3.1 Scenarios for general structural sensitivity analysis.

Fifteen assumptions examined are detailed below, and summarized in Table 1. Twelve of these assumptions were examined further using the factorial simulations.

3.1.1 Recruitment constraints (R) (par, doitall)

Steepness was given alternative values of 0.7 and 0.957.

In MFCL the stock recruitment relationship can be parameterised using steepness, by setting age_flag(163)=0 and age_flags(153 and 154) to 0. Steepness was fixed, by setting age_flag(162)=0. The steepness parameter is stored in sv(29), which is the 29th column in the "Seasonal growth" section of the par file. This requires a change to the par file after the first run.

3.1.2 M with alternative mean value (M) (ini)

Natural mortality is a difficult parameter to estimate in a model, and it is often fixed at a 'reasonable' value. We compared the effect of the base case with mean value of 0.1 per quarter for natural mortality of post-juvenile fish with an alternative value of 0.125 per quarter. Natural mortality was changed in the bet.ini file from 0.11283 to 0.12693. See Table 2.

3.1.3 Juvenile M (J) (ini)

Double the peak rate of juvenile natural mortality. Changing the 'natural mortality' value and the age_pars(2) row in the bet.ini file. See Table 2. Interacts with the alternative mean value scenario above.

3.1.4 M with Seapodym M (S) (ini)

As reported by Inna Senina (pers. comm.). See Table 2. This run was not included in the combination runs, since it could not be combined with either of the two other natural mortality scenarios above. The scaling parameter was estimated, so only the shape of the natural mortality at age distribution was retained.

3.1.5 CPUE CV (C) – trial alternative weightings (doitall)

The penalty weight on the effort deviates reflects assumptions about how much variability there is in the relationship between the catch per unit effort (CPUE) and the vulnerable population (or, more precisely, between effort and fishing mortality). The base case assumption in MFCL is to set the penalty weight (via fish flag 13) on standardized longline fisheries to -50, implying a prior distribution with standard deviation of 0.1, but with the penalty scaled by the square root of the quarterly effort within the fishery. Most non-longline fisheries are given a penalty of -10, implying an effort-scaled prior distribution with standard deviation of 0.22. Penalty on the Indonesia-Philippines mixed fishery in region 3 is set to 10 implying standard deviation of 0.22, not scaled by effort.

The alternative assumption trialled was to use the same prior standard deviation on effort deviates as the IATTC use for their fisheries in A-SCALA (Maunder *et al.* 2003). This involves standard deviation of 0.2 on standardized longline fisheries, 0.3 on un-standardized longlines and purse-seine fisheries involving school sets, and 0.4 on purse-seine fisheries involving FAD sets.

MFCL uses only integer flags so fish flags(13) for standardized longline fisheries were set to 13 (SD = 0.20), unstandardized longline, and purse-seine sets on schools and miscellaneous were set to 6 (SD = 0.29), and purse-seine sets on logs and FADS were set to 3 (SD=0.41). Fish flags(13) for other fisheries were set to 1 (SD = 0.7).

3.1.6 Estimated mixing versus fixed mixing (X) (doitall, ini)

MFCL has a regional structure, with movement among regions. Movement rates can be estimated for each region pair by season and by age. The base case of MFCL estimates movement rates by season, with no age-dependent variation. A number of alternative possibilities could be explored; we examined the effect of running the model with fixed low movement rates. This involved changing the initial values of diffusion coefficients to 1e-3, and turning off estimation of movement rates (age_flags(68) = 0) and age-specific movement rates (age_flags(88) and age_flags(89) = 0).

3.1.7 Spawning biomass (B) (doitall, ini)

Spawning biomass, an important output of the model, is defined in MFCL by the product of numbers at age, mean weight at age, and maturity at age. Maturity at age has not been re-calculated to take into account the effects of updated growth curves, given maturity at length. In addition, it models the mature biomass of both sexes rather than the reproductive potential of the population.

The base case used the standard approach, with maturity 0 for ages 0-6 quarters, 0.25, 0.5, and 0.75 for age 7, 8, and 9 quarters respectively, and 1 for all older ages.

The updated maturity schedule was re-parameterised in terms of relative egg production per unit weight, as equal to the product of sex ratio, maturity, batch fecundity, and spawning fraction (Hoyle and Nicol 2008). These were all estimated based on observations at length, and translated into age based on the growth curve. Spawning fraction was not available for the WCPO and the EPO estimate of spawning fraction at length was used (Schaefer *et al.* 2005).

The alternative maturity schedule was:

0, 0, 0, 0, 0, 0.004049, 0.02213, 0.07169, 0.1656, 0.2956, 0.4358, 0.565, 0.6749, 0.7658, 0.8404, 0.9007, 0.9483, 0.9797, 0.997, 1, 0.9917, 0.9754, 0.953, 0.926, 0.8946, 0.8607, 0.825, 0.788, 0.7512, 0.7133, 0.6755, 0.6381, 0.6014, 0.5656, 0.5309, 0.4974, 0.4652, 0.4343, 0.4049, 0.377

3.1.8 Selectivity parameterization - longline (L) (doitall)

Change the way longline selectivity for the TW/CN LL fisheries 5 and 8 is parameterized. Use 5 parameter cubic splines with non-decreasing selectivity. Set fish_flags(61) = 5, fish_flags(57) = 3, and fish_flags(16) = 1.

3.1.9 Selectivity parameterization – ungroup selectivities of longline fisheries (P) (doitall)

In the base case, selectivities are grouped for longline fisheries in regions 1 and 2 (‘All’ fisheries 1 and 2), and in regions 3, 4, 5, and 6 (‘All’ fisheries 4, 7, 10, & 12, + Chinese / Taiwanese fisheries 5 & 8).

Under this option, selectivity is estimated separately for the two CH/TW fisheries in regions 3 and 4.

3.1.10 Regional recruitment distribution scenarios (D) (ini)

Alternative starting values. Set initial values to 0.16, 0.16, 0.16, 0.16, 0.16, 0.20. This hypothesis was not part of the combination runs.

3.1.11 Re-weighted length frequency data (G) (frq)

An alternative frq file was used with length and weight frequencies adjusted according to the results of an iterative re-weighting procedure by fishery and decade, from the bigeye stock assessment (Langley *et al.* 2008).

3.1.12 Catchability deviate weights (W) (doitall)

Temporal catchability deviates are estimated for some fisheries, every 2 years, with a penalty of 50. These deviates are not completely free – there is still some stiffness and this may be influential. The influence of the remaining stiffness was examined by ‘freeing up’ the catchability sequence. The frequency of the deviates was increased to 6 monthly, and the penalty was reduced from 50 to 1.

Fish flags 15. Instead of the default of 50, change to 1. Add (-999 15 1) to phase 1.

Change fish_flags(23) frequency from 23 to 5, so in phase 8, change (-999 23 23) to (–999 23 5).

3.1.13 Catchability trend (T) (frq)

Increasing trend in catchability in all fisheries. Increase longline fisheries by 0.5% per year before 1985 and 2% per year post-1985. Increase purse seine fisheries by 2% per year throughout. These are equivalent to 0.00125 and 0.005 per quarter. Change effort series for all fisheries to match this assumption – progressively increase quarterly effort.

3.1.14 Down-weight size data (H) (doitall)

Remove the influence of the size data from the CH/TW fisheries, by setting the inverse of the length frequency and weight frequency weighting penalty to 10000 for fisheries 5 and 8.

3.1.15 Initial conditions (I) (doitall)

Instead of using the first 20 periods to compute the mean initial fishing mortality, use the first 40. Change age_flags(95) from 20 to 40.

4 Results

4.1 Individual runs

For each individual run, the fit characteristics of the run are presented in

In two runs, SBFcurrent and BFcurrent were equal to zero. These values were excluded from analyses of SBcurrent / SBFcurrent and Bcurrent / BFcurrent, resulting in a slight downward bias.

The base run resulted in similar parameter estimates to the base run from the stock assessment. The main difference between these two runs is that steepness is estimated in the stock assessment base case, and fixed in the base run presented here.

Applying steepness of 0.7 resulted in a similar quality of fit to the data (delta obj = 7), higher Bmsy, and lower MSY. As expected, this run was the most pessimistic in terms of F/Fmsy, and one of the most pessimistic in terms of B/Bmsy.

The 3 natural mortality runs (increasing the mean adult natural mortality to 0.125 per quarter, increasing the juvenile natural mortality to 0.4 values, and using the Seapodym-calculated relationship between age and natural mortality all resulted in worse fits to the data. The first two runs were close to the base case in terms of B/Bmsy and F/Fmsy, while the Seapodym run was more pessimistic on both axes.

Using the IATTC approach to effort deviates resulted in lower objective function because of the reduced penalty, but did not substantially affect B/Bmsy or F/Fmsy.

Using alternative mixing parameters resulted in a substantially worse fit to the data, and gave higher Bmsy and MSY, but did not greatly affect the ratios B/Bmsy and F/Fmsy.

The recalculated spawning biomass (spawning potential) parameters gave identical quality of fit to the data, and had little effect on the management ratios.

Using the more flexible cubic spline instead of the logistic curve for Chinese and Taiwanese fishery selectivity resulted in very similar fit to the data for an extra 5 parameters. Estimating separate selectivities for these fisheries in regions 3 and 4 also gave similar benefit at the cost of two parameters.

Alternative starting values for the regional recruitment parameters resulted in a slightly better fit to the data, but almost identical management implications.

Applying iterative reweighting to the length frequency data resulted in effectively fitting the model to different data, so is not comparable in terms of the likelihood. The result had more optimistic management implications.

Using a more flexible approach to catchability (q) deviates from non-standardized fisheries resulted in much better fit to the data (2076 likelihood units) at the cost of 860 parameters. Management implications were slightly more optimistic.

Modelling a progressive increase in fishing power (effort creep) resulted in better fit to the data (100 likelihood units) for no extra parameters. Management implications were significantly more pessimistic, with Bcurrent below Bmsy and SBcurrent below SBmsy.

Down-weighting (and effectively ignoring) the Chinese and Taiwanese length frequency data cannot be compared in likelihood terms. Both Bmsy and MSY were increased, and the management ratios were slightly more optimistic.

Changing the initial conditions to give base initial fishing mortality on the first 40 periods rather than the first 20 resulted in slightly worse fit to the data, , lower MSY and Bmsy, and was slightly more pessimistic in terms of management ratios.

4.2 Combined runs

For each management parameter, the distribution of values from all combined runs is presented in Figure 2.

The effects on SBcurr / SB_{MSY}, Bcurr / B_{MSY}, and Fcurr / F_{MSY} of each individual scenario option in the combined run are presented in Figure 3 to Figure 5. Steepness and effort creep were the most important components of the variability for all three management-related ratios.

Relationships between Bcurrent / B_{MSY} and Fcurr / F_{MSY} are presented in Figure 6, and relationships between SBcurrent / SB_{MSY} and Fcurr / F_{MSY} are presented in Figure 7, by factor.

For each management-related parameter, Table 5 presents the mean, standard deviation, coefficient of variation, 90 percent quantiles, and 95% confidence intervals for the mean. It should be understood that the 95% confidence interval is conditioned on the prior assumptions of the sensitivity analysis, which were that each state of each factor was equally likely.

5 Discussion

The steepness parameter and fishing power (effort creep) were the factors with the largest effects on management-related parameters in both the individual run and the combined runs. Steepness had the most effect on F/F_{MSY} and SB/SB_{MSY} because it changes the reproductive output at low population sizes. This becomes more important for populations with lower values of SB_{MSY}/SB_0. The value of this relationship is 0.21 in the base run, which makes the bigeye stock assessment sensitive top assumptions about steepness.

Potential increase in fishing power (effort creep) also had significant influence on estimates of management-related parameters, particularly Bcurrent / B_{MSY}.

The length frequency data re-weighting approach also had some influence on the management parameters. However, the validity of our approach is uncertain given that only the length frequencies were re-weighted, and not the CPUE time series, or the tagging data. Decadal iterative re-weighting is a somewhat experimental approach. Also, the re-weighting was done for the base case stock assessment, and not re-done for each scenario, which would be more appropriate. This is only one approach to weighting length frequency data, and a number of alternatives are possible. The influential nature of this change underlines the importance of carefully examining assumptions about selectivity, and about the representativeness of length frequency sampling.

Further examination of diagnostics and development of acceptance criteria is warranted. Several runs with relatively high gradients (>50) after the standard 4000 iterations were included in the summary statistics. The distributions of management-related parameters for these runs were within the range of values for the other scenarios.

It would be useful in future analyses to apply prior weights to alternate values of the factors. These prior weights could then be used to estimate the mean values and 95% credibility intervals for each management-related parameter. If this approach is to be used in future, the chosen weights will be influential and must be developed carefully.

In future, further analyses should be undertaken to investigate interactions between the factors going into the assessment. For example, steepness is likely to be slightly less influential under the alternative approach to spawning stock biomass, since SB_{MSY}/SB_0 is higher under that scenario. Such analyses could be undertaken using a generalized linear modelling approach.

The partially confounded factorial design successfully processed what had appeared to be an impossibly large number of factor combinations, given 2^12 factors resulting in 4096 runs that average about 20 hours each. The partially confounded design rationalised this down to 2^7 = 128 runs. Since the design is orthogonal, we could use it to integrate across the combined distribution, and estimate sensitivity to multiple uncertainties. A key assumption of the analysis of individual effects is that higher order interactions can be disregarded, and do not (overall) contribute significant additional uncertainty. Further consideration should be given to validating this assumption by examining these higher order interactions.

6 Acknowledgements

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7 Tables

Table 1: List of the assumptions to be adjusted, and the alternative values applied under each scenario.

	Assumptions	**Hypothesis 1**	**Hypothesis 2**
1	R – Steepness	0.7	0.957
2	M – Mean M	0.1	0.125
3	J – Juvenile M	0.2	0.4
4	S – *Seapodym M (not in SSA)*	♂ M constant post-maturity	M based on Seapodym – incl. senescence
5	C - IATTC effort dev pens	LL effort dev sd = 0.1	LL effort dev sd = 0.2
6	X – Alternative mixing	Movement estimated	Mixing rate set at 0.01
7	B – changed spawning biomass	Standard version	From biological SSA
8	L – Change CH/TW selectivity type	Logistic	Cubic spline
9	P – Ungroup sels of regions 3 and 4 (CH/TW)	F 5 & F 8 grouped	5 & 8 independent
10	D – *Regional rec start vals (not in SSA)*	Current initial values	R1–6= 0.16. R6= 0.20.
11	G – Length frequency reweighting	Standard frq file	Reweighted frq file
12	W – Free up q deviates	2 year interval. Penalty wt = 50	Half year interval. Penalty wt = 1
13	T – Trend in q	No trend	LL 0.125% / qtr 52-84, 0.5% / qtr 85-07. PS 0.5% / qtr
14	H – Down-weight CH/TW	Same weight on all size data	CH/TW data effectively omitted
15	I – Initial conditions 40 periods	20 periods	40 periods

Table 2a: Input values for the bet.ini file for each scenario involving alternate values of natural mortality

Means		0.11283		0.45798
Age (qtrs)	Base case	age_pars	Seapodym	age_pars
1	0.2001	0.5727	0.9826	0.7634
2	0.1663	0.3882	0.9543	0.7342
3	0.1337	0.1698	0.7737	0.5243
4	0.1011	-0.1099	0.5285	0.1433
5	0.1000	-0.1204	0.4036	-0.1264
6	0.1001	-0.1202	0.3550	-0.2546
7	0.1001	-0.1197	0.3027	-0.4142
8	0.1002	-0.1190	0.2495	-0.6075
9	0.1003	-0.1176	0.2137	-0.7624
10	0.1005	-0.1155	0.1918	-0.8705
11	0.1009	-0.1122	0.1763	-0.9548
12	0.1013	-0.1074	0.1656	-1.0170
13	0.1020	-0.1006	0.1596	-1.0542
14	0.1030	-0.0916	0.1569	-1.0714
15	0.1041	-0.0801	0.1562	-1.0755
16	0.1055	-0.0668	0.1577	-1.0662
17	0.1072	-0.0512	0.1617	-1.0411
18	0.1090	-0.0346	0.1691	-0.9963
19	0.1108	-0.0181	0.1808	-0.9293
20	0.1125	-0.0030	0.1975	-0.8409
21	0.1139	0.0097	0.2198	-0.7340
22	0.1151	0.0196	0.2482	-0.6126
23	0.1159	0.0267	0.2830	-0.4814
24	0.1164	0.0311	0.3239	-0.3464
25	0.1167	0.0334	0.3703	-0.2125
26	0.1167	0.0341	0.4207	-0.0850
27	0.1167	0.0335	0.4732	0.0326
28	0.1165	0.0320	0.5256	0.1377
29	0.1162	0.0298	0.5757	0.2287
30	0.1159	0.0272	0.6218	0.3058
31	0.1156	0.0241	0.6626	0.3693
32	0.1152	0.0208	0.6976	0.4207
33	0.1148	0.0173	0.7267	0.4617
34	0.1144	0.0137	0.7505	0.4938
35	0.1140	0.0100	0.7694	0.5188
36	0.1135	0.0063	0.7844	0.5380
37	0.1131	0.0026	0.7960	0.5528
38	0.1127	-0.0012	0.8049	0.5639
39	0.1123	-0.0049	0.8115	0.5721
40	0.1119	-0.0086	0.8169	0.5787

Table 2b: Input values for the bet.ini file for each scenario involving alternate values of natural mortality

Means Age (qtrs)	Juvenile peak (double)	0.11765 age_pars	Higher mean	0.12582 age_pars	Juv-pk + Higher mean	0.13119 age_pars
1	0.4000	1.2237	0.2001	0.4638	0.4000	1.1148
2	0.3000	0.9361	0.1663	0.2792	0.3000	0.8271
3	0.2000	0.5306	0.1337	0.0609	0.2000	0.4216
4	0.1000	-0.1626	0.1137	-0.1010	0.1125	-0.1537
5	0.1000	-0.1623	0.1125	-0.1116	0.1125	-0.1535
6	0.1001	-0.1620	0.1126	-0.1114	0.1126	-0.1532
7	0.1001	-0.1616	0.1126	-0.1109	0.1126	-0.1528
8	0.1002	-0.1608	0.1127	-0.1101	0.1127	-0.1520
9	0.1003	-0.1595	0.1128	-0.1088	0.1128	-0.1507
10	0.1005	-0.1574	0.1131	-0.1067	0.1131	-0.1485
11	0.1009	-0.1541	0.1135	-0.1034	0.1135	-0.1452
12	0.1013	-0.1492	0.1140	-0.0985	0.1140	-0.1404
13	0.1020	-0.1425	0.1148	-0.0918	0.1148	-0.1336
14	0.1030	-0.1334	0.1158	-0.0828	0.1158	-0.1246
15	0.1041	-0.1220	0.1172	-0.0713	0.1172	-0.1132
16	0.1055	-0.1087	0.1187	-0.0580	0.1187	-0.0999
17	0.1072	-0.0931	0.1206	-0.0424	0.1206	-0.0843
18	0.1090	-0.0765	0.1226	-0.0258	0.1226	-0.0676
19	0.1108	-0.0600	0.1247	-0.0093	0.1247	-0.0512
20	0.1125	-0.0449	0.1265	0.0058	0.1265	-0.0360
21	0.1139	-0.0321	0.1282	0.0186	0.1282	-0.0233
22	0.1151	-0.0222	0.1294	0.0285	0.1294	-0.0134
23	0.1159	-0.0152	0.1304	0.0355	0.1304	-0.0064
24	0.1164	-0.0107	0.1309	0.0399	0.1309	-0.0019
25	0.1167	-0.0084	0.1312	0.0423	0.1312	0.0004
26	0.1167	-0.0077	0.1313	0.0430	0.1313	0.0011
27	0.1167	-0.0083	0.1313	0.0424	0.1313	0.0005
28	0.1165	-0.0098	0.1311	0.0409	0.1311	-0.0010
29	0.1162	-0.0120	0.1308	0.0387	0.1308	-0.0032
30	0.1159	-0.0147	0.1304	0.0360	0.1304	-0.0059
31	0.1156	-0.0178	0.1300	0.0329	0.1300	-0.0089
32	0.1152	-0.0211	0.1296	0.0296	0.1296	-0.0122
33	0.1148	-0.0245	0.1291	0.0262	0.1291	-0.0157
34	0.1144	-0.0281	0.1287	0.0225	0.1287	-0.0193
35	0.1140	-0.0318	0.1282	0.0189	0.1282	-0.0230
36	0.1135	-0.0356	0.1277	0.0151	0.1277	-0.0267
37	0.1131	-0.0393	0.1273	0.0114	0.1273	-0.0305
38	0.1127	-0.0431	0.1268	0.0076	0.1268	-0.0342
39	0.1123	-0.0468	0.1263	0.0039	0.1263	-0.0380
40	0.1119	-0.0505	0.1258	0.0002	0.1258	-0.0417

Table 3: Individual runs with number of parameters, gradient, objective functions, and offsets of the objective function and number of parameters from the base model.

Run	npars	gradient	objective fn	delta Obj	delta np
Base	5,642	7.1E-02	1,246,172	0	0
Steepness (h) = 0.7	5,642	1.5E-02	1,246,165	7	0
Mean M = 0.125	5,642	6.6E-03	1,246,154	17	0
Juvenile M = 0.4	5,642	2.0E-01	1,246,130	42	0
Seapodym M	5,643	1.8E-01	1,246,139	33	1
IATTC effort devs	5,642	1.8E+02	1,249,277	-3,105	0
Slow mixing	5,586	1.4E+00	1,244,767	1,405	-56
alternative SSB	5,642	2.5E-02	1,246,172	0	0
CH/TW spline	5,647	3.4E-02	1,246,179	-7	5
CH/TW selectivity	5,644	5.6E+01	1,246,179	-7	2
RR starting values	5,642	1.7E-01	1,246,199	-27	0
LF reweighting	5,642	5.3E+01	1,007,674	238,498	0
q devs	6,502	9.4E-03	1,248,248	-2,076	860
effort creep	5,642	3.1E-02	1,246,272	-100	0
Ignore CHTW LF	5,642	1.1E-01	1,153,777	92,395	0
Init conditions	5,642	4.8E-03	1,246,138	34	0

Table 4a: Estimates of management quantities for the single option runs versus the SSA base model. The highlighted rows are ratios of comparable quantities at the same point in time (black shading) and ratios of comparable equilibrium quantities (grey shading).

Management quantity	**Units**	**Base**	**h=0.7**	**M 0.125**	**Juv M 0.4**	**Seapodym M**	**IATTC edevs**
$\widetilde{Y}_{F_{current}}$	mt per year	60,760	17,164	51,840	65,040	45,800	61,600
$\widetilde{Y}_{F_{MSY}}$ (or MSY)	mt per year	64,680	55,360	57,600	68,560	59,800	64,600
$\widetilde{B}_0$	mt	757,100	850,700	700,900	786,400	907,100	704,400
$\widetilde{B}_{F_{current}}$	mt	169,500	49,660	134,800	183,100	113,100	171,600
$\widetilde{B}_{MSY}$	mt	253,600	340,500	232,900	263,200	299,300	240,400
$\widetilde{SB}_0$	mt	486,100	544,500	416,500	505,500	701,800	452,300
$\widetilde{SB}_{F_{current}}$	mt	55,380	16,580	38,910	59,760	51,740	54,520
$\widetilde{SB}_{MSY}$	mt	103,700	166,000	89,450	106,000	186,000	94,180
$B_{current}$	mt	342,021	355,493	319,171	344,343	308,532	337,248
$SB_{current}$	mt	121,528	129,361	96,330	122,506	150,156	117,464
$B_{current,F=0}$	mt	1,261,979	1,251,075	1,241,346	1,240,405	1,929,621	1,208,706
$B_{current}/\widetilde{B}_0$		0.45	0.42	0.46	0.44	0.34	0.48
$B_{current}/\widetilde{B}_{F_{current}}$		2.02	7.16	2.37	1.88	2.73	1.97
$B_{current}/\widetilde{B}_{MSY}$		1.35	1.04	1.37	1.31	1.03	1.40
$B_{current}/B_{current,F=0}$		0.27	0.28	0.26	0.28	0.16	0.28
$SB_{current}/\widetilde{SB}_0$		0.25	0.24	0.23	0.24	0.21	0.26
$SB_{current}/\widetilde{SB}_{F_{current}}$		2.19	7.80	2.48	2.05	2.90	2.16
$SB_{current}/\widetilde{SB}_{MSY}$		1.17	0.78	1.08	1.16	0.81	1.25
$SB_{2006}/\widetilde{SB}_{MSY}$		0.99	0.66	1.01	0.97	0.70	1.00
$\widetilde{B}_{F_{current}}/\widetilde{B}_0$		0.22	0.06	0.19	0.23	0.12	0.24
$\widetilde{SB}_{F_{current}}/\widetilde{SB}_0$		0.11	0.03	0.09	0.12	0.07	0.12
$\widetilde{B}_{MSY}/\widetilde{B}_0$		0.34	0.40	0.33	0.33	0.33	0.34
$\widetilde{SB}_{MSY}/\widetilde{SB}_0$		0.21	0.30	0.21	0.21	0.27	0.21
$F_{current}/\widetilde{F}_{MSY}$		1.45	2.24	1.57	1.41	1.99	1.40
$\widetilde{B}_{F_{current}}/\widetilde{B}_{MSY}$		0.67	0.15	0.58	0.70	0.38	0.71
$\widetilde{SB}_{F_{current}}/\widetilde{SB}_{MSY}$		0.53	0.10	0.44	0.56	0.28	0.58
$\widetilde{Y}_{F_{current}}/MSY$		0.94	0.31	0.90	0.95	0.77	0.95

Table 4b: Estimates of management quantities for the single option runs versus the SSA base model. The highlighted rows are ratios of comparable quantities at the same point in time (black shading) and ratios of comparable equilibrium quantities (grey shading).

Management quantity	**Units**	**Base**	**Slow mixing**	**alt SSB**	**CHTW spline**	**CH/TW sel**	**RR startvals**
$\tilde{Y}_{F_{current}}$	mt per year	60,760	79,240	62,360	61,760	62,480	62,320
$\tilde{Y}_{F_{MSY}}$ **(or MSY)**	mt per year	64,680	80,000	65,240	65,400	65,840	65,560
$\tilde{B}_0$	mt	757,100	857,200	753,900	762,000	763,700	762,300
$\tilde{B}_{F_{current}}$	mt	169,500	246,900	173,700	174,200	177,500	179,100
$\tilde{B}_{MSY}$	mt	253,600	284,800	247,100	255,300	255,400	255,800
$\tilde{SB}_0$	mt	486,100	528,800	494,200	490,800	490,400	491,000
$\tilde{SB}_{F_{current}}$	mt	55,380	72,040	85,350	57,610	58,670	59,980
$\tilde{SB}_{MSY}$	mt	103,700	93,380	134,900	104,500	103,600	104,600
$B_{current}$	mt	342,021	387,339	341,568	345,836	348,761	352,225
$SB_{current}$	mt	121,528	120,167	177,267	124,312	125,357	125,477
$B_{current,F=0}$	mt	1,261,979	1,216,621	1,262,406	1,258,741	1,256,446	1,267,825
$B_{current}/\tilde{B}_0$		0.45	0.45	0.45	0.45	0.46	0.46
$B_{current}/\tilde{B}_{F_{current}}$		2.02	1.57	1.97	1.99	1.97	1.97
$B_{current}/\tilde{B}_{MSY}$		1.35	1.36	1.38	1.36	1.37	1.38
$B_{current}/B_{current,F=0}$		0.27	0.32	0.27	0.27	0.28	0.28
$SB_{current}/\tilde{SB}_0$		0.25	0.23	0.36	0.25	0.26	0.26
$SB_{current}/\tilde{SB}_{F_{current}}$		2.19	1.67	2.08	2.16	2.14	2.09
$SB_{current}/\tilde{SB}_{MSY}$		1.17	1.29	1.31	1.19	1.21	1.20
$SB_{2006}/\tilde{SB}_{MSY}$		0.99	1.12	1.11	1.01	1.02	1.06
$\tilde{B}_{F_{current}}/\tilde{B}_0$		0.22	0.29	0.23	0.23	0.23	0.23
$\tilde{SB}_{F_{current}}/\tilde{SB}_0$		0.11	0.14	0.17	0.12	0.12	0.12
$\tilde{B}_{MSY}/\tilde{B}_0$		0.34	0.33	0.33	0.34	0.33	0.34
$\tilde{SB}_{MSY}/\tilde{SB}_0$		0.21	0.18	0.27	0.21	0.21	0.21
$F_{current}/\tilde{F}_{MSY}$		1.45	1.16	1.40	1.43	1.40	1.40
$\tilde{B}_{F_{current}}/\tilde{B}_{MSY}$		0.67	0.87	0.70	0.68	0.70	0.70
$\tilde{SB}_{F_{current}}/\tilde{SB}_{MSY}$		0.53	0.77	0.63	0.55	0.57	0.57
$\tilde{Y}_{F_{current}}/MSY$		0.94	0.99	0.96	0.94	0.95	0.95

Table 4c: Estimates of management quantities for the single option runs versus the SSA base model. The highlighted rows are ratios of comparable quantities at the same point in time (black shading) and ratios of comparable equilibrium quantities (grey shading).

Management quantity	Units	Base	Iter rewt	q devs	effort creep	Ignore CHTW LF	Init conds
$\tilde{Y}_{F_{current}}$	mt per year	60,760	80,320	66,000	51,520	66,320	57,240
$\tilde{Y}_{F_{MSY}}$ (or MSY)	mt per year	64,680	80,400	68,560	65,520	68,160	62,760
$\tilde{B}_0$	mt	757,100	835,000	766,800	885,500	808,600	750,100
$\tilde{B}_{F_{current}}$	mt	169,500	273,000	191,200	121,400	204,000	152,300
$\tilde{B}_{MSY}$	mt	253,600	286,400	258,900	294,900	264,900	250,600
$\widetilde{SB}_0$	mt	486,100	467,300	488,900	570,300	525,200	482,600
$\widetilde{SB}_{F_{current}}$	mt	55,380	76,410	62,840	36,600	73,280	48,300
$\widetilde{SB}_{MSY}$	mt	103,700	83,260	101,900	131,800	109,800	104,100
$B_{current}$	mt	342,021	427,026	357,616	289,800	372,719	325,772
$SB_{current}$	mt	121,528	122,189	130,332	97,389	143,898	112,273
$B_{current,F=0}$	mt	1,261,979	1,154,365	1,231,813	1,381,765	1,255,487	1,280,970
$B_{current}/\tilde{B}_0$		0.45	0.51	0.47	0.33	0.46	0.43
$B_{current}/\tilde{B}_{F_{current}}$		2.02	1.56	1.87	2.39	1.83	2.14
$B_{current}/\tilde{B}_{MSY}$		1.35	1.49	1.38	0.98	1.41	1.30
$B_{current}/B_{current,F=0}$		0.27	0.37	0.29	0.21	0.30	0.25
$SB_{current}/\widetilde{SB}_0$		0.25	0.26	0.27	0.17	0.27	0.23
$SB_{current}/\widetilde{SB}_{F_{current}}$		2.19	1.60	2.07	2.66	1.96	2.32
$SB_{current}/\widetilde{SB}_{MSY}$		1.17	1.47	1.28	0.74	1.31	1.08
$SB_{2006}/\widetilde{SB}_{MSY}$		0.99	1.44	1.03	0.60	1.11	0.92
$\tilde{B}_{F_{current}}/\tilde{B}_0$		0.22	0.33	0.25	0.14	0.25	0.20
$\widetilde{SB}_{F_{current}}/\widetilde{SB}_0$		0.11	0.16	0.13	0.06	0.14	0.10
$\tilde{B}_{MSY}/\tilde{B}_0$		0.34	0.34	0.34	0.33	0.33	0.33
$\widetilde{SB}_{MSY}/\widetilde{SB}_0$		0.21	0.18	0.21	0.23	0.21	0.22
$F_{current}/\tilde{F}_{MSY}$		1.45	1.05	1.34	1.94	1.28	1.55
$\tilde{B}_{F_{current}}/\tilde{B}_{MSY}$		0.67	0.95	0.74	0.41	0.77	0.61
$\widetilde{SB}_{F_{current}}/\widetilde{SB}_{MSY}$		0.53	0.92	0.62	0.28	0.67	0.46
$\tilde{Y}_{F_{current}}/MSY$		0.94	1.00	0.96	0.79	0.97	0.91

Table 5: Statistical summary parameters for the management related parameters, given the distributions of input scenarios. The 95% confidence intervals on the means are based on studentized bootstrap confidence intervals.

Management quantity	Units	Mean	Std dev	CV	5% quantile	95% quantile	2.5% SE	97.5% SE
$\tilde{Y}_{F_{current}}$	mt per year	66,951	25,357	0.38	20,232	103,824	62,797	71,436
$\tilde{Y}_{F_{MSY}}$ (or MSY)	mt per year	78,939	14,225	0.18	59,664	104,648	76,490	81,386
$\tilde{B}_0$	mt	950,947	146,437	0.15	747,090	1,219,000	925,907	975,614
$\tilde{B}_{F_{current}}$	mt	221,777	97,440	0.44	59,335	372,425	205,764	238,964
$\tilde{B}_{MSY}$	mt	349,230	68,298	0.20	251,895	459,465	337,482	360,908
$\widetilde{SB}_0$	mt	587,597	90,208	0.15	461,360	742,190	572,204	602,679
$\widetilde{SB}_{F_{current}}$	mt	88,490	45,500	0.51	19,644	169,670	80,917	96,685
$\widetilde{SB}_{MSY}$	mt	157,983	43,235	0.27	87,759	231,805	150,651	165,539
$B_{current}$	mt	398,119	61,573	0.15	318,501	508,560	387,746	408,766
$SB_{current}$	mt	168,437	43,107	0.26	105,291	245,928	161,081	176,118
$B_{current,F=0}$	mt	1,147,932	69,529	0.06	1,045,192	1,255,480	1,136,182	1,159,795
$B_{current}/\tilde{B}_0$		0.42	0.06	0.15	0.34	0.52	0.41	0.44
$B_{current}/\tilde{B}_{F_{current}}$		2.37	2.70	1.14	1.22	5.02	1.89	2.80
$B_{current}/\tilde{B}_{MSY}$		1.17	0.21	0.18	0.85	1.55	1.13	1.20
$B_{current}/B_{current,F=0}$		0.35	0.05	0.15	0.27	0.43	0.34	0.36
$SB_{current}/\widetilde{SB}_0$		0.29	0.07	0.24	0.19	0.40	0.28	0.30
$SB_{current}/\widetilde{SB}_{F_{current}}$		2.62	3.21	1.22	1.29	5.81	2.05	3.12
$SB_{current}/\widetilde{SB}_{MSY}$		1.11	0.30	0.27	0.70	1.70	1.06	1.17
$SB_{2006}/\widetilde{SB}_{MSY}$		0.95	0.32	0.34	0.50	1.59	0.89	1.00
$\tilde{B}_{F_{current}}/\tilde{B}_0$		0.23	0.09	0.40	0.07	0.37	0.22	0.25
$\widetilde{SB}_{F_{current}}/\widetilde{SB}_0$		0.15	0.07	0.47	0.03	0.26	0.14	0.16
$\tilde{B}_{MSY}/\tilde{B}_0$		0.37	0.03	0.09	0.32	0.41	0.36	0.37
$\widetilde{SB}_{MSY}/\widetilde{SB}_0$		0.27	0.05	0.20	0.17	0.34	0.26	0.28
$F_{current}/\tilde{F}_{MSY}$		1.47	0.42	0.28	0.89	2.16	1.40	1.54
$\tilde{B}_{F_{current}}/\tilde{B}_{MSY}$		0.66	0.29	0.45	0.17	1.10	0.61	0.71
$\widetilde{SB}_{F_{current}}/\widetilde{SB}_{MSY}$		0.60	0.33	0.54	0.11	1.15	0.55	0.66
$\tilde{Y}_{F_{current}}/MSY$		0.83	0.23	0.28	0.35	1.00	0.79	0.87

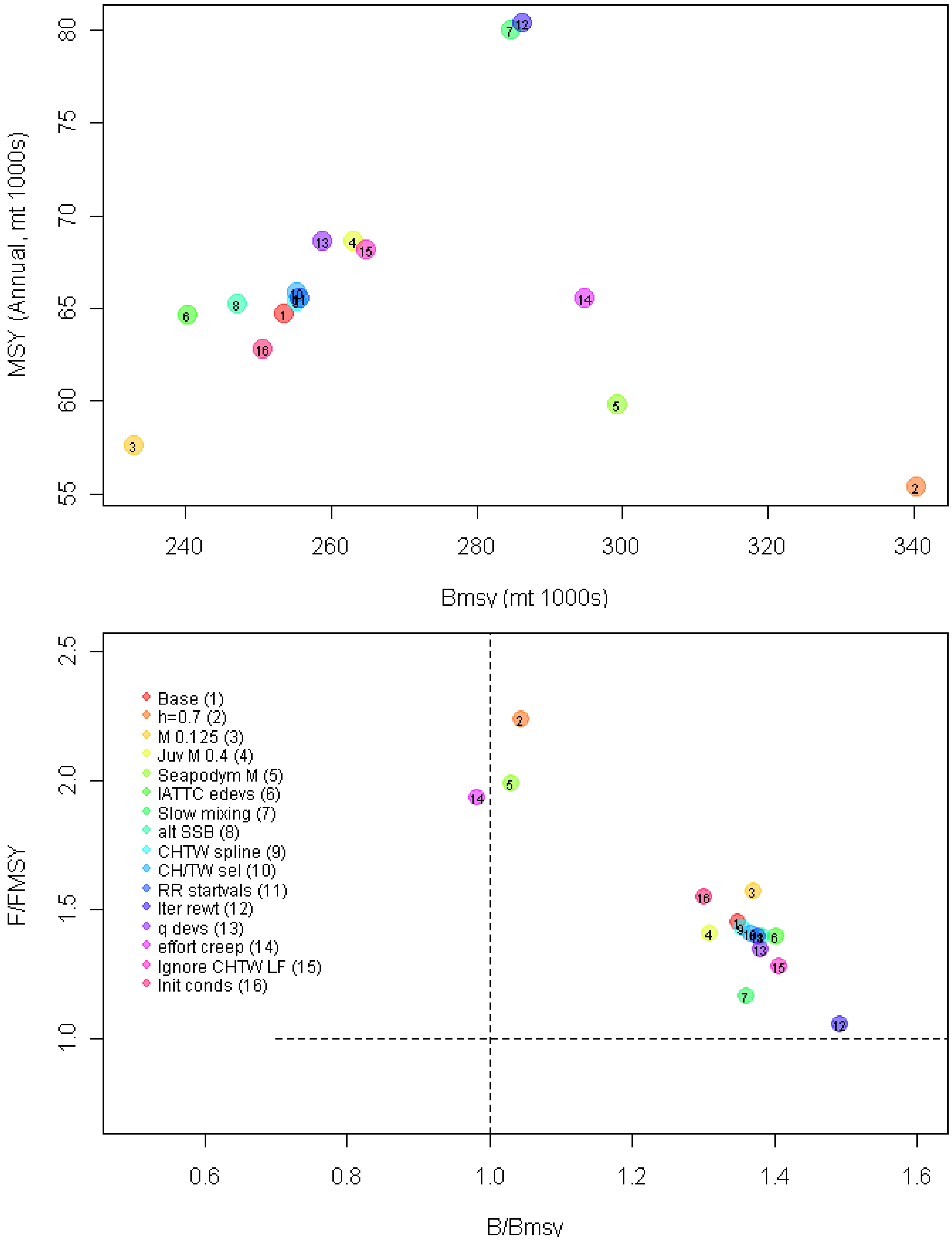

Figure 1:B_{MSY} **versus MSY and** B/B_{MSY} **versus** F/F_{MSY} **for each individual scenario.**

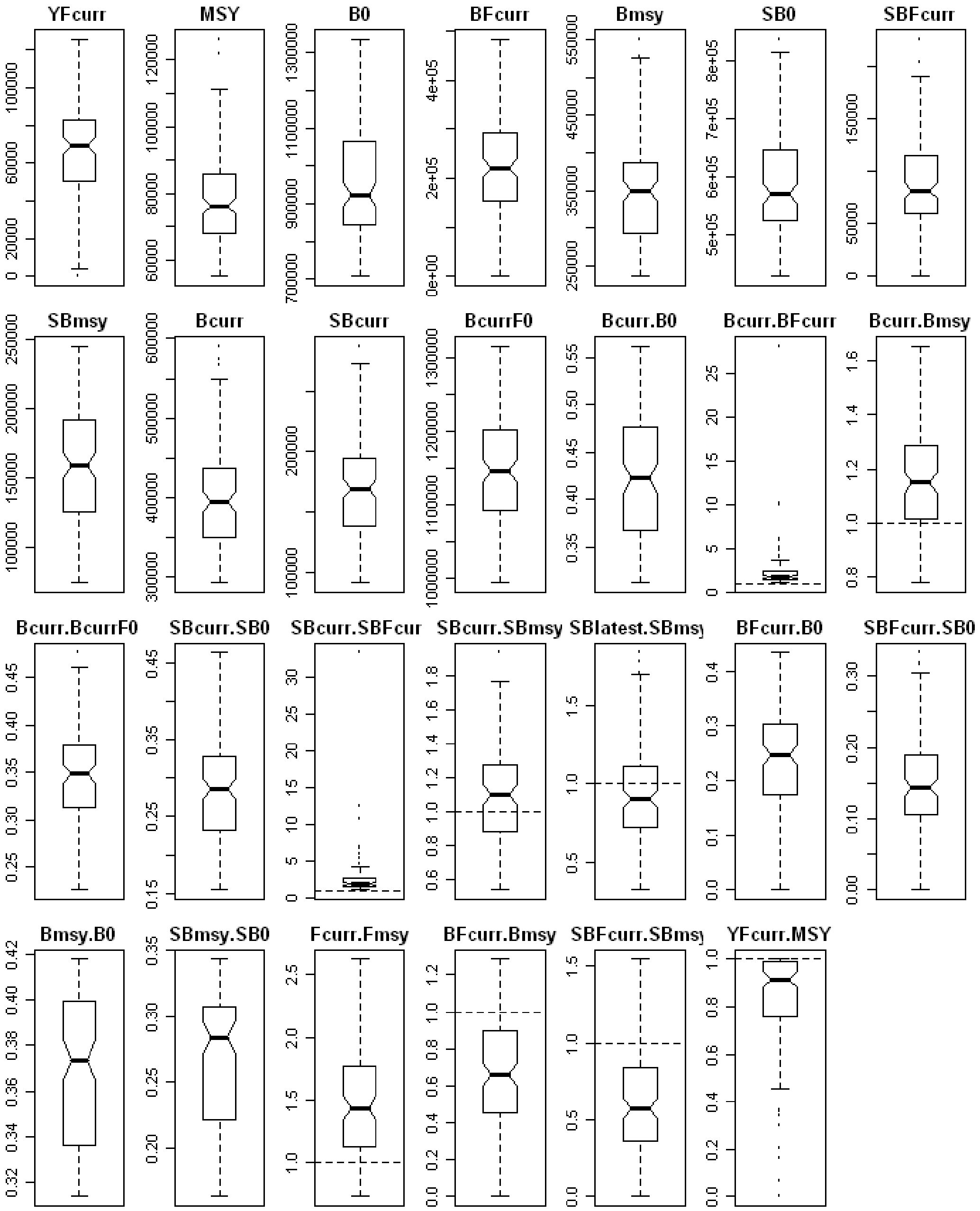

Figure 2: Distributions of values for each management parameter under the range of 128 alternative scenario combinations. The box encloses the upper and lower quartiles, divided by the median, and whiskers extend to either the extreme values or 1.5 times the inter-quartile range from the box, whichever is smaller.

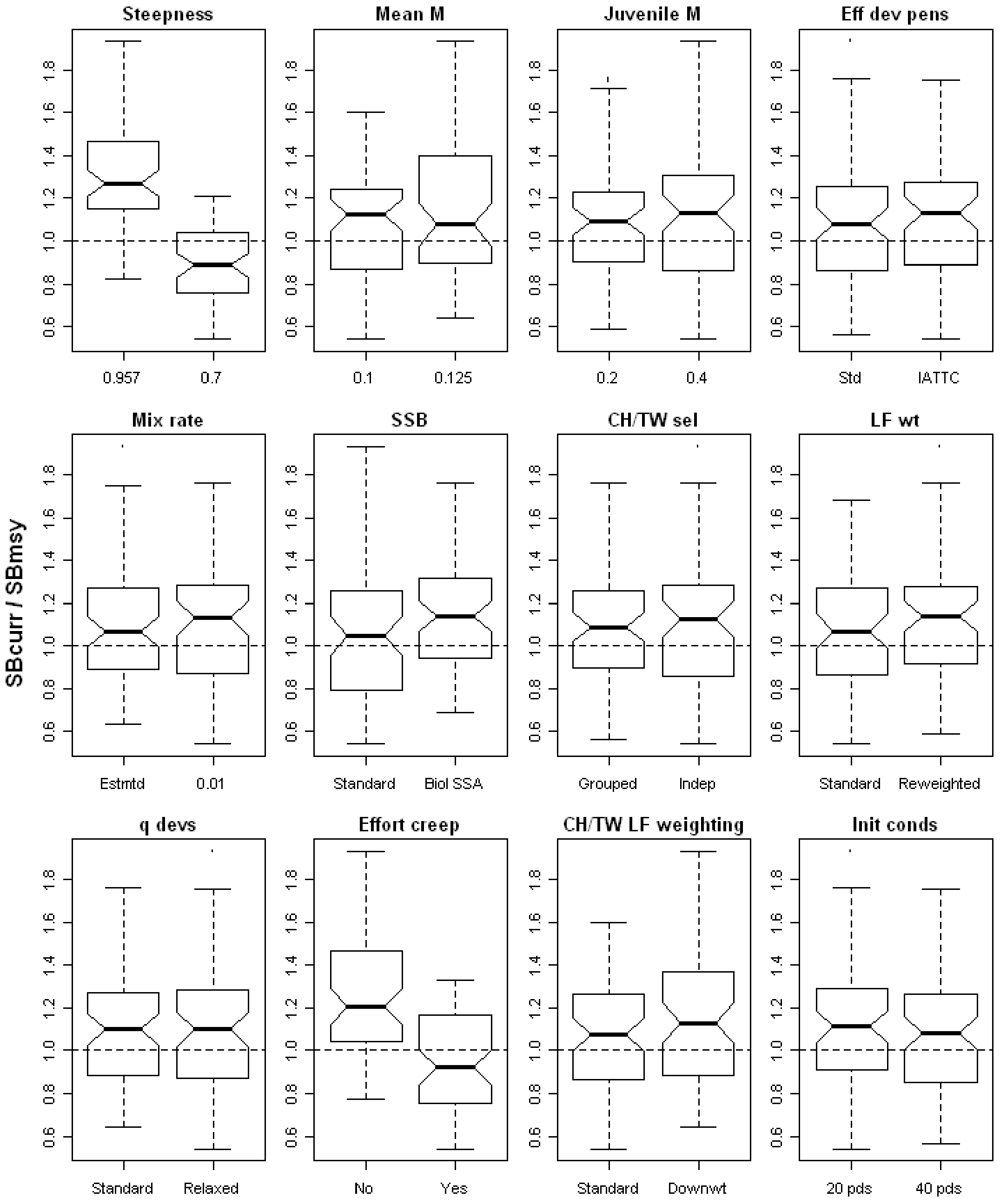

Figure 3: Distribution of SBcurr / SBmsy from 128 runs, grouped by factor. When the notches in the sides of the boxes within a pair do not overlap, this is strong evidence that the two medians differ. The box encloses the upper and lower quartiles, divided by the median, and whiskers extend to either the extreme values or 1.5 times the inter-quartile range from the box, whichever is smaller.

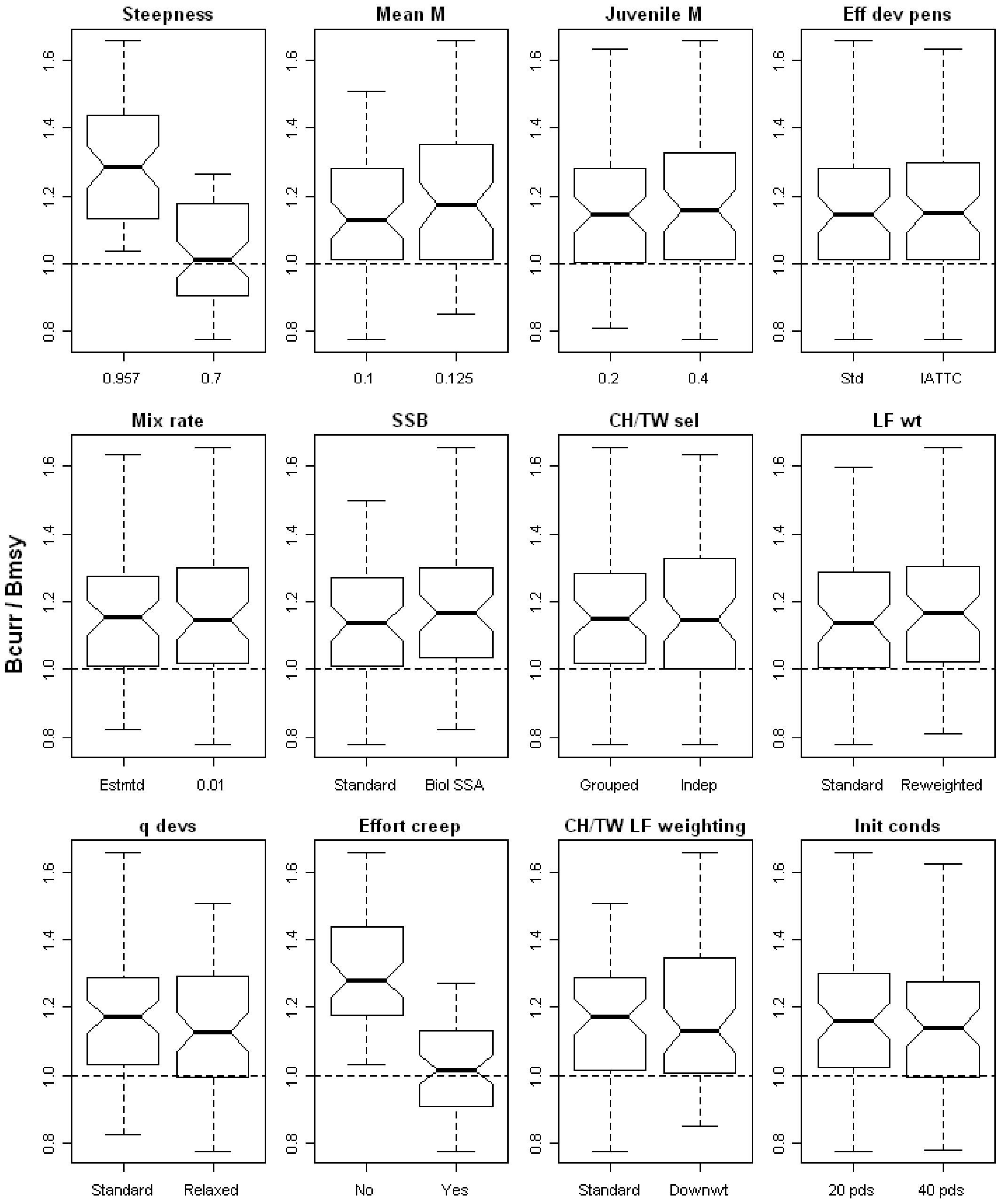

Figure 4: Distribution of Bcurr / Bmsy from 128 runs, grouped by factor. When the notches in the sides of the boxes within a pair do not overlap, this is strong evidence that the two medians differ. The box encloses the upper and lower quartiles, divided by the median, and whiskers extend to either the extreme values or 1.5 times the inter-quartile range from the box, whichever is smaller.

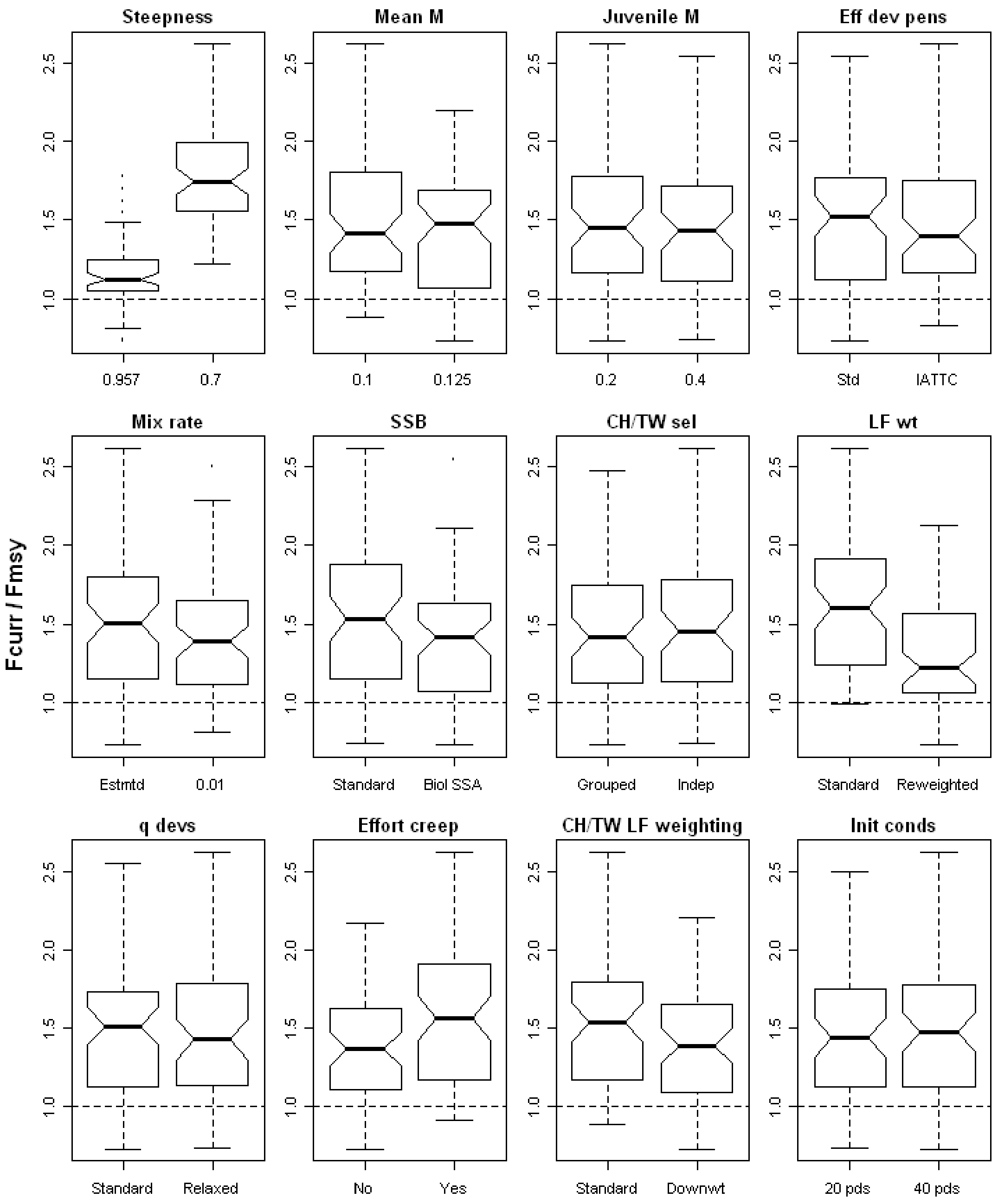

Figure 5: Distribution of Fcurr / Fmsy from 128 runs, grouped by factor. When the notches in the sides of the boxes within a pair do not overlap, this is strong evidence that the two medians differ. The box encloses the upper and lower quartiles, divided by the median, and whiskers extend to either the extreme values or 1.5 times the inter-quartile range from the box, whichever is smaller.

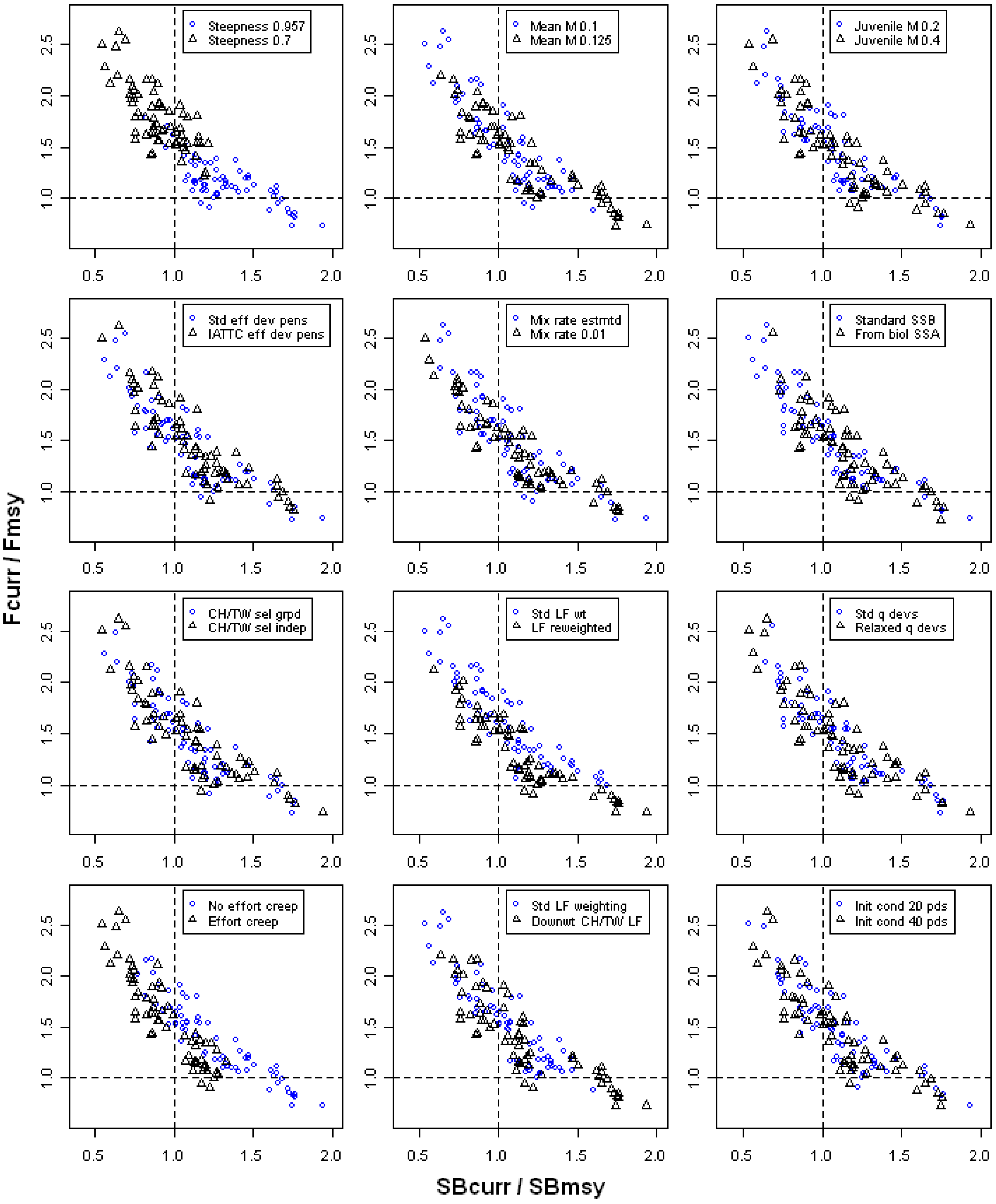

Figure 6: Plots SBcurr / SBmsy versus Fcurr / Fmsy from 128 runs, grouped by factor.

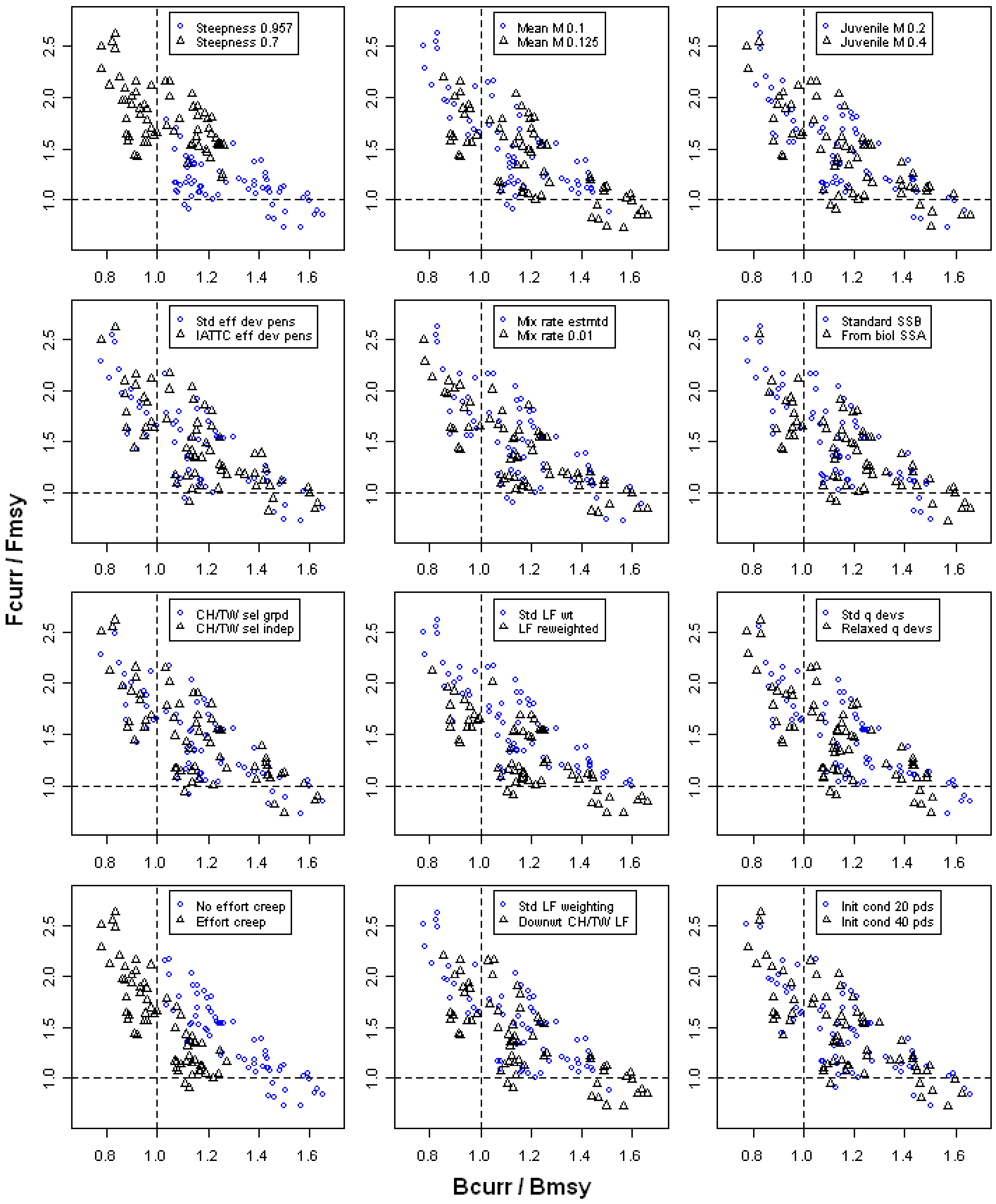

Figure 7: Plots Bcurr / Bmsy versus Fcurr / Fmsy from 128 runs, grouped by factor.

8 Appendix – input files

8.1 Bet.sub

```
universe = vanilla
executable = mfcl.$$(Opsys).bat
getenv = true
error = $(Cluster).$(Process).condor_mfcl.err
log = $(Cluster).$(Process).condor_mfcl.log
output = $(Cluster).$(Process).condor_mfcl.out
notify_user=user@xxx.xxx
should_transfer_files = YES
Requirements = (OpSys == "LINUX" || OpSys =="WINNT51") && \
(Arch=="INTEL" || Arch=="X86_64") && \
((name=="vm1@pc1.xxx.spc.xxx" || \
name=="vm1@ pc2.xxx.spc.xxx" || \
machine== " pc3.xxx.spc.xxx" || \
machine== " pc4.xxx.spc.xxx" || \
name== "vm1@ pc5.xxx.spc.xxx" || \
name== "vm2@ pc6.xxx.spc.xxx" || \
name== "vm2@ pc7.xxx.spc.xxx" || \
(name== "vm1@ pc8.xxx.spc.xxx" && KeyboardIdle > 900) || \
name== "vm2@ pc9.xxx.spc.xxx" || \
name== "vm1@ pc10.xxx.spc.xxx" || \
name== "vm1@ pc11.xxx.spc.xxx" || \
name== "vm1@ pc12.xxx.spc.xxx" || \
name== "vm1@ pc13.xxx.spc.xxx" || \
name== "vm1@ pc14.xxx.spc.xxx" || \
name== "vm1@ pc15.xxx.spc.xxx" || \
name== "vm1@ pc16.xxx.spc.xxx") && \
((NumRestarts < 1) || (CurrentTime - LastMatchTime) > 900))
transfer_output_remaps =
"13.par=$(Cluster).$(Process).13.par;doitall.bet=$(Cluster).$(Process).doitall.bet;
plot.rep=$(Cluster).$(Process).plot.rep"
when_to_transfer_output = ON_EXIT_OR_EVICT
TRANSFER_INPUT_FILES = mfclo32.lin, mfclo32.exe, mfcl.cfg, bet.frq,
doitall.bet, bet.tag, bet.ini
queue
```

8.2 mfcl.WINNT51.bat

```
set ADTMP1=%_CONDOR_SCRATCH_DIR%
set
path  %PATH%;C:\cygwin\bin; %_CONDOR_SCRATCH_DIR%
rename *.par startpar.par
rename *.bet doitall.bet
dir
```

```
bash --login -i  %CD%\doitall.bet
exit
```

8.3 mfcl.LINUX.bat

```
#!/bin/bash
set
export ADTMP1=$_CONDOR_SCRATCH_DIR
echo $ADTMP1
ls -l
mv mfclo32.lin mfclo32
mv *.par startpar.par
mv *.bet doitall.bet
chmod 700 mfclo32
chmod 700 doitall.bet
ls -l
./doitall.bet
```

9 References

Hampton, J., Langley, A., and Kleiber, P. (2006). Stock assessment of yellowfin tuna in the western and central Pacific Ocean, including an analysis of management options. WCPFC SC2 SA WP-1, Manila.

Hoyle, S. D. and Nicol, S. (2008). Sensitivity of bigeye stock assessment to alternative biological and reproductive assumptions. No. WCPFC-SC4-2008/ ME-WP-1 (Secretariat of the Pacific Community: Noumea, New Caledonia.)

Langley, A. D., Hampton, J., Kleiber, P. M., and Hoyle, S. D. (2007). Stock assessment of yellowfin tuna in the western and central Pacific Ocean, including an analysis of management options. No. WCPFC-SC3, SA WP-1 (Secretariat of the Pacific Community: Noumea, New Caledonia.)

Langley, A. D., Hampton, W. J., Kleiber, P. M., and Hoyle, S. D. (2008). Stock assessment of bigeye tuna in the western and central Pacific ocean, including an analysis of management options. No. WCPFC-SC4-2008/SA-WP-1 (Secretariat of the Pacific Community: Noumea, New Caledonia.)

Maunder, M. N., Watters, G. M., and Inter-American Tropical Tuna Commission. (2003). 'A-SCALA: An Age-structured Statistical Catch-at-length Analysis for Assessing Tuna Stocks in the Eastern Pacific Ocean.' (Inter-American Tropical Tuna Commission.)

Montgomery, D. C. (1991). 'Design and analysis of experiments.' Third.Edn. (John Wiley and Sons: New York.)

Schaefer, K. M., Fuller, D. W., and Miyabe, N. (2005). Reproductive biology of bigeye tuna (*Thunnus obesus*) in the eastern and Central Pacific Ocean. *Inter-American Tropical Tuna Commission Bulletin* **23**, 1-31.

Tannenbaum, T., Wright, D., Miller, K., and Livny, M. (2001). Condor - A Distributed Job Scheduler. In 'Beowulf Cluster Computing with Linux'. pp. 307-350.(The MIT Press).