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

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Update of recent developments in MULTIFAN-CL and related software for stock assessment

Nick Davies, Simon Hoyle, Dave Fournier, Pierre Kleiber, John Hampton, Fabrice Bouyé, and Shelton Harley.

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 Ltd for application to south Pacific albacore tuna (Fournier *et al.* 1998).

MFCL is typically fitted to total catch, catch rate, size-frequency and tagging data stratified by fishery, region and time period. Recent tropical tuna assessments (e.g. Harley *et al.* 2010; Hoyle *et al.* 2010) encompass a time period of 1952 or 1972 to 2009 in quarterly time steps, and model multiple separate fisheries occurring in 3 to 6 spatial regions. The main parameters estimated by the model include initial numbers-at-age in each region (usually 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), catch (unless using the catch-conditioned catch equation), 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 penalized likelihood distributions for various parameters.

Each year the MFCL development team works to improve the model to accommodate changes in understanding of the fishery, to fix software errors, and to improve model features and usability. This document records changes made since August 2009 to the model and other components of the MFCL project, and updates the report for the previous period, 2008-09, (Hoyle *et al.* 2009).

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 J 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

The project management website based on the open source GForge software established in 2008-09 has been maintained and provides the nucleus for source code management and versioning. The repository for MFCL source code development is held on the website and uses the open source software SVN (http://tortoisesvn.net/). Code developments are consecutively committed to the repository while tracing the different versions chronologically. The repository and overall development are coordinated via the GForge website http://gforge2.spc.int/, that is administered by Fabrice Bouye fabriceb@spc.int.

Problems with MFCL operation or compilation have been reported to the project management website so as to maintain a list of desired enhancements, and to allocate tasks among the project team. Some of the tasks identified during the previous reporting period (2008-09) have been addressed in the current period in the way of model developments. A main trunk exists for the MFCL source code, and a development branch has been created to hold these recent developments to the source currently being tested. A formal testing procedure has been designed before source code is committed from the development branch to the trunk (Appendix A), and a manual has been drafted for standardizing the source code compilation procedure, and posting of executables.

A version of the source code for ADMB (http://admb-project.org/) has been added to the project management website in a separate repository. Minor modifications were required to the ADMB source (currently held in a development branch) to facilitate the recent MFCL developments.

Tool development

1. The R scripts for working with MFCL, developed and released on the internet (http://code.google.com/p/r4mfcl/) have been updated to adapt to the recent MFCL file formats. 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 Hoyle *et al.* (2009) for a list of these R scripts. Further development is planned to consolidate new features created as part of the 2010 stock assessments to the utilities package. One such feature is R script that creates input files (*.frq and *.par) required for undertaking deterministic or stochastic population projections, and also script for collating simulation projection outputs for desired quantities of interest, e.g. biomass, relative to reference points.

2. A task has been noted to update the MFCL viewer with new diagnostic plots associated with the new feature for tag release group-specific recapture reporting rates (see below).

3. The Condor (www.condor.wisc.edu) facility has been used routinely for managing multiple MFCL model runs on a grid currently numbering over 55 processors. This grid enables intensive model runs for stock assessments, structural sensitivity

analyses, and management strategy evaluation. The Condor version was recently updated.

MFCL manual

Drafts of new sections to the manual are in preparation that document the recent developments for stochastic population projections and tag release group-specific reporting rates (Appendix B). It is proposed that these be added to the manual before the next MFCL workshop (January 2011).

New MFCL features

Stochastic population projections

The most significant change to MFCL since August 2009 has been the facility to undertake model simulation runs that include projections into the future with stochastic recruitments.

Rationale

The concept of risk associated with a reference point, e.g. B_{MSY}, is gaining importance with fisheries managers, since it takes account of model uncertainty and natural variability when interpreting population model estimates for the purpose of management. A risk-based limit reference point may therefore be defined, for example, as: a 10% probability of the stock size being less than that which supports B_{MSY}. Risk analysis may be used to evaluate the performance on alternative management strategies against the threshold 10% probability level. Typically, this analysis would incorporate the main sources of uncertainty, such as statistical uncertainty, model structural assumptions, and natural variability, such as recruitment variation. Incorporating this stochasticity in model projections creates variability in future population states from which estimates of risk relative to a particular reference point can be calculated.

Stochasticity in future recruitments is a dominant source of natural variability in fish populations and largely determines temporal fluctuations in biomass for some tuna species, e.g., skipjack (Hoyle *et al.* 2010). Including this feature in simulation projections using MFCL was therefore an important development, which ensures the stock assessment advice can be delivered in a contemporary format, i.e., with respect to threshold levels of risk.

Methods

Details of the method for setting up input files for undertaking MFCL projections and incorporating stochastic recruitments in projections is provided in Appendix B, and only a brief outline is provided here of the method used to generate future recruitments for projections and test results of this feature.

MFCL currently incorporates uncertainty in the initial population state, future recruitment and other model parameters into the projection by sampling the parameters from a multi-variate probability distribution (i.e. the variance-covariance matrix from the likelihood-based analysis). In MFCL statistical uncertainty for model parameters is calculated by employing the usual second order approximation to the mode of the posterior distribution (Fournier *et al.* 1998), and confidence intervals for derived variables are calculated by the inverse Hessian –

Delta method. In this way, the distribution of estimated historical recruitments is derived using the following MFCL commands:

./mfclo32 example.frq example.par example_out.par -switch 1 1 145 1

- Produces the Hessian report file "bet.hes"

./mfclo32 example.frq ttt ttt -test.out -switch 2 1 145 7 2 20 $$$

- run the Hessian calculation for the stdev of the recruitments

./mfclo32 example.frq ttt ttt -test2.out -switch 2 -999 55 0 1 145 8

- produces report file "checkhess.rpt"

where "$$$" is the number of simulations. These commands generate the necessary files for undertaking the projections, one of which is "simulated_numbers_at_age" that contains the stochastic recruitments for each simulation and for every time period in the projections. The next command undertakes a single model evaluation for each simulation and draws from the respective rows of simulation recruitments:

./mfclo32 example.frq proj.par test3.par -test3.out -switch 4 1 1 1 -999 55 0 2 20 $$$ 1 145 0

The primary output file from the simulations is "projected_numbers_at_age" holding population numbers by age (across), year (down) and region, for both historical years and projected years. R script has been developed that collates this output, and other parameters, to calculate predicted biomass relative to reference points.

Testing

The operation of the new feature for stochastic recruitments was tested using a "cut-down" bigeye tuna population model (years 1990-2008) for which the distributions of historical and future log-recruitments were compared (Table 1).

Table 1: Comparison of model estimated recruitments versus stochastic future recruitments over 200 simulations.

	Estimated			Projection	
	Mean	cv		Mean	cv
Reg_1	13.65	0.0993		12.86	0.1175
Reg_2	13.26	0.0974		12.88	0.1174
Reg_3	13.49	0.0905		12.86	0.1168
Reg_4	13.95	0.0617		12.86	0.1167
Reg_5	11.39	0.0775		12.89	0.1161
Reg_6	11.48	0.0713		12.84	0.1166

The estimated average recruitments (historical) appear to be region-specific such that the variance within a region is lower than that for projected recruitments. However, the mean and variance of model estimated recruitments among all regions combined (12.87, 0.1167) are the same as for projection recruitments.

Tag release group-specific reporting rates

The tagging approach used in programmes undertaken in the western and central Pacific Ocean entails the placement of externally visible tags. Obtaining observations of recaptured tagged fish requires the <u>voluntary</u> reporting of a tag by capture or processing staff within the tuna fishing industry. Incentives, such as monetary rewards, are offered to encourage the reporting of information relating to a recaptured fish. Given the voluntary basis for obtaining these observations, a probability of less than 1 is most likely and its value depends upon factors relating to the tag release group and within the fish processing sector. These factors may include the visibility characteristics of tags, processing methods that entail individual fish identification, and most importantly, the goodwill of industry staff. Consequently, the probability of a recapture being reported may be specific to each tag release group and the factors surrounding it, such as the physical characteristics of the tag employed (colour, printed information), the perceived value of the incentive (reward), and the extent of publicity associated with the tag release group. These factors are determined by the agency undertaking the tagging experiment. It is, therefore, advantageous to the analysis of tag-recapture data to estimate the probability of a recaptured tagged fish being reported, specific to each tag release group. This parameter is termed the tag release group-specific reporting rate.

Method

Previously in MULTIFAN-CL tag recapture reporting rates were assumed to be constant within a fishery group, i.e., independent of a release group. The new development uses the existing grouping of tags into tag release groups, which represent the tags released by quarter x region x tagging program stratum. This permits individual reporting rate parameters to be estimated for each release group and for each fishery group, i.e., all possible combinations of release groups and fishery groups, for example 5 release groups x 20 fisheries produces 100 parameters. Should this entail too many parameters to be estimated, the facility exists to share parameters among release groups and fisheries that have similarities in the factors determining reporting rates, such as publicity, liaison and cooperation.

The MFCL formulation for calculating expected recaptures remains the same except that recapture reporting rates now include the added subscripted dimension of tag release group. The *.par file now includes the following additional parameters:

```
-  # tag flags
-  # tag fish rep
-  # tag fish rep group flags
-  # tag_fish_rep active flags
-  # tag_fish_rep target
-  # tag_fish_rep penalty
```

The `tag_fish_rep target` and `tag_fish_rep penalty` parameters specify the mean and variance of the priors associated with the tag release group-specific reporting rates being estimated.

Other enhancements and bug fixes

A listing of the current and proposed tasks in the project is presented in Table 2. The main developments against tasks 23 and 25 completed to date have been discussed above, and other lesser enhancements and fixes are briefly mentioned.

Model testing

A "cut-down" bigeye tuna model (cutbet) has been prepared with a reduced time period (1990-2008) and fewer fisheries. This facilitates rapid model evaluations and makes more efficient development of source code, debugging and testing. It was used in the development of the stochastic recruitments feature, and it is proposed to use it for building the testing procedure outlined in task 4 (Table 2).

Projections for management options project

As part of the methodology for undertaking stochastic projections using the bigeye 2009 stock assessment model (Davies & Harley 2010), R script was drafted to prepare *.frq and *.par files as input for MFCL model evaluations that include projections. This entails adding fishery data for the projection period, and formatting the *.par file according to the 00.par generated from the projection *.frq file. This script will have direct utility for automating the production of input files for projections under alternative management options for the **TUMAS** project.

Application of new features

Stochastic projections in MFCL simulations

The new feature for implementing stochastic recruitments was used in an evaluation of the consequences of adopting particular biological limit-based reference points (BLRPs) based on stochastic projections using the bigeye 2009 stock assessment model (Davies & Harley 2010). Using the procedure described in Appendix B, a set of 200 simulation recruitments was produced for a 10 year (40 time step) projection period. For a given (status quo) level of fishing effort in the future, 200 simulation projections were undertaken. The probability that the BLRPs were exceeded was based on the number of 200 simulations where the biomass in any one quarter of the final three years of the projections was below the BLRP. Fishing effort was then scaled to a value that meets the criteria for the BLRP. The determination of the effort scalar was determined using a numerical hill climb algorithm.

A representation of the stochasticity in projected recruitments is shown in Figure 1 for 5 of the 200 simulations. Note that the first year of the projection period was 2009. Variation in projection adult biomass is shown in Figure 2 for four separate evaluations (200 simulations in each), illustrating the range in this quantity attributable to recruitment variability.

Figure 1: Annual recruitment from five of the 200 stochastic projections undertaken for bigeye tuna. Quarterly recruitment was used in the projections, (taken from Davies & Harley 2010).
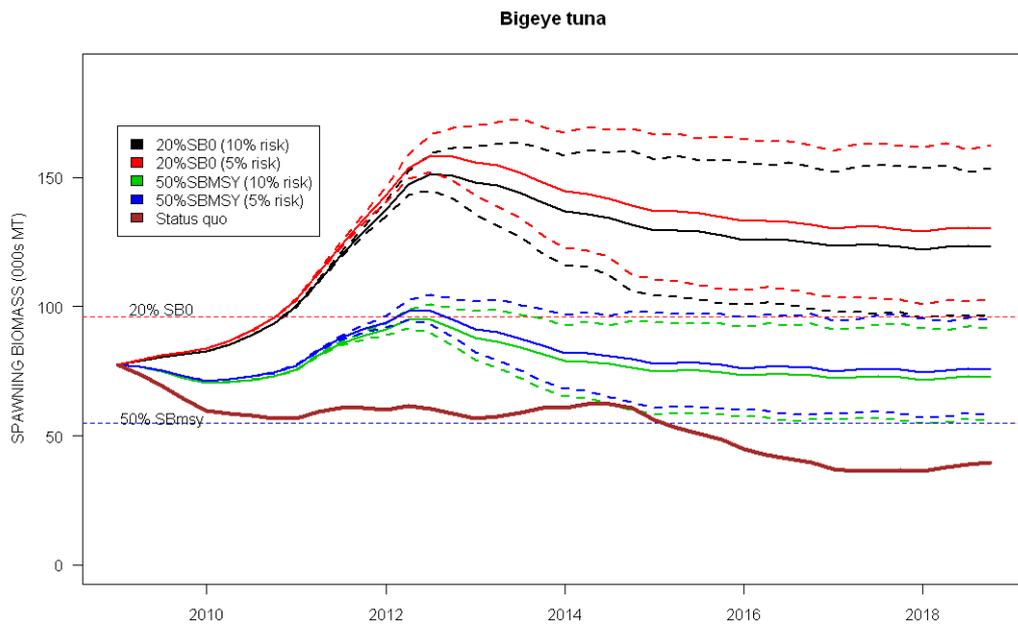

Figure 2: Mean adult biomass (solid lines) and 90th percentiles (dashed line) for the stochastic projections for four BLRP / risk level combinations. The dark brown line presents the deterministic projection adult biomass obtained for status quo levels of effort, (taken from Davies & Harley 2010).

<u>Tag release group-specific reporting rates</u>

Approaches for constant and tag release group-specific reporting rates were applied in the skipjack 2010 stock assessment (Hoyle *et al.* 2010). The following is an extract from the assessment report explaining how this feature was applied.

"Tags in MULTIFAN-CL are grouped into tag release groups, which represent the tags released by quarter x region x tagging program stratum. The new approach permits individual reporting rate parameters to be estimated for each release group for each fishery. This, however, would require too many parameters to be estimated, so parameters were shared among release groups and fisheries, as follows:

    a. Reporting rates were grouped for all Japanese fisheries, as in previous assessments. For these fisheries, separate reporting rates were estimated for a) Japanese tagging programs, b) SSAP and RTTP tagging programs, and c) the PTTP tagging program.

    b. All equatorial purse seine fisheries shared reporting rates, and separate parameters were estimated for the SSAP, RTTP, PTTP, and Japanese tagging programs.

    c. The Papua New Guinea, Solomon Islands, and Fiji Islands pole and line fisheries, and the Philippines and Indonesia domestic fisheries each had their own reporting rate parameters. The Papua New Guinea pole and line fishery had one parameter for SPC releases and one for Japanese releases, as did the Fiji Islands pole and line fishery. The Solomon Islands pole and line fishery had a separate parameter for each tagging program, as did the Philippines and Indonesian domestic fisheries.

While the model has the capacity to estimate tag-reporting rates, we used a penalised likelihood approach to assign prior distributions (similar to Bayesian priors) to the release-group and fishery-specific reporting rates.

Relatively informative priors were provided for reporting rates for the RTTP (and, where appropriate, PTTP) purse seine fisheries, as independent estimates of reporting rates for these fisheries were available from tag-seeding experiments and other information (Hampton 1997). The proportions of tag returns that were provided with sufficient information to allow them to be classified to the various fisheries in the model were also incorporated into the reporting rate priors. For the various Japanese pole-and-line fisheries, we have no auxiliary information with which to estimate reporting rates, so relatively uninformative priors were used for these fisheries – the reporting rates were essentially independently estimated by the model. Tag reporting rates from all tag groups were assumed to be constant through time." (Hoyle *et al.* 2010).

Variation in the mean reporting rates with respect to release group was marked as was the estimated precision of each (Figure 3, taken from Hoyle *et al.* 2010). Relaxing the assumption for constant reporting rates within a fishery group had a visibly marked impact on model absolute biomass estimates (Figure 4, taken from Hoyle *et al.* 2010).
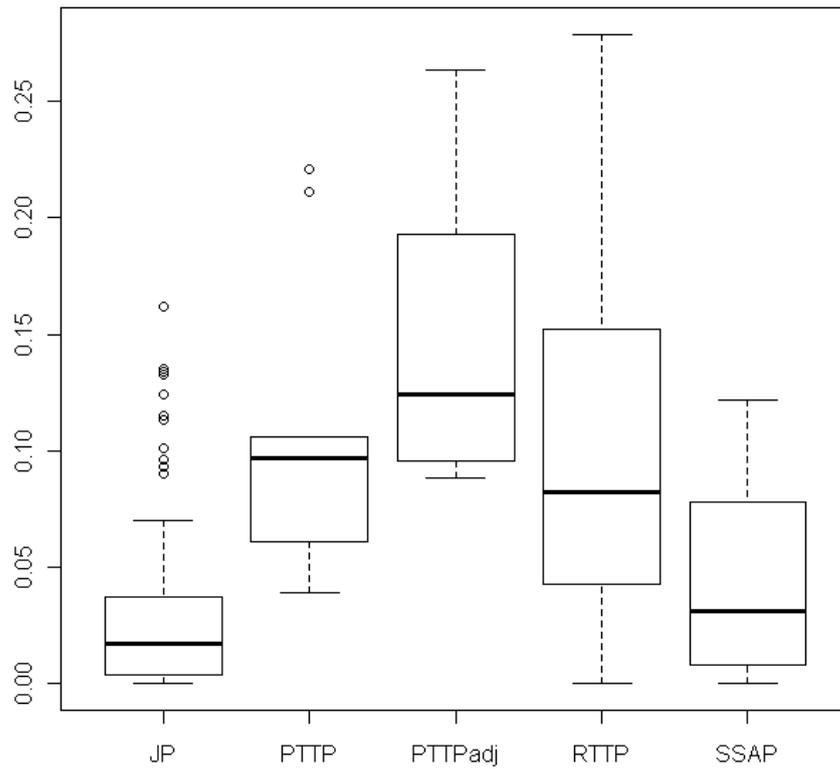
Figure 3: Boxplot of return rates per release group, by tagging program. The tagging program 'PTTPadj' represents the PTTP tagging program with a reduced number of releases, in proportion to the reduced number of recaptures (i.e. fewer than actually recaptured) in the stock assessment dataset (taken from Hoyle *et al.* 2010).
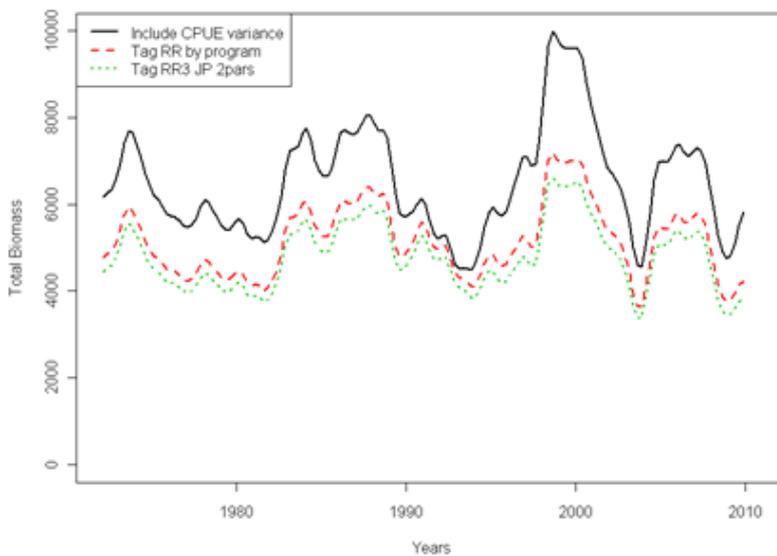

Figure 4: Total skipjack biomass for a model for which recapture reporting rates were assumed constant within each fishery group (**Include CPUE variance**), and total biomass for models that relax this assumption to be specific to each tag release group (**Tag RR by program**, **Tag RR3 JP 2pars**), (taken from Hoyle *et al.* 2010).

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Future work

The future work plan for MFCL is outlined in Table 2.

Discussion

A number of changes have been made to MFCL during 2009-2010. Although model shortcomings were found over this period and rectified, they did not change the management implications of model results, such as stock status relative to reference points employed by the Commission, 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. Although, substantial progress has been made, it remains a very important task for 2010-2011 to develop the model testing routine to facilitate more rapid development and compilation of executables. It is proposed to use the cut-down model as part of this routine.

The two main developments in 2009-2010 have dramatically improved MFCL's application in two areas: its estimation capability using complex tag-recapture data, and, in formulating management advice in terms of risk relative to biological reference points. These two features were rapidly incorporated into OFP's research programme and results of the applications of these features were presented to the sixth meeting of the WCPFC Scientific Committee in August 2010.

A task is recommended to consolidate the wide range of tools supporting MFCL since increasingly, MFCL model evaluations are made within the structure of a particular project; examples include, structural uncertainty grid analysis, risk analysis, or evaluation of alternative management options (TUMAS). These tools are being developed somewhat independently of the MFCL project repository, and a repository structure for this code would assist in avoiding conflicts among their various applications.

Table 2: 2009-2010 work plan for MFCL, including work completed and suggested future enhancements.

ID	Item	Description / Comment	Priority	Comments	Status
Bugs					
12 & 27	Hessian problems	Mostly fixed, just problems with dependent variables due to (probably) variables changed type to doubles from dvars. Pierre working on this.	1	-	Pierre working on it, more testing is required.
39	Fix line 249 of newmult.cpp	Fix line 249 of newmult.cpp where compilation falls over. The line is 'ppstf=new plotstuff(nfsh)'.	5	-	Fixed
	Projection problem	Possible problem with effort devs and catchability dev with zero effort devs in the projections. Large change in F. May require change to projection approach. Cause needs more analysis - initially try q devs at shorter time step.	5	-	Fixed
New features					
19	Region-specific environmental recruitment correlates	Allowing for recruitment deviates in each region to be correlated with some environmental variable. See the following file for a discussion of recruitment modelling options: I:\assessments\Pop dy modelling\MFCL\Recruitment.doc	3	-	

20	Selectivity varying with a covariate	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)	2		
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	Seasonally varying selectivity coefficients	Implement a scheme to estimate seasonal variability in selectivity coefficients	3		
23	Independent tag reporting rates for different groups of tag releases	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	Requires further testing of the priors.	Completed.
24	Time-series variation in movement coefficients	Implement a scheme to allow time-series variation in movement coefficients correlated with an environmental index. Probably best done in conjunction with 21 and 23 when the new tagging data is incorporated.	2		
25	Stochastic projections	Compute uncertainty in projected population biomass by propagating uncertainty in recruitment and effort deviations. Parameter estimates and likelihood function for the time period supported by data must be unaffected	5	Dave has prepared source code – has been added to repository.	Completed and tested.

|						
			(e.g. Maunder, Harley, and Hampton paper in ICESJMS).			
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		
36	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.	5	Region-specific yield calculations are already an option in MFCL. (See section in code called "Daves_folly")	Dave is working on this
37	Hyper-stability		Implement fishery-specific hyperstability, as a relationship between vulnerable biomass and catchability	3		
38	Projections for mgmt options project		1. Modify MULTIFAN-CL to run under the control of the management options application. [Probably no changes needed, but output cleanup might help] 2. Automate production of input files for projections under alternative management options. Adding projection period into par file could be done in R. 3. Link to an encrypted catch-effort database in order to define effects of time-area closures at one month (or less) and 1 degree square resolution (as in IATTC-77-04). (N.B. the model itself will still run at a regional level). Area boundaries will be selected from a predefined set, in order to help maintain data confidentiality. 4. Link to encrypted catch-effort database and estimate indicative yields by location.	5	Fabrice + Dave + Simon + Shelton + Nick	Drafted read.par +write.par; Drafted script to make the *.frq and *.par files for projections.

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	In progress
	Cut down dep vars	Design a new dependent variable report (i.e. *.dep -> *.var) that is relevant for what we now need for our assessments. The existing one, if it works, contains a lot of time consuming stuff that is no used.	4		
Other					
4	Testing routine	Set up an automated procedure for testing MFCL executables before use. 1. Design a set of doitall files that test the full range of important MFCL options. This would initially be the current doitall'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.	4		Started but not complete.
	Testing 2	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.	5		BET cut-down model set up.

Reference List

1. Davies, N. and Harley, S. 2010. Stochastic and deterministic projections: a framework to evaluate the potential impacts of limit reference points, including multi-species considerations. Secretariat of the Pacific Community No. WCPFC-SC6-MI -WP-01

2. Fournier, D.A., Hampton, J., and Sibert, J.R. 1998. MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, Thunnus alalunga. Can. J. Fish. Aquat. Sci 55:2105-2116

3. Harley, S., Hoyle, S., Williams, P., Hampton, J., and Kleiber, P. 2010. Stock assessment of bigeye tuna in the western and central Pacific Ocean. WCPFC-SC6-2010/SA-WP-04

4. Hoyle, S.D., Fournier,D., Kleiber, P., Hampton, J., Bouyé, F., Davies, N., and Harley, S. 2009. Update of recent developments in multifan-cl and related software for stock assessment. Secretariat of the Pacific Community No. WCPFC-SC5-2009/ SA-IP-06.

5. Hoyle, S., Kleiber, P., Davies, N., Harley, S., and Hampton, J. 2010. Stock assessment of skipjack tuna in the western and central Pacific Ocean. WCPFC-SC6-2010/ SA-WP-10

Appendix A: Formalised process for testing and adding MFCL source code developments to the project management repository.

Schema for testing MFCL updates
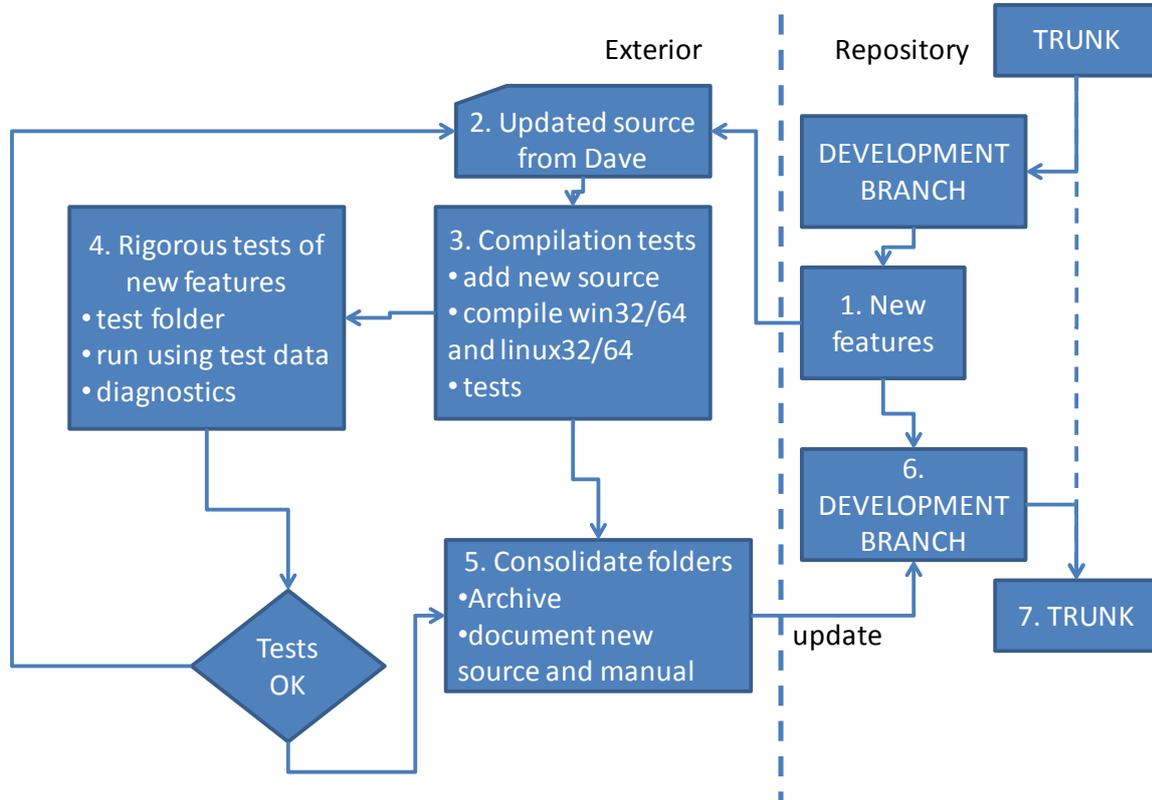
Figure 1: Procedural schema for incorporating new features into the MFCL project.

Appendix B: Proposed manual entry for undertaking stochastic projections

As of May 2010 a new feature has been added to MULTIFAN-CL for undertaking projections with stochastic recruitments, which has utility for risk analyses and evaluating relative performance of assumed future fishery management strategies.

Algorithm for simulations

Simulations with stochastic recruitments in projections requires five steps:

1. Hessian calculation for the fitted model parameters encompassing the estimation period (e.g. 1952 – 2008).
2. Construction of "*.frq" and "proj.par" files for input to the projections.
3. Hessian calculation for the log-normal distribution of historical recruitments
4. Hessian calculation to generate time series of future simulated recruitments
5. Actual simulation run.

Step 1

Using the fitted model parameter file, e.g. 12.par, calculate the Hessian matrix as follows:

    ./mfclo32 bet.frq 12.par 12_out.par -switch 1 1 145 1

This constructs the file "bet.hes" that is required for the subsequent steps. Note that for typically large tuna models, this calculation can takes around 24 hours to complete. Parallelisation of this calculation is possible, that reduces the time required by 50%, and although it is not explained here, this will be added to the MFCL utilities and the manual in the near future.

Step 2

It is necessary to extend both the *.frq and *.par files for undertaking future projections, i.e., to extend the time series of fisheries data under assumed levels of future effort and catch, and to extend the parameter sets for the additional projection period. R script has been drafted to assist with constructing these files:

    make_projn_frq.r

This procedure will be added to the MFCL utilities and explained in the manual in the near future.

It is recommended to test the newly constructed proj.par operation with a single model evaluation to ensure that it works, e.g.:

    ./mfclo32 bet.frq proj.par test.par -test.out -switch 6 1 1 1 2 190 0 2 191 0 2 148 4 2 155 0 -999 55 0

Steps 3 to 5

The line commands for these steps may be placed in a shell command file, with an example following for 200 simulations:

./mfclo32 bet.frq ttt ttt -test.out -switch 2 1 145 7 2 20 200

./mfclo32 bet.frq ttt ttt -test2.out -switch 2 -999 55 0 1 145 8

./mfclo32 bet.frq proj.par test3.par -test3.out -switch 4 1 1 1 -999 55 0 2 20 200 1 145 0

Note that in the input par file "ttt", age flag(20) is also specified to the number of simulations, (in this example 200), and this is necessary for steps 3 and 4. The proj.par file does not require this to be set, but rather it is taken from the flags of the line command in step 5.

Further notes on the flag settings of the above example follow.

Step 3:

- Parest flag(145)=7; run the Hessian calculation for the stdev of the recruitments

- Age flag(20) is set to 200 simulations

Step 4:

- Parest flag(145)=8; additional Hessian calculation

- Fish flag (55) = 0; this does not disable the fisheries, i.e. it maintains the current catchabilities

Step5:

- Parest flag (1) - single model evaluation

- Fish flag (55) = 0; this does not disable the fisheries, i.e. it maintains the current catchabilities

- Age flag(20) is set to 200 simulations

- Parest flag(145)=0; normal estimation (i.e. no Hessian calculation)

File outputs from this algorithm

Step 3:

histrec - log(recruitments) historical; n = no. regions x qtr x yr, numbers are log(number of recruits)

deplabel.tmp – number of regions x age classes

Step 4:

checkhess.rpt

Step 5:

tester – number of regions, pointers for each time-step

simulated_numbers_at_age - contains the simulated recruitments; number of regions x number of simulations by number of projection time periods

bet.cov - covariance matrix for dependent variables

xinit.rpt - listing of model variables

taglike - components of tagging likelihood

ttt - input par file that also becomes the output par file; includes age flag 20 (no. of simulations)

tag.rep; weight.fit; length.fit - model fits

projpop - num_fish; catch; fishing mortality by 6 regions; 40 age classes

projected_numbers_at_age - Population Number by age (across), year (down) and region - historical years and projected years

other_projected_stuff - for each simulation:

      - Catch by region and year (historic and projected)

      - Numbers of fish by region and year (historic and projected)

      - Catchability by realization (across) by fishery (down)

      - Catchability+effort dev. by realization (across) by fishery (down)

      - Population Number by age (across), year (down) and region (historic and projected)

fishmort testproj - Projected catch by fishery (down) and time (across)

projected_randomized_catches - for each simulation:

      - Observed catch by fishery (down) and time (across)

      - Predicted catch by fishery (down) and time (across)

projected_randomized_catch_at_age - for each simulation:

      - Predicted catch at age by fishery for projection time-steps

compare

plot-ttt.rep - output of projection model results (plot-rep) file

catch.rep - standard output

gradient.rpt - standard output