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**UPDATE OF RECENT DEVELOPMENTS IN MULTIFAN-CL AND RELATED
SOFTWARE FOR STOCK ASSESSMENT**

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Introduction

MULTIFAN-CL (MFCL) is a statistical, age-structured, length-based model routinely used for stock assessments of tuna and other pelagic species. The model was originally developed by Dave Fournier of Otter Research for application to south Pacific albacore tuna.

MFCL is typically fitted to total catch, size-frequency and tagging data stratified by fishery, region and time period. Recent tropical tuna assessments (e.g. Langley *et al.* 2007; Langley *et al.* 2008) encompass a time period of 1952–2007 in quarterly time steps, and model >20 separate fisheries occurring in 6 spatial regions. The main parameters estimated by the model include initial numbers-at-age in each region (constrained by an equilibrium age-structure assumption), the number in age class 1 for each quarter in each region (the recruitment), growth parameters, natural mortality-at-age (if estimated), selectivity-at-age by fishery (constrained by smoothing penalties or splines), effort deviations (random variations in the effort-fishing mortality relationship) for each fishery, initial catchability and catchability deviations (cumulative changes in catchability with time) for each fishery (if estimated). Parameters are estimated by fitting to a composite likelihood comprised of the fits to the data and prior distributions for various parameters.

Each year the MFCL development team work to improve the model to accommodate changes in understanding of the fishery, to fix software errors, and to improve usability. This document records changes made since August 2007 to the model and to the other components of the MFCL project.

Development overview

Team

The senior developer of MFCL is Dave Fournier, of Otter Software in Canada. Occasional programming is carried out by Pierre Kleiber (NMFS Hawaii), Simon D Hoyle, Nick Davies, and John Hampton (all SPC, New Caledonia). Other tasks include testing and debugging (SDH, ND, PK, JH, and Fabrice Bouye (SPC)); documentation (PK, SDH); and planning and coordination (SDH, JH, Shelton Harley). Related project software are developed or managed by FB (MFCL Viewer, Condor, Gforge), PK (R scripts), and SDH (R4MFCL, Condor).

Calendar

September – December: Planning and ongoing code development

January: MFCL development meeting, 1-4 weeks

February – March: Testing and finalizing production version

April-July: Stock assessments

MFCL collaboration and versioning

We have established a project management website based on the open source Gforge software. It is used to report problems, list and document potential enhancements, and to allocate tasks. It also hosts a code repository.

The code repository for MFCL development uses the open source software SVN. This repository keeps track of different versions of the software, and allows our international team of developers to merge different versions of the software. The repository is held at SPC, but is accessible via the internet to the development team. The repository and overall development are coordinated via the GForge website <http://gforge2.spc.int/>. This website is administered by Fabrice Bouye fabriceb@spc.int.

Tool development

1. The libraries of R scripts written by Pierre Kleiber have been updated so that they now work in a standard Windows installation, as well as in Linux as they did before.
2. A new set of R scripts for working with MFCL has been developed and released on the internet at the following URL: <http://code.google.com/p/r4mfcl/>. These scripts are used to manipulate the input files, so that runs can be automated. Other scripts can be used to read in the output files, analyze the results, and generate plots and tables. See Table 4 for a list of these R scripts. Further development is planned to provide a comprehensive environment, within which the routine aspects of stock assessments can be automated.
3. The MFCL viewer has been updated with a new residual plot. It has also been modified to deal with new versions of the MFCL output files.
4. Condor (www.condor.wisc.edu), a tool for high throughput computing, as been used to manage a grid currently numbering 50 processors. We have written scripts to enable it to run MFCL, R, and Stock synthesis. This enables multiple jobs to be run in a short time. It is currently used for running the stock assessments, and for the structural sensitivity analysis. It could also be used for other computer intensive tasks such as management strategy evaluation.

MFCL manual

The MFCL manual has been converted by Pierre Kleiber from LaTeX to Microsoft Word 2007. This change will enable more people to work on the manual, and we hope that it will accelerate the process of updating it. The manual has also been added to the SVN repository, to ensure that changes are distributed to the development team in a timely way. Recent updates include adding information about length-specific selectivity and parallelizing the Hessian. However, many further changes are still required.

New MFCL features

Length-based selectivity

The most significant change to MFCL since 2007 has been the addition of length-based selectivity. Recent stock assessments have noted problems fitting to size frequency data (e.g. bigeye assessment). A comparative analysis (Hoyle and Langley 2007) using Stock Synthesis (Methot 2007) suggested that size-based selectivity could give a better fit to the data.

Need

Fishery selectivity is in many cases a size-based process. Fish behavior, and hence vulnerability to fishing, may change with size. Some gear types are also inherently size-selective. To date, MFCL has defined selectivity by fishery in terms of age. It has had a selectivity option sometimes referred to as ‘length-based selectivity’, but this implementation was limited in scope – it constrained selectivity of age classes to be similar, to the extent that their length distributions were similar. The expected distribution of catch at length was still calculated by multiplying catch at age by the distribution of length at age.

Age-based selectivity tends to be an approximation to real-world fishery selectivity, because of the implicit assumption that all fish of the same age are selected at the same rate. It will give different results from length-based selectivity, to the extent that the observed distribution of catch at size includes some of the lengths within an age class, but not others. The importance of these effects is greater in some fisheries than others.

The bigeye stock assessment (Langley *et al.* 2008) may have been affected by the way the selectivity is modeled in the Chinese/Chinese Taipei longline fisheries. The size data in these fisheries appears to be driving the observed increasing recruitment estimates. Given the few fish in the older age classes, the model has difficulty matching the number of large fish observed in these fisheries, and progressively increases recruitment. Omitting size frequency data from these fisheries resulted in a more stable recruitment trajectory and different stock status. A version of the bigeye stock assessment in Stock Synthesis version 3 was developed, and when run with length-based selectivity the resulting recruitment trajectory was more stable.

The growth curve in the albacore stock assessment (Hoyle *et al.* 2008) also appears to be affected by problems fitting using age-based selectivity. The stock assessment estimated a growth curve with a narrow distribution of length at age. In fact, the standard deviation of length at age shrank with increasing age, which is unrealistic. The factors driving this narrowing of length at age were thought to be a combination of the increasing average size observed in the catch and the need to fit this increase with age-based selectivity. It was suspected that a narrow distribution of length at age might permit the model to shift the distribution of sizes in the expected catch by shifting the age distribution in the catch.

In a further test for small-fish fisheries based on trolling and drift-netting, age-based selectivity in MFCL was compared with length-based selectivity implemented in Stock Synthesis, in the albacore stock assessment. Length-based selectivity appeared to fit these data better.

Methods

Equations used to implement length-based selectivity.

i indexes length intervals

j indexes age classes

f indexes fisheries

t indexes time periods

q_{ij} proportion of age class j fish in length interval i at time t

α_{fi} length-dependent component of instantaneous fishing mortality for fishery f

β_{fj} age-dependent component of instantaneous fishing mortality for fishery f

λ_{ft} determines the level of fishing mortality for fishery f at time period t .

F_{fijt} instantaneous fishing mortality for fishery by age and length

Z_{ijt} instantaneous total mortality for fishery by age and length

F_{fjt} instantaneous fishing mortality for fishery by age

N_{ijt} number of fish in the population of age class j and length interval i .

N_{jt} number of fish in the population of age class j

C_{fijt} number of fish in the catch of fishery f of age class j and length interval i .

C_{fjt} number of fish in the catch of fishery f of age class j

The instantaneous fishing mortality satisfies the relationship

$$F_{fijt} = \lambda_{ft} \beta_{fj} \alpha_{fi}$$

and if the SS parameterization is assumed then

$$C_{fijt} = F_{fijt} N_{ijt} \quad (A1)$$

and since

$$N_{ijt} = q_{ijt} N_{jt}$$

A1 can be written as

$$C_{fijt} = F_{fijt} q_{ijt} N_{jt} \quad (A2)$$

and summing over length intervals yields

$$C_{fjt} = \left(\sum_i F_{fijt} q_{ijt} \right) N_{jt} \quad (A3)$$

So that with the SS parameterization since

$$C_{fjt} = F_{fjt} N_{jt} \quad (A4)$$

it follows that

$$F_{fjt} = \sum_i F_{fijt} q_{ijt} \quad (A5)$$

For other parameterizations this will not be the case, i.e. A5 will not be true, so that for the Baranov

$$C_{fijt} = \frac{F_{fijt}}{Z_{ijt}} (1 - \exp(-Z_{ijt})) q_{ijt} N_{jt} \quad (A6)$$

and summing over i yields

$$C_{fjt} = \left(\sum_i \frac{F_{fijt}}{Z_{ijt}} (1 - \exp(-Z_{ijt})) q_{ijt} \right) N_{jt} \quad (A7)$$

so that there is no simple relationship between F_{fijt} and F_{fjt} in this case.

Assuming no length-based component in F ,

$$C_{fjt} = \frac{F_{fjt}}{Z_{jt}} (1 - \exp(-Z_{jt})) N_{jt}$$

(A8)

where fishing mortality at age is a function of length-based selectivity, as follows.

$$F_{fjt} = \lambda_{ft} \int_i \alpha_{fi} q_{ijt}$$

(A9)

Then, given p_{fjt} which is catch C_{fjt} normalized across ages, observed distribution of length in the catch LF_{fit} is calculated by renormalizing across lengths

$$LF_{fit} = p_{fjt} \frac{\alpha_{fi} q_{ijt}}{\sum_i \alpha_{fi} q_{ijt}}$$

(A10)

Parallelizing the hessian matrix and the variance-covariance matrix for dependent variables

Given the number of parameters calculated by MFCL, calculating the Hessian matrix has been very time consuming, taking as long as 2 days for some of the larger models. However, this time can be reduced by calculating the Hessian in multiple parts on different computers – essentially parallelizing the process. MFCL was changed so that it calculates only part of the Hessian, as determined by flag settings. The same approach was applied to the variance-covariance matrix for dependent variables.

Method

The Hessian matrix is calculated one section at a time using separate MFCL runs. For each run, the start and end parameters are defined with the values of parest flags 223 and 224. Similarly, the variance-covariance matrix for dependent variables is calculated one section at a time, with start and end defined by values of parest flags 229 and 230.

The full Hessian matrix must be reconstructed from its parts before it can be used. Each part is a binary file which begins with three integers: $npar$, $start$, and end , where $npar$ is the number of estimated parameters in the model, and the parameters $start$ to end are estimated in this section of the Hessian. These are followed by $npar \cdot (end - start + 1)$ doubles, which are the elements of the Hessian matrix.

The following R code can be used to rebuild the Hessian matrix. A similar approach is used for the variance-covariance matrix for dependent variables.

```
setwd(dir)
fnames <- c("test.hes_1_40", "test.hes_41_80", "test.hes_81_120", "test.hes_121_160")

file1 <- fnames[1]
outfile <- paste(c(dir, "lensel_split.hes"), collapse="")
# open the first file
con1r <- file(file1, open="rb") # opens binary file for reading
con2w <- file(outfile, open="wb") # opens binary file for writing
```

```

close(con2w)
con2w <- file(outfile, open="ab") # opens binary file for appending

# read the first file
size<- readBin(con1r, "integer", n = 3)
npar <- size[1]
nrows <- size[3] - size[2] + 1

a <- matrix(nrow=nrows,ncol=npar)
proW <- 0
writeBin(npar, con2w)
for (i in 1:nrows)
  {
  proW <- proW+1
  a[i,] <- readBin(con1r, "double", n = npar)
  writeBin(a[i,],con2w)
  }
close(con1r)

for (ff in 2:length(fnames))
{
  con <- file(fnames[ff], open="rb") # opens binary file for reading
  s2 <-readBin(con, "integer", n = 3)
  a <- matrix(nrow=nrows,ncol=npar)
  for (i in 1:min(c(nrows,npar-nrows*(ff-1))))
  {
  proW <- proW+1
  tmp <- readBin(con, "double", n = npar)
  a[i,] <- tmp
  writeBin(a[i,],con2w)
  }
  close(con)
}
close(con2w)

```

Projection with a mixture of catch and effort

Multifan-CL can predict future population levels and catches by projecting the population forward, using either expected catch or expected effort to constrain the catch removed. However, it has not previously been able to project using a mixture of catch and effort. Some proposed management measures place catch limits on some fisheries and effort limits on others, and MFCL has been changed in order to model these scenarios.

Time-varying effort deviate weights (sd on CPUE)

MFCL's approach for modeling uncertainty in CPUE has been enhanced to include an option to weight CPUE temporally according to values input in the frq file. This will permit the inclusion of variances estimated during CPUE standardization.

The data file is changed to version 6, and an additional column is added, to the right of the effort column.

This effort weight column is multiplied by the standard effort weight for that fishery, which is entered as fish flag 13, as before.

No associated changes were required to the output formats.

Other enhancements and bug fixes

Missing effort problem

Missing catch or missing effort information is indicated in MFCL by the code -1 in the .frq file. Where the standard catch equation is being used, MFCL estimates missing catch values from the effort, and does not produce a catch deviate. When effort is missing and the standard catch equation is being used, MFCL has until now interpolated a value from other effort values for that fishery, and down-weighted the penalty due to the effort deviate. However, problems have arisen in cases where the effort deviate has been so large as to hit the boundary. With the effort deviate at the boundary, the model could not estimate the appropriate catch, resulting in a large catch deviate. Large catch deviates reduce the model fit and so can significantly bias the parameter estimates. This was a serious problem for the 2008 albacore assessment.

MFCL was changed to resolve this problem. For observations with catch but missing effort, the catch conditioned approach is applied. This means that the catch is assumed to be known, and no effort deviate is estimated. As a result, the correct catch is taken out, but no catch deviate or effort deviate penalties are added to the likelihood.

Impact analysis

The ‘no fishing’ analysis was not working when steepness (e.g. the stock recruitment relationship) was taken into account, i.e. with age flag 171 turned on. An error was reported during impact analysis, and recruitment values for all but $t=1$ were set to low values. As a result, impact analyses had to be run with the flag switched off, so they did not adjust recruitment for the higher spawning biomass of unfished populations.

The reason for this bug was discovered and the code changed, so the stock recruitment relationship can now be taken into account.

Application of length-based selectivity

Both the standard and the length-based selectivity models were applied to the albacore and bigeye tuna data sets, as used in the 2008 assessments (Hoyle *et al.* 2008; Langley *et al.* 2008).

Table 1: Likelihood components for the age-selectivity and length-selectivity models, as applied to WCPO albacore tuna.

Likelihood component	Age-based selectivity	Length-based selectivity
Number of active parameters	5255	5255
Effort deviation penalties	2227.88	2218.0
Catchability deviation penalties	245.5	233.2
Other penalties	395.2	391.1
Length data	-349647.3	-349809.4
Tagging data	514.6	491.4
Total catch data	196.9	192.9
TOTAL	- 346,425.8	- 346,630.8

Table 1 provides a comparison of the likelihood components obtained from applying the two models to albacore tuna.

A comparison of the main results of the two models is shown in Figures 1–3. The growth curves are substantially different between the two models, with much broader distribution of length at age, and slightly larger asymptotic mean length.

Table 2: Likelihood components for bigeye tuna models with a) age-selectivity, b) age selectivity applied to all fisheries except the Chinese/Chinese-Taipei longline fisheries, and c) length-selectivity applied to all fisheries.⁴

Likelihood component	Age-based selectivity on all fisheries	Length-based selectivity on CH/TW LL	Length-based selectivity on all fisheries
Number of active parameters			
Effort deviation penalties	6515.8	6513.3	6496.1
Catchability deviation penalties	7090.4	7093.1	7089.3
Other penalties			
Length data	-403624.1	-403681.4	-403195.5
Weight data	-852170.5	-852156.4	-851974.1
Tagging data	1525.2	1526.4	1533.7
Total catch data	637.6	635.6	644.1
TOTAL	-1246467.7	-1246510.5	-1245827.1

Table 2 illustrates the effects on likelihoods of using length-based selectivity in the bigeye stock assessment. All models were run from the final par file of the 2008 stock assessment. Applying length-based selectivity to the Chinese and Taiwanese longline fisheries improved the fit to the length frequency data but not to the weight frequency data. Overall, the likelihood improved by 43 units. The estimated variability of length at age in the growth curve increased, though to a lesser extent than for albacore. Applying length-based selectivity to all fisheries resulted in a much worse fit overall, by 640 units. In this case there was a reduced standard deviation of length at age in the growth curve, and larger asymptotic length.

⁴ These runs were undertaken with a bug in the code for length-specific selectivity, which has now been fixed.

These were unexpected results that require further analysis. A better solution may be found by starting from the bet.ini file, rather than from the converged age-based selectivity fit.

Future work

The future work plan for MFCL is outlined in Table 3.

Discussion

A number of changes have been made to MFCL during 2008-2009. Although a number of model shortcomings were found and rectified, they did not change the management implications of model results in any significant way. However, considerable further work is required to comprehensively test all changes to the model, and to update all the changes to the manual. One very important task for 2009-2010 will be to develop an automated model testing routine.

The two other major development areas for 2008-2009 will be to increase the flexibility of tag modeling, as the Pacific Tuna Tagging Program results become available, and to improve model diagnostics, so that problems in model fit can be identified and resolved.

We also see a strong need to develop 'extension' tools that will allow managers and stakeholders to gain a better understanding of the model results, and of the results of management options analyses. We see this requiring the development of a purpose-built software tool, which will work as an add-in to MFCL.

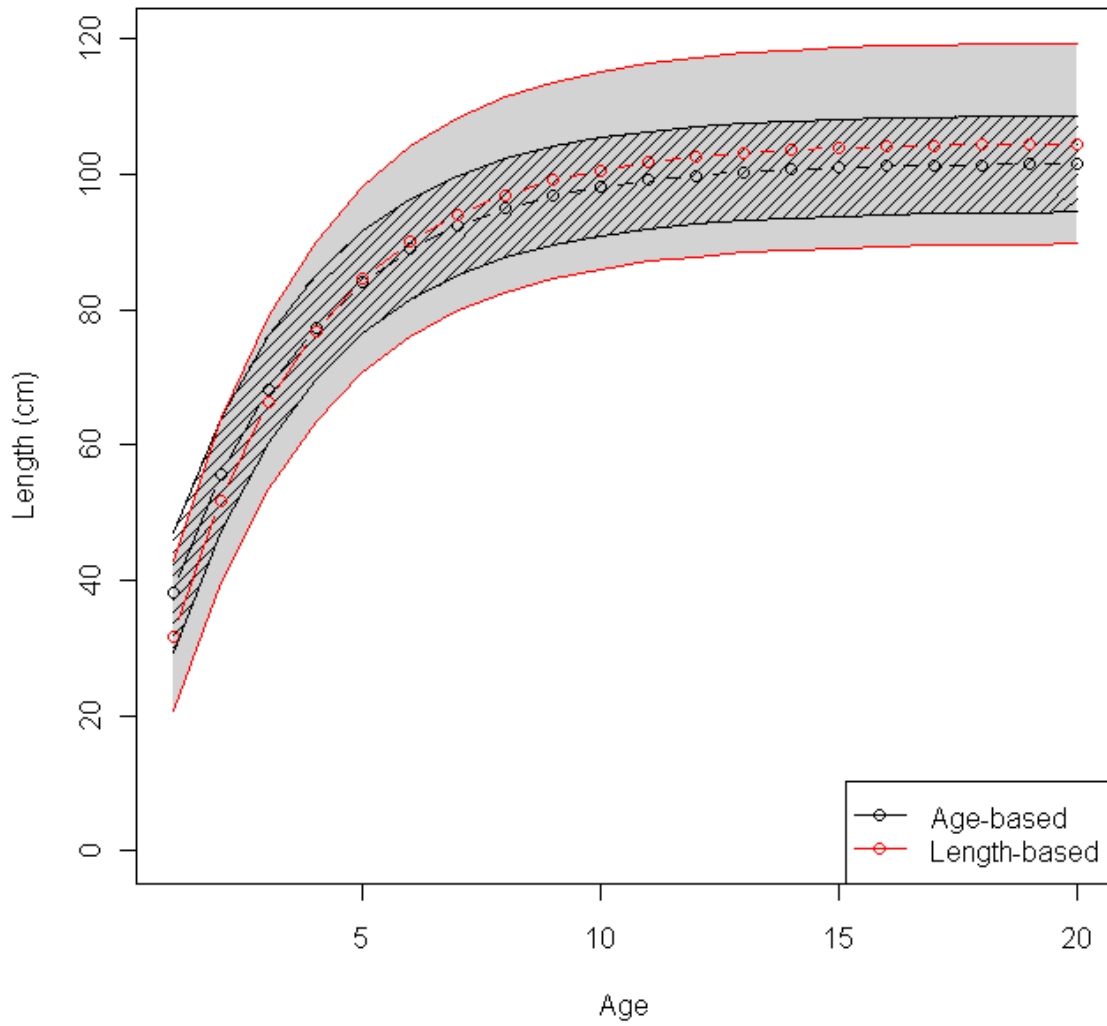


Figure 1: Growth curves for south Pacific albacore estimated using age-based and length-based selectivity. The value of K is fixed, but the model estimates lengths at age 1 and 20, and the standard deviation of length at age.

Table 3: 2008-2009 work plan for MFCL, including work completed and suggested future enhancements.

ID	Item	Description / Comment	Priority	Comments	Status
Bugs					
	No fishing analysis	The no-fishing analysis does not work if steepness (e.g. the SRR) is taken into account. When af_171 is turned on, an error is reported during impact analysis, and recruitments for all but t=1 are set to low values. See the following URL for example with attached files.	1	Bug report Nov 20. See emails.	Works. Simon to do more testing
5	Catches in projections	Previously there have been problems with the predicted catches (longline) from the projection period. Unsure if this has been fixed or if there are other catch / projection problems.	1	Issue related to running out of fish may be outstanding. John to check current status.	
12 & 27	Hessian problems	<ol style="list-style-type: none"> 1. Errors in xinit.rpt. Has this been fixed already? 2. Currently doesn't seem to put Hessian back together in a usable way when it is parallelised using Condor. Simon to work on with Dave 3. Dependent variable Hessian needs to be parallelized too. Also needs pruning. Simon to make a list and distribute. 	1	An example model should be developed for Dave to work with.	<ol style="list-style-type: none"> 1. Fixed 2. Works 3. In progress
15	MSY in projection period	Problem with estimating MSY and related in the projection period. Has this been fixed already?	1	Fixed	Works
28	Missing effort	When effort is missing, an effort value is interpolated between actual effort estimates in the time series. Sometimes this value is such an outlier (given the catch) that effort devs hit the boundary. Also, multiple missing efforts can result in bias. Suggestions include calculating an effort value by solving the equations for the total catch (as in catch conditioned model).	1	Done.	Works. Simon to do more testing

New features					
14	Length-specific selectivity	Allowing selectivity to be defined as length-specific rather than age-specific	1	The main 2009 workshop topic.	Works. Simon to test more.
19	Environm. recruitment correlates	Allow recruitment deviates in each region to be correlated with an environmental variable. See the following file for a discussion of recruitment modelling options: I:\assessments\Pop dy modeling\MFCL\Recruitment.doc	3		
11	Parallelize var-covar for dep vars	Parallelize dependent variable variance-covariance matrix, as has been done for estimated parameters. But note the bug in 27 above. Need to fix this first.	3		
20	Selectivity covariates	Implement a scheme to allow time-series variation in selectivity, both as a random effect and correlated with an environmental or other index (e.g. mean latitude fished)	4		
21	Individual movement penalty wts	Allow individually-specified penalty weights (priors) for movement coefficients. Probably best done in 2010 in conjunction with 23 and 24 when the new tagging data are incorporated.	3		
22	Seasonal selectivity	Implement a scheme to estimate seasonal variability in selectivity coefficients	3		
23	Indep. rr by tag release group	Implement a scheme to allow independent tag reporting rates for different groups of tag releases. Probably best done in 2010 in conjunction with 21 and 24 when the new tagging data is incorporated.	2	Current kludge is to re-scale recaps to account for reporting rate. This gets the mean right but likelihood wrong.	
24	Time-series variation in movement	Implement a scheme to allow time-series variation in movement coefficients correlated with an environmental index. Probably best done in 2010 in conjunction with 21 and 23 when the new	4		

	coefficients	tagging data is incorporated.			
25	Uncertainty in projected biomass	Implement a scheme to compute uncertainty in projected population biomass by propagating uncertainty in recruitment and effort deviations in the projection period. This must be done in such a way that the parameter estimates and likelihoods for the time period supported by data are unaffected (e.g. Maunder, Harley, and Hampton paper in ICESJMS).	2	Dave had previously drafted notes on how to do this correctly - need to dig these up.	
26	Estimate biological parameters at length	Maturity, fecundity, spawning fraction are typically length-specific properties (at least the data on them is) and so they are converted to age based on the initial growth curve. As soon as a growth curve is estimated there is an inconsistency.	3		
	Projection-related analysis capabilities	Being able to do projections based on F (all fisheries) and for effort and catch for different fisheries (e.g. evaluate effort based limits for purse seine and catch based limits for longline). Also to keep consistent with the yield-based approaches we need to be able to use an average catchability for the future (if we can't already). Also see 25 above.	1	Nick to document notes from FFA Bio-economic workshop projections (with Adam). Use YFT projections as an example model for generating output. Run tests for either effort- or catch-specified projections.	In progress. Nick follow up with Dave.
	Yield-related analysis capabilities	Estimate indicative yields by fishery for both MSY and Equilibrium yield. Also, the current MSY calculations estimate a single F-scalar across all fisheries. It would be useful to estimate region-specific scalars. Anything more than that would lead to estimation difficulties.	2	Region-specific yield calculations are already an option in MFCL. (See section in code called "Daves_folly")	
	Hyper-stability	Implement fishery-specific hyperstability, as a relationship between vulnerable biomass and catchability	3		
	Projections	Add projection period into par file automatically. Could be done in R. 1. Write read.par & write.par. 2. ID all fields in par obj. 3. Write functions to modify par object	3	New task13/1	Drafted read.par +write.par

Output					
13+	Report effort penalties .	A new output file should be created that provides all values for penalties and likelihood components. For diagnostic purposes it would be good to have it for each phase. Simon to put together a potential file structure.	1	Can be done "in-house" and doesn't require Dave's immediate attention	Simon to do.
Other					
4	Testing routine	Set up an automated procedure for testing MFCL executables before use. 1. Design a set of doital files that test the full range of important MFCL options. This would initially be the current doital's for the YFT SKJ BET and ALB assessments. 2. Store the output files the above runs with a stable version of MFCL in a test directory. 3. Write an R script to produce figures that compare outputs between the 'good' runs and the new runs. 4. Write an R script to automate the whole procedure including (as an option) submitting all the runs to condor. Also cut down an assessment to make it work faster, for testing the Hessian.	2	Simon to start. Set up "cut-down" models (say 1987 init-year) for quick runs and testing, one for each species. Follow John's approach for modifying the *.par file according to a specified 00.par file. Enables rapid runs for checking code operation.	Started but not complete.

Table 4: R functions written for the library R4MFCL.

<u>Read and write files</u>		
read.frq.r	read.ini.r	read.par.r
read.rep.r	read.tag.r	read.var.r
write.frq.r	write.ini.r	write.par.r
write.tag.r	get.outcomes.r	
<u>Change inputs</u>		
Doitall		
add.flag.r	change.fishflag.r	change.flag.r
rename.fisheries.doitall.r	steepness.doit.r	timesplit.doitall.r
rm_fisheries.doitall.r	seas.flag.r	rename.fishery.grps.doitall.r
Frq file		
seas.frq.r	sort.frq.r	rename.fisheries.frq.r
start_year.frq.r	timesplit.frq.r	pack.fisheries.frq.r
merge.frq.r	retro.frq.r	rm_fisheries.frq.r
frq.change.nint.r	NZtrollglm.r	pagocatch.r
clean.lfdata.r		
Tag file		
seas.tag.r	timesplit.tag.r	merge.tag.r
rm_fisheries.tag.r	retro.tag.r	rename.fisheries.tag.r
Utility	datfromstr.r	varfromstr.r
<u>Set up runs</u>		
condor.go.r	effortcreep.r	initial_clean_2008.r
run.profile.r		
<u>Plots</u>		
plot.base.comparison.r	Plot.biomass.combined.r	Plot.biomass.r
Plot.F.time.r	Plot.fishery.impact.r	Plot.Kobe.r
Plot.Kobe.template.r	Plot.nofishing.combined.r	Plot.nofishing.r
Plot.recruitment.combined.r	Plot.recruitment.r	

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3. **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. Secretariat of the Pacific Community No. WCPFC-SC3, SA WP-1.**
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