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Developments in the MULTIFAN-CL Software 2024-25

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EXECUTIVE SUMMARY

This paper summarises the developments made within the MULTIFAN-CL software project as carried out by the team at the Oceanic Fisheries Programme (OFP, The Pacific Community, Noumea, New Caledonia) from August 2024 to July 2025, and updates the report of Davies et al. (2024).

The current production version 2.2.7.2 has been benchmark-tested (Nov. 2024) and is available for wide distribution. The development version 2.2.7.6 has been tested for the specific developments to existing features, has undergone abbreviated benchmark tests, and has been used by the OFP-SPC for the 2025 skipjack tuna stock assessment.

During 2024-25, no significant mathematical innovations were implemented into the MULTIFAN-CL source code, consistent with the agreed 2024-25 workplan. Rather, the aim was for the relatively recent features added since 2019 (e.g., catch-conditioned method for estimating fishing mortality) to be consolidated, enhanced, and extended for their implementation in stock assessment models, and undertaking population projection analyses.

A substantial achievement in updating MULTIFAN-CL during 2024-25 was to upgrade the sex-structured model feature, enabling this model structure to have the equivalent features of the single-sex models routinely used for WCPFC stock assessments. This included:

- employing the catch-conditioned method for estimating fishing mortality and the CPUE likelihood, particularly for the instance of catches and relative abundance indices aggregated among sexes;
- incorporating the age-specific, independent offsets of the growth curve as estimated for each sex into the derivation of the selectivity at length function shared among the sexes;
- implementing the sex-specific Lorenzen functional form for natural mortality; and,
- input of conditional age-length data specific to each sex that enables this data type to contribute to the estimation of sexually-dimorphic growth.

Both billfish (swordfish) and tuna (albacore) examples were developed as sex-structured models employing the catch-conditioned method with the CPUE likelihood to test and demonstrate the implementation of the above enhancements.

Various other enhancements have: improved the user's operating environment; enabled simulation projections for the case where a catch-conditioned operating model (OM) employs projection fisheries all of which are effort-conditioned; and, added the capability for applying prior constraints to the estimation of length-based selectivity.

A substantive work component of 2024-25 was to update the User's Guide to include all the changes and new features that have been added over 9 separate release versions (2.0.6.0 to 2.2.7.2) since August 2018. Descriptions of new features now routinely employed in WCPFC stock assessments, MSE and TRP analyses, were added including the:

- Catch-conditioned method for fishing mortality estimation;
- CPUE likelihood;
- Diagnostics of the MLE model and Hessian solution;
- Variance calculations of WCPFC reference point dependent variables; and,
- Catch-conditioned operating model projections and simulations.

The compilation framework performed successfully for all three platforms: Linux, macOS and Windows, with no disruptions experienced. Similarly, the testing framework required little maintenance, with benchmark tests being successfully executed – one comprehensive, and two abbreviated. No substantive issues were identified during the tests, and only two corrections were necessary to the development version.

Nick Davies, the current (and only) developer of MULTIFAN-CL, also contributed to the WCPFC Project 123 ("Scoping the Next Generation of Tuna Stock Assessment Software") in making good progress towards establishing a public repository for MULTIFAN-CL, which may have utility as providing a reference and source code resource.

The focus of the 2025-26 workplan is a continuation of that for the past 3 years, i.e., to: consolidate recent new features; enhance existing features; improve processes and reporting; make corrections; and update user support documentation. No substantial new or mathematically innovative developments to the project are proposed in the coming year.

1 INTRODUCTION

MULTIFAN-CL 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 Dr David Fournier (Otter Research Ltd) and Dr John Hampton (The Pacific Community) for its initial application to South Pacific albacore tuna (Fournier et al. 1998). It has since provided the basis for undertaking stock assessments in the Western and Central Pacific Ocean.

The MULTIFAN-CL model is described in detail in the User's Guide (Davies et al. 2025). It is typically fitted to total catch, catch rate, size-frequency and tagging data stratified by fishery, region and time period. For example, recent tuna and billfish assessments (e.g., Teears et al. 2025) encompass long time periods, e.g., 1952 to 2024 in quarterly time steps, and model multiple separate fisheries occurring in up to 9 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), movement, 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 (integrated) likelihood comprised of the fits to the various data types, and penalized likelihood distributions for various parameters.

Each year the MULTIFAN-CL development team works to improve the model to accommodate changes in our understanding of the fishery, to fix software errors, and to improve model features and usability. This document records changes made since August 2024 to the software and other components of the MULTIFAN-CL project both for the current release version (2.2.7.2), and the current unreleased development version (2.2.7.6), and updates the report for the previous period, 2023-24 (Davies et al. 2024).

2 DEVELOPMENT OVERVIEW

2.1 Team

The senior developer of MULTIFAN-CL until December 2021 was Dr David Fournier, of Otter Research Ltd, (Canada), who has since retired. Development and testing are now undertaken by Mr Nick Davies. Other tasks include testing and debugging (ND, John Hampton, and Fabrice Bouyé (SPC)); documentation (ND); and planning and coordination (ND, Paul Hamer and JH). Related support project software is developed or managed by FB (MULTIFAN-CL Viewer, Condor, GitHub, Jenkins), Arni Magnusson, ND, and Robert Scott (R4MFCL, FLR4MFCL).

2.2 Calendar

In the absence of more than one developer, developer's workshops are no longer held, and the calendar year is less structured. However, broad periods may be identified with those for which more support is given to OFP stock assessment modelling.

August – November: Consolidating recent developments, benchmark testing, developments required for risk analyses

December – February: Code development, and testing

March – April: Training, stock assessment support, code development, and testing

May – July: Code development, and testing

2.3 Collaboration and versioning

The repository and overall development are coordinated via the GitHub website on GitHub.com at https://github.com/PacificCommunity/ofp-sam-mfcl which is administered by Fabrice Bouye (fabriceb@spc.int) (section 2.4.7).

Problems with MULTIFAN-CL 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. A “master” branch exists for the MULTIFAN-CL source code from which release versions are posted, and development branches (“ongoing-dev”, “mac-dev”) have been created for holding development versions of the source undergoing development and testing. A formal testing procedure has been designed before source code is merged from the branch to the trunk, and a manual for the testing of new compilations, standardizing the source code compilation procedure, and posting of executables is maintained.

2.4 Compilation framework and Source code repository

2.4.1 Compilation framework

A continuous integration facility allows for automatic nightly compilations of the MULTIFAN-CL source on the GitHub repository “master” branch. This automation is done using the software called Jenkins (https://jenkins-ci.org/), an Open-Source continuous integration tool that comes bundled with a web server used for administration. This software is now installed on a Linux Virtual Machine (VM) that is dedicated to MULTIFAN-CL development and administers the compilations over the OFP network.

In this tool, we’ve added a custom scheduled task that automatically retrieves the MULTIFAN-CL source code out of the GitHub code repository (master branch); it also retrieves required libraries for the compilation. When done, our task compiles both debug and optimized versions of the software. We’ve also configured this task to produce code documentation out of the source code and to run some C++ code quality checking.

Doing a nightly compilation allows us to find out more quickly whether issues have been included in the source code repository without being solved by the developer. It also helps us identify issues in the makefile configurations that may prevent the compilation of MULTIFAN-CL on some more neutral environment (i.e. on a machine that is different from that of the developer’s).

During 2018-19 this facility was extended to support automated builds of the Windows (Visual Studio 2019) and the macOS release executables. The Windows10 VM used for undertaking the benchmark testing framework (see section 2.6) and the Mac Mini provides the platform for undertaking the routine compilation administered by Jenkins (see section 2.4.4). These automated builds were maintained throughout 2024-25, apart from a problem encountered with accessing the Mac Mini during 2022-23 (see section 2.4.4), that has since been corrected. During 2024-25, some minor issues were encountered including: when compiling on Windows some files from the User’s Guide were locked due to Windows Defender; and, Xcode updates that changed the compiler and system libraries on the mac OS due caused disruptions. These have since been resolved.

It is also intended to add to the Jenkins tool the running of automated tests using example fish model data, and, in the future, unit tests for the software.

A directory structure on the dedicated VM was used that is mirrored on all the developer’s platforms in respect of source code **Projects/**, associated libraries **libs/**, and **Testing/** directories. This ensures portability of source and makefiles among the developers and the automated build software.

2.4.2 Compilation of dependent libraries

For compilation of the dependent **OpenBLAS** library, the "dynamic architecture feature" is included to the routine compilations that builds several kernels for various processor types and allows selection of the appropriate kernel at run-time. This may avoid the case where a MULTIFAN-CL executable that was compiled with OpenBLAS on a platform having a very recent processor, fails upon execution because function calls to the OpenBLAS library are attempted on platforms having relatively older processors. This compilation method results in a substantial increase (22 MB) in the executable size. However, it was noted that OpenBLAS libraries are important for the calculations used for the eigenvalues and eigenvectors of the Hessian and also aspects of the self-scaling size composition likelihood. This trade-off is therefore considered acceptable for the increased utility achieved.

In order for the MULTIFAN-CL project to be completely portable, three shell scripts automate the compilation of all the dependent libraries, before compiling MULTIFAN-CL. These scripts apply different options for OpenBLAS, QD and compilation flags for MULTIFAN-CL. The script "build_openblas4mfcl.sh" builds 3 options of this library: "default", "generic", and "dynamic", where the "dynamic architecture feature" builds several kernels for various processor types and allows them to be selected at run-time. Similarly, the script "build_qd4mfcl.sh" builds 4 options of the QD library: "default", "O3", "O3fma", and "native". Given the various combinations of compilation options among the dependent libraries, ADMB and MULTIFAN-CL, compilations of 25 different executables may be produced. For a single option, it compiles in total: 49 minutes 5 seconds. This facilitates the portability of the entire MULTIFAN-CL compilation project including the dependent libraries, such that the complete project may be constructed and compiled with one step.

Note however, that for the automated compilation administered by Jenkins, compilation of the MULIFAN-CL source code is undertaken using the independently pre-compiled dependent libraries QD and OpenBLAS.

2.4.3 Compilation of Linux executable

In August 2023 the Linux version used for compilations was upgraded to Ubuntu 20.04.2, with the gcc compiler version 9.4.0. No changes were required to the source code for the new compiler, and all compilations were stable during 2024-25.

2.4.4 Compilation of Mac OS executable

During 2018-19, routine macOS compilations of the "master" and "development" branches were added to the compilation framework of the MULTIFAN-CL project. Compilations are done on the MULTIFAN-CL Testing PC (Mac Mini) that has the macOS Mojave installed ("macOS 10.14.6 Mojave").

In October 2022, a major setback occurred in respect of the macOS compilations. The MULTIFAN-CL Testing PC (Mac Mini) was removed from the Pacific Community computing network for security reasons. During 2023-24, a secure arrangement suitable for the network's standards to reinstate this PC was made, such that the Mac Mini was again accessible to the MULTIFAN-CL project. The opportunity was taken to: complete updates of the macOS from Mojave (2018) to Sonoma (2023); apply all recent security updates; update Xcode, Xcode command line tools, and Homebrew distribution and packages, to the most recent release versions. Subsequently on 20 April 2024, a successful compilation for the macOS executable was produced of the current release version 2.2.7.2, with a successful test using a tuna model example with respect to the corresponding Linux executable.

The Mac Mini PC has two compilation directories:

- Local compilation - stand-alone directory for testing development versions
- Jenkins compilation - for routine automated Jenkins compilations of the master branch (checked out from the repository, see section 2.4.1)

A Software ID certificate was assigned to the macOS compilation using an Apple Developer ID certificate for SPC. The macOS version is signed "Developer ID Application: The Pacific Community" issued by Apple. No differences were detected in the computations or performance among the signed and un-signed compilations.

No substantive problems with the macOS compilations were experienced during 2024-25, either with the operating system, compilation libraries, nor the C++ code.

Apple has now officially announced that they are ceasing production with Intel's CPUs in favour of their own RISC ARM-based CPUs. The macOS compilation of MULTIFAN-CL will ultimately need to accommodate this change. A draft strategy for changing to the ARM-mac compilation for MULTIFAN-CL may entail:

- Following the 2021 Apple conference decide on a machine purchase to be made during 2022 (no machine has been purchased)
- Explore the potential for compiling on the existing Intel-mac with output target set to the new ARM-CPU using flags in the most up-to-date or the next version of XCode (the Apple dev tools/compiler)
- Maintain a careful watch of the capability of the Rosetta 2 emulator for running the MULTIFAN-CL executable (compiled for the Intel CPU) on an ARM-mac; this could offer a "breathing space" for our switch to the ARM-mac compilation
- Consider the merits of upgrading the mac Mini from Mojave to Catalina or Big Sur
- Potentially consider the lead developers purchasing an ARM-mac (external of SPC) for developing the compilation
- Aim for making the ultimate switch to the ARM-mac compilation for MULTIFAN-CL

The macOS x86 architecture is approaching its end point. If MULTIFAN-CL development is to continue with a macOS compilation, there will need to be some investment in both people and hardware to port to macOS AARCH64 instead.

2.4.5 Visual Studio 2019 Windows compilation

Compiling the Windows executable is done using Visual Studio 2019, (VS2019) and all compilations were successfully completed during 2024-25 on the developer's workstation. No issues were encountered with the compilations as a result of updates to the VS2019 compiler.

2.4.6 Development version

Upon completing benchmark testing of a development version, the source code in the repository development branch is merged to the master branch and tagged with a release version number. At this point the development branch is created afresh for implementing any subsequent code developments, and a new compilation directory created. Other points where a new development version number is assigned is immediately following changes that may impact upon a minimised model solution, or alterations to the format of output files. These are then added to the development branch following preliminary testing and tagged with the new version number. During 2024-25 a new development version was created following the benchmark testing of version 2.2.7.2.

A number of changes to the development version have been made since version 2.2.7.2 (Dec. 2024), and most of these were accompanied by abbreviated benchmark testing of the implications on the function evaluation and dependent variable estimates. These are described in sections 2.6.2 to **Error! Reference source not found.**~~2.6.6~~. While not fully benchmark tested, the detailed testing of the effects specific to each development, and the abbreviated testing, confirm no negative impacts on other existing features employed in the 2025 stock assessment models produced using the development version.

2.4.7 Source code repository

The MULTIFAN-CL project is hosted on GitHub.com at:

- https://github.com/PacificCommunity/ofp-sam-mfcl

This site is only accessible to registered members of the OFP-SAM team. In order to better coordinate developments within components of the project, separate repositories were created for the:

- User's Guide: https://github.com/PacificCommunity/ofp-sam-mfcl-manual
- ADMB dependent library: https://github.com/PacificCommunity/ofp-sam-admb

The branches of the repository are managed such that following benchmark testing, the development version that has tested positive and held in either of the "mac-dev" or "ongoing-dev" branches, is then merged to the "master" branch. This creates a clear node in the "master" branch tagged as being the next release version. At that point a new development version is created in one of the "mac-dev" or "ongoing-dev" branches for undertaking the next phase of developments. This approach was followed for each of the versions during 2024-25, with the current development version being maintained in the "ongoing-dev" branch (version 2.2.7.6).

Between 9 Aug. 2024 and 8 Jul. 2025, a total of 27 source code commits were made to the master and development branches (67 source files have been modified, and 1 source file renamed, see section 12), including two merges of the development branch to the master branch on: 3 Dec. 2024 for the distribution of version 2.2.7.2; and, 4 April 2025 for version 2.2.7.3; to the Pacific Community. The current version in the "ongoing-dev" development branch is version 2.2.7.6.

During 2024-25, assistance was provided to the WCPFC Project P123: "Scoping the Next Generation of Tuna Stock Assessment Software". Specifically, this related to developing a public version of the MULTIFAN-CL github repository. The tasks completed related to the source code and repository files, including:

- Revising the screen output error messages to be more informative
- Resolving temporary variable names and source code filenames
- Updating the release documents (README, RELEASE_NOTES)
- Removing redundant source *.cpp not included in EXE_dependencies (41 files); compiled, tested execution
- Inserting a Copyright statement in all source *.cpp; compiled, tested execution
- Listing all header files that are in `#include` statements in all source *.cpp; identified those present in local compilation folder; identified those present in local compilation folder that are redundant

The next steps to preparing the source code for the public repository are to:

- remove the redundant header files from the compilation directory; attempt compilation and test execution
- Review the list of source *.cpp and header files with conflicting copyright statements (those relating to software sources other than MULTIFAN-CL); and resolve the copyright statement
- insert the copyright statement in all remaining header files
- Ascertain with Pacific Community legal department, the appropriate License for the public source code

Following these steps, the github public repository will be created during 2025-26.

2.5 Developer's workshops

In the absence of more than one developer, no workshops were held during 2024-25. Since January 2022, Mr. Nick Davies has continued alone with the consolidation, enhancement and corrections to the existing features.

2.6 Benchmark testing during 2024-25

The benchmark testing framework is described in section 2.10.2~~2.9.2~~, and one set of benchmark tests, and several abbreviated tests, were undertaken in 2024-25. When relatively few changes have been made, the abbreviated tests explore their specific effects on example solutions obtained with the previous version. This is a precursor for undertaking the comprehensive benchmark test at a later date. A brief description of the tests, and the features tested, is provided in this section.

2.6.1 Version 2.2.7.2

In October-November 2024, comprehensive benchmark testing was done between the MULTIFAN-CL development version, and the benchmark release version 2.2.5.0 previously tested in October 2023. A complete set of tests were undertaken, to examine the cumulative effect of a number of enhancements and corrections made to the development version source code since version 2.2.5.0., as described in section 5 and by Davies et al. (2024), primarily including:

- **Catch-conditioned model CPUE likelihood**

    - Replaced the definition of fish_flags(92) for the non-concentrated CPUE likelihood from: penalty weight, to CV/100.

- **Independent variables report**
    - A new feature was developed for the production of a consolidated parameter output file that contains:
        - The parameter index number and a text descriptor (as in xinit.rpt but corrected to deal with selectivity grouping)
        - The parameter estimate, as provided by the model fit
        - The final gradient
        - The standard deviation
        - Bounds applied for the parameter

- **Simulation projections of the catch-conditioned model**
    - Added an option for applying the model "observed" catchabilities for projections with effort-conditioned fisheries. This is an enhancement to the feature for undertaking population projections under the assumption of constant catchabilities in the projection periods that are equivalent to those of the terminal year of the estimation model time periods.

- **Various enhancements and corrections**
    - Alternative approach was conceived that retains as intact the diagnostic case model solution (i.e., to keep all the independent variables fixed at their estimated values), but to add in a subsequent phase estimation of only the "internal" regression for the fishing mortality:effort relationship (fml_effort_rltnshp) in respect of the model's implicit fishery catchabilities.
    - Lorenzen parameter estimation – include the estimated von Bertalanffy growth offsets into the derivation of the Lorenzen formulation of natural mortality at age.
    - Correction to the output report "plot.rep" section "# Exploitable population in same units as catch by fishery (down) and year-season (across)" such that it is expressed in numbers of fish where relevant.
    - Correction to remove the duplication of the recruitment penalty calculation among both sexes in a multi-sex model, but rather to calculate the penalty for only the female sex.

- **New section for first model year to .par file**
    - Reporting the MULTIFAN-CL compilation version number (e.g., 2.2.7.1) to the .par report. To maintain backward compatibility of older .par file versions, the file version number (in parest_flags(200)) was increased from 1066 to 1067.

Note: all the benchmark testing was done using the compilation of the development version for the "standard" 64-bit precision, as this ensures comparability with the benchmark version 2.1.0.0. The range of testing data sets was the same as for the previous benchmark test, comprising: 7 single-species sets; a multi-species set; a multi-sex set; a single-species deterministic projection set; and, a single-species stochastic projection set.

<u>Issues identified during testing</u>

Code changes made in the development version were identified that caused notable differences in the operation or results obtained versus those of **vsn2.2.5.0**.

- <u>Flag settings for the CPUE variance term.</u> The development version included a change in the definition of fish_flags(92) for the non-concentrated CPUE likelihood from: penalty weight/100; to, CV/100. This makes it impossible to replicate exactly the variance terms with that of the benchmark version. Close approximations are possible, and were applied in the testing of the development version. This difference produced different solutions among the versions for the catch-conditioned model examples.
- <u>Differences in the gradient calculation</u>. This was identified for the catch-conditioned model solutions obtained using the development version when undertaking a single model evaluation. This was attributed to the correction made as part of the enhancement to the feature for undertaking population

projections under the assumption of constant catchabilities in the projection periods. This correction removed unnecessary assignments to class members for the implicit catchabilities. This change is considered an improvement, as it avoids unnecessary assignments to a dvar_vector that affects the gradient calculation, resulting in a better minimisation solution.

- Multi-sex recruitment penalties – duplication avoided. The development version included a correction to remove the duplication of the recruitment penalty calculation among both sexes in a multi-sex model, but to rather calculate the penalty for only the female sex. The effect of this is to reduce the total likelihood by a small amount (around 1 – 2 points), resulting in slightly different solutions relative to the benchmark version.
- Logistic selectivity – arithmetic exception error. An arithmetic exception (divide by zero) occurred in the logistic selectivity calculations during a minimisation when parameter estimates approached an extreme (and implausible) value. A method for robustness was implemented to account for values very close to this extreme that avoids the exception error. It was noted that for the BET2017 example, poor minimisation performance for the Windows platform was attributable to implausible logistic selectivity parameter estimation. This test data example appears to produce poorly-determined solutions, which can complicate testing evaluations.

Results

Single evaluation tests for single-species, multi-species, multi-sex data, and deterministic single species projection, with or without gradient calculations and a minimisation step – produced identical model quantities among versions; except for the catch-conditioned examples due to the change to the CPUE likelihood penalties.

Minimised solutions of the catch-conditioned model examples employing the non-concentrated CPUE survey fishery CPUE likelihood produced different solutions among the versions due to the differences in the input variance terms. These differences do not reflect an error in the implementation of the CPUE likelihood feature, but rather the effect of changing the flag setting assignments for the variance term employed. This change most likely accounts for the differences in the dependent variable estimates; between 2 and 12% for BET2023, and around 2% for YFT2023 and SKJ2023.

Doitall fits for the catch-errors examples produced different solutions among the versions, and were probably attributable to the slight differences in the gradient calculations, resulting in different minimisation paths being taken.

Tests of the development version concluded that the results were consistent with respect to the benchmark version 2.2.5.0 as all existing features remain intact, therefore the development version was advanced to the new MULTIFAN-CL release version, **2.2.7.2**.

2.6.2 Abbreviated test – version 2.2.7.3

On 26 March 2025, an abbreviated test was undertaken, to examine the effect of enhancements made to the development version source code described in section 5, specifically:

- enhancements for multi-species/sexes/stocks models employing catch-conditioned method with the CPUE likelihood
- Independent variables report – added orthogonal-polynomial coefficients
- Tagging data likelihood – reinstated the grouped case for tags_inform_movement
- Size composition likelihood – improved the self-scaling multinomial likelihood with random effects estimation
- Catch-conditioned model projections – projections enabled with no available catch data
- Correction: Fishing impact analysis – correction of the initial equilibrium population calculations (orthogonal-polynomial models)

Single evaluations and doitall fits of five single species examples (three of which were catch-conditioned) were undertaken. Single evaluations indicated identical results relative to the benchmark version 2.2.7.2. For the doitall fits, comparisons among versions within platforms: for the catch-conditioned models almost negligible differences in model quantities and objective functions were found. Slight differences in the gradient calculations were found among the versions, resulting in different minimisation paths being taken, producing slightly different solutions. Overall, the differences were minimal, with the key dependent variables differing by <1% for most examples.

Tests of the development version concluded that the results were consistent with respect to the benchmark version 2.2.7.2 as all existing features remain intact.

2.6.3 Abbreviated test – version 2.2.7.4

On 19 May 2025, an abbreviated test was undertaken, to examine the effect of enhancements made to the development version source code described in section 5, largely relating to constraints on the length-based selectivities.

Doitall fits of one single species example (catch-conditioned) were undertaken (YFT2023). Identical results were obtained relative to the previous development version 2.2.7.3. indicating the existing features unrelated to the developments are unaffected.

2.7 Postings to website

There have been no postings of the MULTIFAN-CL release versions to the website since July 2020.

2.8 Independent Peer Review of the 2011 bigeye tuna stock assessment

An outcome of an independent peer review of the 2011 bigeye tuna stock assessment (Ianelli et al. 2012) was a set of recommendations for improvements and developments to the MULTIFAN-CL software. These aimed not only to improve the software's application in the context of the bigeye assessment specifically, but also its stock assessment application more generally. These recommendations have been the basis of MULTIFAN-CL developments since the review, and an outline of the status in fulfilling these recommendations is provided.

At the beginning of 2024-25, of the thirteen recommendations, 12 had been implemented and tested, and 1 remained yet to be developed:

- Non-uniform size bins (recommendation "b")

No further progress was made on recommendation ("b") during 2024-25, and remains as an incomplete task on the work plan.

2.9 Yellowfin Tuna Independent Peer Review 2022

In 2022, an independent peer review was undertaken of the 2020 yellowfin tuna stock assessment model (Punt et al. 2023). The outcome included five recommendations for improvements to be made to MULTIFAN-CL relating to: the length-weight relationship variance; selectivity splines; age-reading error; CPUE overdispersion parameter; and, natural mortality at age. These recommendations have been included in the MULTIFAN-CL workplan, and are within the tasks proposed for 2025-26 (Table 4).

2.10 Tool development

2.10.1 R4MFCL

The R scripts for working with MULTIFAN-CL, developed by OFP are maintained on a GitHub repository and have been partially updated to adapt to the recent MULTIFAN-CL release version file formats. These scripts are used to manipulate the input files, so that submitting model runs can be automated from R. Other scripts can be used to read in the output files, analyze the results, and generate plots and tables. No commits were made to the repository during 2024-25, indicating the low use or maintenance of this package, as it has now been surpassed by FLR4MFCL and the Shiny App.

2.10.2 Testing framework

The testing framework for MULTIFAN-CL compilations first developed in 2011-12, was applied during 2024-25 for the benchmark testing of version 2.2.5.0 (section 2.6). This framework ensures the repeatability and traceability of testing by streamlining the process for new source code developments through a system of model testing procedures and directories. The testing criterion is based upon pair-wise comparisons of model run results obtained using an existing MULTIFAN-CL compilation (usually the current release version) versus those from a development version compilation. Tests are undertaken over multiple processor platforms (64-bit architecture only), with application to multiple input testing data sets, and with various options for the MULTIFAN-CL operation, viz. single or multiple model evaluations, or full doitall model fits to convergence. This ensures a thorough integrity-check of model quantities and components of the objective function prior to the distribution of new versions.

Since March 2013, the MULTIFAN-CL source code has undergone substantial developments, and those have been described in earlier reports (e.g., Davies et al. 2024), and the recent developments in 2024-25 are described in Sections 4 and 5.

Following the addition of these new features to the development version, regular testing of this versus the release version aims to ensure the integrity of existing operations. Known as "benchmark tests", those undertaken in 2024-25 are described in section 2.6. The development version was last tested in May 2025 versus the version 2.2.7.3 in abbreviated tests. The positive result of a comprehensive benchmark test of this development version will then define it as being the **benchmark** source code, and then posted as the release version. Subsequent development versions will then be tested relative to the benchmark to establish their integrity, after which they may be defined as the new benchmark development version. The testing framework entails two levels of tests:

1. Establish the accepted development version

The first level of testing ensures the integrity of existing model features by undertaking tests using a selection from a range of single-species data including: ALB2012, ALB2015, BET2011, BET2014, BET2017, BET2023, SKJ2011, STM2012, SWO2013, SWO2017, SWO2021, YFT2011, YFT2014, YFT2017, YFT2020, YFT2023, SKJ2014, SKJ2016, SKJ2022, and SKJ2023. During 2024-25, three additional catch-conditioned model examples were added to this range of single-species data (BET2023, YFT2023, SKJ2023). The aim of the tests is to evaluate the similarity of single model evaluations and the fitted solutions obtained using the development version relative to that of the benchmark version. Identical or close similarity indicates the integrity of the development version for undertaking single-species model evaluations. Results are compared among the versions and operating systems, to confirm that the development and release versions produced identical, or very similar, solutions. When differences are found, which can be attributable to improvements in the development version, these are accepted.

Tests using multi-species data disaggregated among species are done which entails comparing the fitted solutions of the development version code versus those solutions obtained using the corresponding data for each species fitted individually. These tests concluded that the operations applying to each population in the disaggregated model have integrity and effectively emulate the solutions obtained when each population is modelled individually. Note that species-specific fisheries data were supplied to the models in the test data examples used. Testing was not conducted using test data for which all fisheries data were aggregated among species (or sexes).

Similarly, tests are done for deterministic and stochastic projections with the pair-wise comparisons among versions and operating systems being made.

A positive test result is when the benchmark tests conclude that the development version conserves the existing features, and so can either be advanced as the new release version, or accepted for the new benchmark development version.

2. Establishing integrity of new features, enhancements, and corrections

This second level of testing entails a detailed examination of new features. The inputs and model configuration are customized for the new features and the operation of the new algorithms are evaluated in respect of the original formulations. During 2024-25 this level of testing was done for the enhancements and corrections (see section 5), to ensure the correct calculations and the expected results.

Review of Testing Framework

In January 2016 the testing framework was reviewed by project members with the following agreed tasks for improvements:

a) Tidy up the testing framework functions and utilities so as to be as automated as possible and more user-friendly with a view to including other team members in running the tests.
b) Upgrade testing framework functions and utilities for applicability to both single-sex and multi-sex file formats, with portability over condor.
c) Integrate the testing framework functions and utilities into the R4MFCL package and ensure compatibility with all assessment modelling applications.
d) Create a GitHub repository for the testing framework functions, utilities, and testing data.
e) Consolidate the R4MFCL GitHub repository with Rob Scott as the lead developer, and add access levels to Nick Davies as a support developer.
f) Construct a suite of routine tests for the R4MFCL package to be run following each revision to the repository, and load the updated R4MFCL package to the testing framework.
g) Construct a single routine MULTIFAN-CL test operation (e.g., single-evaluation of a fitted test model solution) to be conducted daily and directly from the Jenkins compilation utility that returns an exit status value, with an email report sent to the project developers.

Little action has been taken on these tasks and is also unlikely in the remaining part of 2024-25. It has been identified as a concern, and therefore that they be included in the 2025-26 work plan for the MULTIFAN-CL project.

The routine compilation and development of a macOS executable is fundamental to the project, and the testing framework includes the MacMini host, and the macOS executable within tests among platforms and versions. The framework therefore has capacity for conducting tests upon all 3 platforms simultaneously over the Condor network. The test analyses perform pair-wise comparisons among versions and over three platforms: Linux, Windows, and macOS.

2.10.3 Viewer

The MULTIFAN-CL Viewer provides a ready means of examining independent and dependent variables of model solutions by illustrations and plots. No substantive changes nor corrections were made during 2024-25, and the current version has not yet been placed on the MULTIFAN-CL website for public release.

2.10.4 Condor parallel processing facility

The Condor (www.condor.wisc.edu) facility has been used routinely for managing multiple MULTIFAN-CL model runs on a grid currently numbering more than 75 computers; being Linux (66 machines and 4 VMs), Windows (4), or macOS (1) platforms. This grid enables parallel model runs for: benchmark testing MULTIFAN-CL development versions; undertaking stock assessments that entail multiple model runs (e.g. sensitivity analyses and structural uncertainty grid analyses), and for management strategy evaluations. During 2024-25, additional Linux Virtual Machines were added to the grid to increase the number of parallel runs possible using the Linux development version executable. All Linux machines were updated to Ubuntu 22.04 and HTCondor 24.

2.11 User's guide

During January-February 2025, the long-standing task of updating the MULTIFAN-CL User's Guide was completed. A substantial revision to the version of Kleiber et al. (2018) was undertaken to include all developments made since version 2.0.5.1., released in August 2018. In total, all the changes and new features that have been added over 9 separate release versions (2.0.6.0 to 2.2.7.2) were documented, including those for substantive new features including:

- SSMULT size compositions – implementation of the likelihood formulation
- Censored gamma tagging likelihood; long-term tag loss

- Catch-conditioned method for fishing mortality estimation
- CPUE likelihood
- Diagnostics of the MLE model and Hessian solution
- Variance calculations of additional dependent variables
- Output reports – descriptions added
- Catch-conditioned operating model projections and simulations

The technical appendix was updated for the SSMULT, catch-conditioned method, CPUE likelihood and tagging likelihood features. Also, the complete list of flags was reviewed such that all undocumented flags were listed and described. Other flags that have functionality but lack descriptions and relate to features not fully implemented or tested, have been indexed in Appendix B for future reference purposes. While this is now up to date, there do remain some historical sections requiring corrections or updates, and this will be an ongoing task.

The updated User's Guide (Davies et al. 2025) has been committed to the MULTIFAN-CL github repository, and will be posted to the Website following the next set of comprehensive benchmark tests.

3 TRAINING WORKSHOP

No formal training tutorials were required during 2024-25, although regular training support and Q and A support was provided to SPC analysts, and Nick Davies attended most weekly meetings of the stock assessment team to contribute to the 2025 assessment model developments.

4 NEW FEATURES

No significantly mathematically innovative or new features were implemented into the MULTIFAN-CL source code during 2024-25. Rather, the features added since 2019 (e.g., catch-conditioned method for estimating fishing mortality) have been consolidated, enhanced, and extended for their implementation in multi-sex and multi-species models and for undertaking population projections. The current development version is **2.2.7.6** which holds all the developments described in section 5 that relate to enhancements and corrections made to the existing features since July 2024. These will be merged to the next release version upon the completion of the forthcoming benchmark testing.

5 ENHANCEMENTS AND BUG FIXES

An overview of the enhancements and corrections made to existing features in MULTIFAN-CL during 2024-25 (up to March 2025) was provided to the pre-assessment workshop (Hamer, 2025). Those, and other developments made subsequent to that meeting, are described in more detail in this section.

5.1 Catch-conditioned model

Substantial enhancements have been made to the catch-conditioned feature in respect of:

5.1.1 Sex-disaggregation

The catch-conditioned method and the implementation for the survey fishery CPUE likelihood has been extended to employ the cases of multiple species or sexes. This entails accommodating fishery data, specifically catches and survey fishery indices, that is aggregated among species/sexes, and to apportion them according to the model predicted sex-ratios of vulnerable numbers at age. The derived species-, or sex-specific catches are the basis for the Newton-Raphson solution for the fishing mortalities of the respective fisheries. For the multi-species/sexes cases, the CPUE likelihood was extended to accommodate the options of ungrouped/grouped fisheries, and to derive the predictions aggregated among species/sexes in either numbers or biomass.

5.1.1.1 Method - apportion aggregated observed catches

When employing the catch-conditioned method for estimating fishing mortality with a sex-disaggregated model structure, the problem exists with how to derive sex-specific estimates when catches are aggregated among the sexes. An approach was developed similar to that employed successfully in the catch-errors method for estimating sex-specific fishing mortalities. In that case, effort deviates were estimated for each sex, the predicted sex-specific catches were derived from the vulnerable numbers at age for each sex, and the aggregated predicted catches were then fitted to the observed aggregate values in the total catch likelihood. In this sense, the sex ratios of the predicted catches were estimated implicitly within the model in respect of the sex-specific vulnerable numbers at age and effort deviates.

Taking this approach and adapting it to the catch-conditioned method, the sex-specific vulnerable numbers at age estimates are used explicitly to apportion the observed catches among the sexes. The Newton-Raphson solutions for fishing mortality are then obtained for the estimated sex-disaggregated catches. Note that the estimated sex ratio will be dynamic and will be a dependent variable of the minimisation procedure, which is essentially the same underlying approach as used for the catch-errors method.

Let C_t be the observed catch aggregated among the sexes in time step *t*. The estimated numbers at age *a* by sex *s* in *t* is N_{tsa}. Then the vulnerable sex-specific numbers at age is:

$$V_{tsa} = S_{sa} * N_{tsa} \qquad \text{Eq. 1}$$

where S_{sa} is the estimated selectivity at age for sex *s*.

The estimated sex ratio of V_{tsa} over all ages is:

$$R_{ts} = \frac{\sum_a V_{tsa}}{\sum_s \sum_a V_{tsa}} \qquad \text{Eq. 2}$$

In the case where observed catches are in terms of numbers of fish caught, the derived sex-disaggregated observed catch for sex s is:

$$\hat{C}_{ts} = R_{ts} * C_t$$

In the case where observed catches are in terms of the weight of fish caught, the estimated sex ratio of V_tsa over all ages is expressed in weight.

$$R_{ts} = \frac{\sum_a V_{tsa}\overline{w}_{sa}}{\sum_s \sum_a V_{tsa}\overline{w}_{sa}}$$

where $\overline{w}_{sa}$ is the mean weight at age *a* for sex *s*.

The $\hat{C}_{ts}$ is then applied in the Newton-Raphson procedure for solving for the sex-specific fishing mortalities in each time step *t*.

5.1.1.2 Method - fitting aggregated survey fishery indices of relative abundance

The predicted index of relative abundance (CPUE) is:

$$\hat{I}_{ki} = \sum_a N_{ria}^{mid} * S_{ka}$$

Where N_{ria}^{mid} are the mid-period numbers at age *a* in region *r* for the time period associated with the i^{th} index, and S_{ka} is the selectivity at age for fishery *k*. Note that the fisheries are sex-specific, and therefore S_{ka} is sex-specific, as is $\hat{I}_{ki}$. The predicted index in this case is expressed in numbers. For indices in terms of biomass, the summation will include the multiplier for $\overline{w}_{sa}$ being the mean weight at age *a* for the sex *s* defined for fishery *k*.

When the observed survey fishery indices of relative abundance are aggregated among sexes, the predictions are similarly aggregated by summating the $\hat{I}_{ki}$ over the two fisheries, *k*, defined for the two sexes *s* in the same region, i.e.,

$$\hat{I}_i = \sum_k \sum_a N_{ria}^{mid} * S_{ka}$$

The CPUE likelihood implementation that: apportions the predicted vulnerable numbers at age by sex in each survey fishery time step; and, assigns to the aggregated predicted indices of relative abundance; has been developed to take account of the cases of ungrouped and grouped fisheries.

5.1.1.3 Testing

Two existing multi-sex catch-errors models were tested as suitable examples for implementing the catch-conditioned method - SWO2017 and SWO2021. Both were updated to use the latest MULTIFAN-CL development version (2.2.7.3). The updated solution of the SWO2021 model was validated and selected as the example for this development, as it was more comprehensive and consistent with the single-sex equivalent (Ducharme-Bath et al. 2021). The input fisheries data was converted to suit the catch-conditioned method, having survey index fisheries supplying CPUE indices, and with CVs that correspond to the assumed penalty weights as applied in the original catch-errors method. The initial "-makepar" operation was completed, and the input 00.par file structure was assessed. The phase 1 flags were converted from the catch-errors method, to implement the catch-conditioned method, the phase 1 operation was completed, and then all subsequent phases of the minimisation.

5.1.1.4 Results

Fishing mortality estimation

As expected, the predicted catches in each sex-specific fishery are a fraction of the observed aggregated catch according to the predicted sex ratio and the sex-specific selectivity (Figure 1). The aggregated predicted catches correspond almost exactly to the observed aggregate values, with the maximum percentage difference in any one time period being 3% for catches greater than the 1st quartile (Table 1). This confirms that the Newton-Raphson solutions for the sex-specific fishing mortality are operating correctly, producing aggregated catches corresponding closely to those observed.

An interesting case was fishery 9, where the predicted catches for sex 1 (male) were almost negligible, with almost all of the aggregated catches derived from that of the sex 2 (female) fishery 25 (Figure 1). This was attributable to the sexually dimorphic growth and the strongly skewed, shared selectivity function at length for these fisheries (Figure 2). This dimorphism results in marked differences in the selectivity-at-length shared among the sexes, such that the effective selectivity for the males was almost zero at the largest male lengths (Figure 3). This exemplifies the processes for growth and selectivity-at-length explicit within the sex-structured model that define the estimated sex-specific fishing mortalities as inferred from the observed size compositions and aggregated catches.

Survey fishery abundance indices

The sex-specific estimates of the vulnerable numbers at age in the survey fisheries were validated within the code implementation, and the aggregated values were being correctly assigned for input to the CPUE likelihood function. The model fit to the observed sex-aggregated CPUE indices was visibly good (Figure 4), showing general consistency in the predictions with the observed temporal trends.

5.1.1.5 Comparisons among the catch-errors and catch-conditioned models

The implications of transferring from the catch-errors method for fishing mortality estimation to the catch-conditioned method was examined using the SWO2021 example. Three models were considered:

Label	Description
catch-errors	2021 catch-errors diagnostic case
catch-cond_nomiss	Catch-conditioned model, no missing catches, initial population in unexploited equilibrium, no catchability-regression for extraction fisheries
catch-cond	The **catch-cond_nomiss** model, but with estimation of the catchability-regression for extraction fisheries with constant catchability

The steps to transition from the catch-errors method to the catch-conditioned model included:

- The input survey fisheries data was converted with CVs that correspond to the assumed penalty weights as applied in the original **catch-errors** model
- Instances of missing catches (109 events out of 4178) in the extraction fisheries observed data were replaced with the corresponding predictions derived from the **catch-errors** model
- The method for initial population conditions was converted from: deriving an estimated mean total survival rate; to, an unexploited equilibrium state
- Implementing the concentrated CPUE likelihood formulation, because this is consistent with the catch-errors penalty function for the effort_devs with a time-variant penalty weight
- Setting the CPUE sigma equal to CV of 0.2 for all survey fisheries, that is consistent with the mean of the time-variant penalty weights applied in the **catch-errors** model
- De-activating all catch-errors method flag settings
- Activating the relevant catch-conditioned method flag settings for catch and CPUE fit

5.1.1.6 Comparison results

As may be expected, the size composition data likelihood terms are comparable among the catch-errors and catch-conditioned model, with a better fit to the length-frequency data obtained for the catch-errors model (Table 2). A slightly better fit was obtained to the weight-frequency data for the catch-conditioned model that excluded the catchability regression.

The CPUE fit is slightly improved when the catchability-regression is included in the model fit (Table 2), with a visible difference in the fit to the observations, although the general predicted trends are very similar (Figure 4).

Markedly different model estimates of absolute biomass were obtained from the catch-errors and catch-conditioned models, with the former having a decreasing trend overall, and the latter an increasing trend or generally flat (sex 2), (Figure 5).

The effect of including the catchability-regression on the model estimates of absolute biomass are marked, with a decreasing trend being estimated that is comparable to that of the original catch-errors model (Figure 6).

For the catch-conditioned model, the extraction fisheries fishing mortality is solved by the Newton-Raphson; from which the implicit catchabilities are derived: $q = F/E$. For the model excluding the catchability-regression (catch-cond_nomiss_bzero), there is no constraint on catchability. Some clear trends are visible in fisheries: 2, 4, 6, 7,10 and 12, with most declining (Figure 7). The overall effect of this catchability decline on model estimates might be: lower biomass in the early periods; and, higher biomass in the latter periods. This was evident in this model (Figure 5, black line), particularly for sex 1, with sex 2 being flat/slightly increasing.

5.1.1.7 Conclusions

The catch-conditioned model has been successfully extended for its application to the sex-disaggregated model structure, and to accommodate observed catches and relative abundance indices that are aggregated among sexes.

This extension has been demonstrated in a real model example, with results that are feasible and comparable with the catch-errors model equivalent. For this example, catchability estimation was stabilised by fitting a catchability regression within the integrated likelihood, which produced more plausible trends in catchability, and hence, absolute biomass.

5.1.2 New output files – "cpue_obs_mls" and "cpue_pred_mls"

A minor enhancement was made to the CPUE likelihood diagnostics, such that validation of the observed indices applied in the likelihood may be possible. Reproducing the original input survey fishery indices from the observed values in the likelihood is difficult because observed effort is log-transformed and normalised. The report provides the mean value used for normalisation, as well as the log-transformed observations applied in the likelihood; allowing back-calculation to the original values.

5.2 Simulation projections

5.2.1 Simulation CPUE pseudo-observations without error

A minor enhancement was made for generating pseudo-observations of CPUE from the catch-conditioned model, that allows output of the projected CPUE without observation error. This may be useful for evaluating candidate Estimation Models relative to the Operating Model pseudo-observations without error.

A new output file "cpue_sim_true" is generated, and was tested with an existing example over 3 simulations. A comparison of one of the fisheries was made between the pseudo-observations with and without observation error (Figure 8). The identical CPUE without error is obtained over the 3 simulations for the estimation model time periods (up to 188). For the projection periods:

- The CPUE without error has considerably less variability than the CPUE with error, and
- the CPUE without error differs among the simulations presumably due to the simulation recruitment variability only.

5.2.2 Catch-conditioned projections with all projection fisheries being effort-conditioned

In the case where a catch-conditioned operating model (OM) needs to have future fishing conditions projected on defined effort levels, the Newton-Raphson solution for fishing mortalities would not be employed during the projection time periods; but rather the predictions of the catchability regression provide fishing mortality estimates given the supplied effort.

Enabling this scenario required adjustments to the code for the catch-conditioned fishing mortality calculations, such that the routines are called even in the event of no positive catches in the fishing incidents of each projection time period.

5.2.2.1 Testing example

The ALB2024 OM was configured for the two cases of fisheries being either catch- or effort-conditioned during the projection time periods:

- **F1catch** – fishery 1 was catch-conditioned, all other fisheries were effort-conditioned
- **alleffort** – all fisheries were effort-conditioned

For all fisheries besides fishery 1, the predicted catches during the projection time periods of both models were essentially identical. The predicted catches for fishery 1 were moderately lower for the **alleffort** model compared to the **F1catch** model (Figure 9). This is probably due to the differences in the effective fishing mortality associated with the fixed catches compared to the assumed constant effort in the **alleffort** model.

The total biomass trajectories of the two models were essentially identical (Figure 10), indicating the essentially identical fishing mortality estimates for all fisheries besides fishery 1, and the slight differences for fishery 1 had negligible effect on the biomass, or the projection depletion levels (Figure 10).

5.3 Sex-structured model

5.3.1 Shared selectivity at length – include von Bertalanffy independent growth offsets

An existing feature in MULTIFAN-CL allows for age-specific selectivity to be estimated for each sex such that the corresponding selectivities at length are essentially the same among the sexes. However, the sex-specific von Bertalanffy growth function may include age-specific independent offsets from the curve estimated for each sex. These offsets must be accounted for when deriving the shared selectivity at length function.

5.3.1.1 Method

The method for deriving the scaled length-at-age and the shared selectivity at length among sexes is described in Davies et al. (2025). Therefore, not all of the component terms in the following equations are reproduced here. The modification required for including the independent offsets, δ_{ga}, for gender *g* and age class *a* is made to the scaled length, *tl*, that is used to map from the scaled interval as

$$tl_{ga} = ll_g + (uu_g - ll_g)\frac{1-\rho_g^{a-ff75_g-1}}{1-\rho_g^{ff3_g-ff75_g-1}} + t\delta_{ga}$$

Where $\rho = e^{-\kappa_g}$, and $ff75_g$ and $ff3_g$ are the fish_flags specifying the minimum and maximum age classes of the interval, and the scaled growth offset, $t\delta_{ga}$, is

$$t\delta_{ga} = \frac{\delta_{ga}}{smaxL_A - sminL_1}$$

In this instance, the minimum age class for which the offset is applied is $ff75_g + 1$, and the mean length-at-age is

$$L_{ff75_g+1} = L_{1g} + \left(L_{A_g} + L_{1g}\right)\left[\frac{1-\rho_g^{ff75_g}}{1-\rho_g^{A-1}}\right] + \delta_{ff75_g+1}$$

And $sminL_1$ is then calculated using the L_{ff75_g+1} for each gender g accordingly, and this includes the effects of the constraints imposed by $ff75_g$ and $ff3_g$ if activated, and the ll_g is derived that includes the offsets.

5.3.1.2 Testing example

The South Pacific albacore tuna model (Teears et al. 2024) was taken as the base model example, and extended to be sex-structured given that sex-disaggregated conditional age-at-length data were available, such that sex-specific growth, with independent offsets, was estimated. The shared selectivities at length for each fishery were obtained before the enhancement (that accounts for the offsets) was made to MULTIFAN-CL so as to provide a basis for comparison (Figure 11). Differences in the selectivities at length existed for the age classes to which offsets were estimated (ages 1 to 4). A deterministic model evaluation (using the existing parameter estimates) was then performed with the version that includes the enhancement, and the resulting selectivities at length were compared with those prior to the enhancement (Figure 11). Accounting for the sex-specific growth offsets in the scaled lengths-at-age has produced the shared selectivities at length that are very similar among the sexes. The minor differences evident are due to the interpolation made between the sex-specific mean lengths-at-age that differ among the sexes.

5.3.2 Input sex-specific movement diffusion rates

The existing feature that allows for the input of pre-determined movement diffusion rates (matrix) was extended for the multi-species or multi-sex model. The input is managed by the command line argument "**-move**" followed by the filename that contains the input matrices. This is performed when undertaking phase 1 to specify either the fixed values for the movement matrices. It was necessary to extend the input implementation to account for the data structures for the species- or sex-structured dimensions.

5.3.3 Natural mortality Lorenzen function

The existing feature for the estimation of natural mortality at age using the Lorenzen function was extended to allow the calculation and assignments in respect of multiple species or sexes. Whereas, this capability was existing only in respect of spline-based selectivity forms.

The example model used was the sex-structured swordfish model, for which the Lorenzen function was specified as being inversely proportional to the mean length-at-age. Given that sex-specific growth was estimated, the shapes of the estimated natural mortality functions differed among the sexes, while assumed asymptotic mortality was fixed for each sex (Figure 12).

5.3.4 Input sex-specific conditional age-length data

The existing feature that allows for the input of conditional age-length data was extended for the multi-species or multi-sex model. This entailed the correct assignment of the fishery-specific observations according to the "Species" (also proxies for "sex") field of the input files. Whereas the observations are indexed in respect of the model fishery definitions, the fishery indices for species/sexes > 1 must be incremented to the corresponding "mirrored" fisheries within the model for the species/sex indexed for the observation. This adjustment was made upon the input of the conditional age-length data.

5.4 Independent variables report

5.4.1 Tagging negative binomial likelihood overdispersion parameters

The overdispersion parameters, τ, of the tagging negative binomial likelihood were added to the output summary report "indepvar.rpt", together with their bounds, indices, and gradients.

5.4.2 Indices for complex parameter structures

A number of parameters have complex data structures, e.g., 4-dimensional arrays, with each dimension relating to an aspect of the model stratification, such as fishery, region, time-step, tag release event, etc. Interpretation of such parameters displayed as a single vector in the report file creates difficulties for the analyst to identify to which stratum the parameter relates. The statum indices were already displayed for some parameters, such as fishery-specific selectivity, but others were not.

The statum indices were included in the "xinit.rpt" and "indepvar.rpt" report labels for the complex parameters: diffusion coefficients, regional recruitment deviates, temporal recruitment deviates, tagging reporting rates, and intial population survival rates.

5.4.3 Orthogonal-polynomial recruitment parameters

While the mean+deviate recruitment parameters were already displayed in the report, those of the orthogonal-polynomial parameterisation were not. This required a new routine that replicates the parameter assignments for the four polynomial levels to ensure the correct order and structure of the parameters was reflected in the report. The labels of the parameters indicate the levels: year, season, region, and season-region; with the vector length of each being that as specified for the number of degrees. Also, the xinit.rpt was necessarily modified such that the labels for the coefficients indicate the hierarchical levels of the parameterisation (year, season, etc.):

- orth_recr_all_year
- orth_recr_all_season
- orth_recr_all_region
- orth_recr_all_season_region

As with all parameters in the report, together with the estimated values, the bounds and gradient are reported.

5.5 Length-based selectivity - constraints

5.5.1 Rationale

Davies et al. (2023) describe the implementation of the length-based selectivity feature in MULTIFAN-CL. While estimation of length-based selectivity was possible, it lacked the capability of applying certain constraints in respect of the selectivity form that are routinely applied for estimating selectivity at age. These include:

- Non-decreasing
- Common selectivity above a specified age
- zero selectivity above a specified age
- zero selectivity below a specified age

5.5.2 Method

The constraints upon selectivity within MULTIFAN-CL are age-based. Within the length-based selectivity feature, the selectivity-at-age is derived from that in respect of length as this is required for the fishing mortality calculations (that are age-structured). Therefore, constraints in respect of age will also act upon the estimated selectivity at length. The exception to this is the non-decreasing constraint, where the penalty function is expressed in terms of the length-based selectivity.

5.5.3 Testing example

The SKJ2024 model was used for testing this feature enhancement, with each of the four constraints applied to selected fisheries: non-decreasing right-hand limb (fishery 3); common selectivity above a specified age (fishery 2); zero selectivity above a specified age (fishery 14); and, zero selectivity below a specified age (fishery 1). The resultant length- and age-based selectivities obtained are shown in Figure 13, illustrating the effects of the constraints after a number of function minimisations.

5.6 Age-based selectivity, no functional form, with constraints

An enhancement was made to the estimation of age-based selectivities with no functional form, for which the number of parameters equals the number age-classes, such that certain age-specific constraints could be applied. This may be desirable in the case of a survey fishery for which relative recruitment indices may be obtained for the youngest age class = 1, while the selectivity for all other age-classes is assumed to be zero. This entailed implementing in the non-functional form selectivity calculations, the constraints activated by fish_flags(16), in particular, the case where selectivities above a specified age are assumed to be zero. Another option is for selectivity indices for all age classes to be estimated, i.e. there is no constraint in respect to a specified age, above which common selectivity is to be assumed. The implementation of these two options was tested with the SKJ2023 model example (Figure 14).

5.7 Upgrades to initial values input from *.ini file

The format of the input ***.ini** file was upgraded to allow the input of the initial values for several more independent variables and flag settings:

- Richards growth parameter ***γ***
- Total population scaling parameter
- Flags for setting tag-related assumptions (tag_flags)

The version number of the ***.ini** file was incremented successively for the above three upgrades to: 1005, 1006, and 1007, respectively. These upgrades enable the ready input of initial or fixed values for the parameters, and easier formatting and input of a large matrix of flags.

5.8 Version number added to *.par file

The MULTIFAN-CL compilation version number has been included in the output ***.par*** file format. While this information is already available in the ***plot.rep*** file, this has previously not been available in the solution ***.par*** files being input for undertaking a model evaluation. This is a potential cause of confusion when running model solutions derived using historical versions of MULTIFAN-CL, and may introduce errors due to backward compatibility issues or changes made to the actions of flag values.

The new line is located near the bottom of the ***.par*** file, as follows…

```
…
# First year in model
1972
# MULTIFAN-CL compilation version number
2271
# The grouped_catch_dev_coffs flag
 0
…
```

Where, the integer value corresponds to the version number (in this example): **2.2.7.1**.

5.9 SSMULT_RE – enabled estimation of additional coefficient

The size composition self-scaling multinomial likelihood with the estimation of random effects (SSMULT_RE), may include the estimation of an additional parameter for a multiplier coefficient of the variance of the size frequency heterogeneity. While this parameter was part of the code implementation for SSMULT_RE, it was not part of the minimization procedure in respect of the parameter placements. The enhancement to include its estimation was tested using a bigeye tuna model, and found to substantially improve the integrated likelihood by 692 points, with a 740 point improvement in the size composition likelihood.

5.10 Initial population survival as a function of natural mortality

An option for estimating the initial equilibrium population is to specify the initial total survival rate as a function of natural mortality with a fixed multiplier assigned using age_flags(128). The assignment of the flag value was: age_flags(128)/10. However, this offers a resolution of the rate to only a single decimal place, e.g., 11/10=1.1, which may be limiting in terms of that desired. This was enhanced by altering the assignment of the flag value to: age_flags(128)/100. This was tested using a SKJ2024 model and found to improve the assumed initial population conditions relative to the early estimated exploitation rates.

5.11 Output file control

A minor enhancement was made to enable independent control of, what can be, large output files. Previously the flags controlling the output was nested for the ***ests.rep*** and the ****.fit*** files, such that control of the latter was conditional upon the former. The flags actions were modified to allows independent control of the output to either, or both of the "ests.rep" and "*.fit" files. So, any combination of the flags will disable, or enable, the output of each file, respectively.

5.12 Bug fixes

5.12.1 <u>Correction: logistic selectivity calculation arithmetic exception</u>

In calculating the logistic selectivities an arithmetic exception was possible due to the rare instance of one of the two parameters being estimated as a negative value, which caused a divide-by-zero arithmetic exception error. A simple algorithm was inserted to avoid this instance.

5.12.2 <u>Tagging observations “inform” fish movement only</u>

Davies et al. (2019) described the MULTIFAN-CL feature for using tagging data to explore solutions with the tagging likelihood in “recapture-conditioned” mode, as an alternative to solutions with total mortality being implicit. This alternative approach is sometimes loosely termed as using tagging data to “inform” the model in respect of movement only. During 2024-25, it was found that this feature failed for the case where recaptures were grouped among defined fisheries. The likelihood implementation was corrected to account for the grouped recaptures option.

5.12.3 <u>Flags setting for orthogonal-polynomial recruitments</u>

The age_flags(177) = 1 setting activates the estimation of the total population scaling parameter as required for the mean + deviates recruitment parameterisation. As such, this parameter, and hence, the flag setting is not required when applying the orthogonal-polynomial recruitment parameterisation. However, an error was revealed when undertaking a zero-fishing mortality evaluation of the orthogonal-polynomial model that required this flag setting. All instances of the flag were reconciled, and removed in cases of the orthogonal-polynomial recruitment parameterisation.

5.12.4 <u>Implementation of Richards growth curve – mean weight calculation</u>

As part of implementing the input of the Richards growth curve parameter from the ****.ini*** file, it became evident that the calculation of the mean weights-at-age in one of the routines lacked the Richards growth curve case. This was duly implemented and tested for the integrity of its calculation.

6 APPLICATION OF FEATURES

6.1 Stock assessments for SC21

The 2025 skipjack stock assessment model (Teears et al. 2025) and the stochastic projection OM models for the MSE analyses (Scott et al. 2025a, 2025b, 2025c, and Yao et al. 2025) were undertaken with implementation of selections of the above-mentioned enhancements in the updated development version 2.2.7.6 of MULTIFAN-CL.

7 FUTURE WORK

A listing of the status of the work: originally proposed, that is pending, in progress, or completed during 2024-25 is provided in Table 3. While a large proportion of what was proposed, as well as unforeseen tasks, were completed, a substantial number of tasks were not completed.

The proposed future work plan for the development of MULTIFAN-CL in 2025-26 is presented in Table 4. Those tasks not completed in 2024-25 have been carried over into this workplan. As was the case for the 2024-25 workplan, no new developments that require substantive mathematical innovation are proposed for the 2025-26 workplan. Rather, resources are directed to: consolidating those aspects that are incomplete for recent new features; enhancements of existing features; and, documentation. The general approach for the future workplan is the same as that of 2024-25, and includes:

- Testing the implementation of examples that employ all the new features and refine the I/O and diagnostic reports.
- The code for existing features will be reviewed and refined; a backlog of bug fixes will be completed; outstanding tasks from the bigeye and yellowfin tuna independent review panel recommendations will be addressed; and any "small-scale" requests in the tasks list.
- Provide training and support for OFP stock assessment scientists.
- Provide support for WCPFC Project 123 to scope the next generation tuna model and the succession beyond MULTIFAN-CL.
- Providing support for MSE requirements and improvements.
- Maintaining the documentation required for the MULTIFAN-CL User's Guide.

Some of the items in Table 4 (tasks rolled over from 2024-25) have been retained, but will be fit within the context of the 2025-26 workplan, and others have been set aside for the years that follow.

8 DISCUSSION

No significantly innovative or new features were implemented into the MULTIFAN-CL source code during 2024-25. Rather, as for 2023-24, the approach set out in the 2024-25 work plan was followed for the substantive features (e.g., catch-conditioned method for estimating fishing mortality) to be consolidated, enhanced, and extended for their implementation in multi-sex and multi-species models, and for undertaking population projections for MSE and TRP analyses.

A substantive achievement in updating MULTIFAN-CL during 2024-25 was to enable the sex-structured model to employ the catch-conditioned method for estimating fishing mortality and the CPUE likelihood. This enables this model structure to have the equivalent features of the single-sex models routinely used for WCPFC stock assessments. The testing of this enhancement exemplified the processes for sexually dimorphic growth and shared selectivity-at-length explicit within the sex-structured model, that define the estimated sex-specific fishing mortalities as inferenced from the observed size compositions and aggregated catches. During 2024-25, both billfish (swordfish) and tuna (albacore) examples were developed as sex-structured models employing the catch-conditioned method with the CPUE likelihood. No major differences, that could not be explained, were evident relative to the original catch-errors model from which the examples were derived.

Three other enhancements were made to the sex-structured model implementation in MULTIFAN-CL, as follows. Firstly, several WCPFC tuna stock assessment models include the estimation of independent offsets from the von Bertalanffy growth curve, (e.g., albacore, yellowfin), and it is likely that sex-structured versions of these models would retain this feature. Therefore, an essential enhancement was to include the age-specific independent offsets estimated for each sex into the derivation of the selectivity at length function shared among the sexes. The utility of the assumption for equivalent selectivity in respect of fish size among the sexes is retained, while allowing growth to differ among the sexes, and also allowing deviates from the growth formulation. Secondly, while average, or age-specific natural mortality deviates were estimable in respect of sexes, the sex-specific Lorenzen functional form was not yet developed. Implementing the sex-specific estimation of this function was demonstrated clearly for the sex-structured swordfish model, for which the Lorenzen function was specified as being inversely proportional to the mean length-at-age, given the estimated sexually-dimorphic growth. Thirdly, the input of conditional age-length data specific to each sex enabled this data type to contribute to the estimation of sexually-dimorphic growth. This capability was demonstrated using the albacore tuna example for which clear differences in the growth estimates were evident among the sexes.

Collectively, the above enhancements raise the sex-structured model as implemented in MULTIFAN-CL to an equivalent standard to that of the single-sex models routinely developed for WCPFC stock assessments.

A valuable enhancement made to undertake simulation projections allows for the case where a catch-conditioned operating model (OM) employs projection fisheries all of which are effort-conditioned. The Newton-Raphson solution for fishing mortalities would not be employed during the projection time periods; but rather the predictions of the catchability regression provide fishing mortality estimates given the supplied effort, in all the projection time periods. This offers another scenario to the OM range possible in MSE analyses using MULTIFAN-CL.

Adding the capability for applying constraints to the estimation of length-based selectivity considerably improved this feature, and which proved useful for the development of the 2025 skipjack stock assessment model (Teears et al. 2025). The constraints included: a non-decreasing function; common selectivity above a specified age; and, zero selectivity above or below a specified age.

Various other enhancements simply improved the user's operating environment, such as: independent control of what can be large output files; including the compilation version number in the output .par file format; upgrading the input *.ini file to allow the input of the initial values for several more independent variables and flag settings; and, improvements to the diagnostic report of the independent variables; inter alia. These may improve the analyst's performance in using MULTIFAN-CL to replicate historical model solutions, to decrease model minimization processing time, and when reviewing MLE model diagnostics. The input of OFP scientists in respect of these enhancements is gratefully acknowledged.

Updating the User's Guide was assigned a high priority for 2024-25 (Davies et al. 2024), and completing this task was a landmark achievement. In total, all the changes and new features that have been added over 9 separate release versions (2.0.6.0 to 2.2.7.2) since August 2018 were documented, including those for substantive new features now routinely employed in WCPFC stock assessments, MSE and TRP analyses, including:

- Catch-conditioned method for fishing mortality estimation;
- CPUE likelihood;
- Diagnostics of the MLE model and Hessian solution;
- Variance calculations of WCPFC reference point dependent variables; and,
- Catch-conditioned operating model projections and simulations.

This was a substantive work component of 2024-25, and was essential to ensure analysts were equipped with the necessary reference document that describes the model structures, features, and the associated flag settings. It may also provide a useful reference document for the WCPFC project 123 (see below).

All the enhancements and corrections were accompanied by detailed testing with tuna stock assessment model examples, with the outcomes and implications illustrated and described. This confirms the developments to have been correctly implemented. Also, they were accompanied by benchmark testing to assess their implications on the function evaluation and dependent variable estimates. The testing framework required little maintenance during 2024-25, with benchmark tests being successfully executed – one comprehensive, and two abbreviated. No substantive issues were identified, and only two corrections were necessary to the development version. Testing is essential in assuring the integrity of the existing features in the release and development versions. During 2024-25, three additional catch-conditioned model examples were added to the range of single-species data employed in the tests, so that the recently added features are included in the evaluations.

During 2024-25 a contribution was made to the WCPFC project P123 "Scoping the Next Generation of Tuna Stock Assessment Software" (Magnusson et al., 2025). Good progress was made towards establishing a public repository for MULTIAN-CL, in terms of improving the: source code, compilation directory, copyright, licensing and release documentation. **This public version may have utility as a reference and source code resource over the coming years during which a next-generation software may be developed for undertaking future tuna stock assessments.**

A number of the tasks set out in the 2024-25 workplan were replaced by higher priority tasks introduced during the year as were required, or considered more important, for completing the 2025 stock assessments. This flexibility in implementing the workplan is necessary for ensuring that the production version, i.e., the version being applied currently to produce stock assessment models for delivering advice to the WCPFC, has all the functionality required to implement the chosen assumptions, parameter configurations, and to obtain well-determined solutions. Consequently, those lower priority, incomplete tasks for 2024-25 have been carried over to the 2025-26 workplan. An important first step in the coming year will be to prioritise the list of tasks to identify those of immediate priority for the forthcoming 2026 stock assessments.

As already mentioned, the developments in 2024-25 were restricted to consolidating recent features (e.g., catch-conditioned sex-structured models), enhancing existing features, improvements to processes and reporting, and making corrections. The workplan for 2025-26 continues with this theme, with a number of the proposed tasks seeking to further improve the catch-conditioned method and the sex-structured model. These will be the focus for the coming year.

9 REFERENCES

Bull, B., Francis, R.I.C.C., Dunn, A., McKenzie, A., Gilbert, D.J., Smith, M.H., Bian, R., and Fu, D. 2012. CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.30-2012/03/21. NIWA Technical Report 135. 280 p.

Davies, N., Fournier, D., Bouyé, F., and Hampton, J. 2016. Developments in the MULTIFAN-CL software 2015-16. WCPFC-SC12-2016/SA-IP-10. Bali, Indonesia, 3 – 11 August 2016.

Davies, N., Fournier, D., Takeuchi, Y., Bouyé, F., and Hampton, J. 2019. Developments in the MULTIFAN-CL software 2018-19. WCPFC-SC15-2019/SA-IP-02. Pohnpei, Federated States of Micronesia, 12 – 20 August 2019.

Davies, N., Fournier, D., Bouyé, F., and Hampton, J. 2021. Developments in the MULTIFAN-CL software 2020-21. WCPFC-SC17-2021/SA-IP-01. Electronic Meeting.

Davies, N., Fournier, D., Bouyé, F., and Hampton, J. 2022. Developments in the MULTIFAN-CL software 2021-22. WCPFC-SC18-2022/SA-IP-03. Electronic Meeting.

Davies, N., Fournier, D., Bouyé, F., Hampton, J. and Magnusson, A. 2023. Developments in the MULTIFAN-CL software 2022-23. WCPFC-SC19-2023/SA-IP-02. Koror, Palau, 16 – 24 August 2023.

Davies, N., Bouyé, F., and Hampton, J. 2024. Developments in the MULTIFAN-CL software 2023-24. WCPFC-SC20-2024/SA-IP-02. Manila, Philippines, 14 – 21 August 2024.

Davies, N., Fournier, D., Hampton, J., Kleiber, P., Bouyé, F., and Hoyle, S. 2025. MULTIFAN-CL User's Guide. http://www.multifan-cl.org/

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

Hamer, P. 2025. Summary report from the SPC Pre-assessment Workshop – April 2025. WCPFC-SC21-2025/SA-IP-01. Nuku'alofa, Tonga, 13 – 21 August 2025

Ianelli, J., Maunder, M., and Punt, A. 2012. Independent review of 2011 WCPO bigeye tuna assessment. WCPFC-SC8-SA-WP-01

Kleiber, P., Fournier, D., Hampton, J., Davies, N., Bouyé, F., and Hoyle, S. 2018. MULTIFAN-CL User's Guide. http://www.multifan-cl.org/

Magnusson, A., N. Davies, G. Pilling, and P. Hamer. 2025. Scoping the Next Generation of Tuna Stock Assessment Software: Progress Report (Project 123). WCPFC-SC21-2025/SA-WP-01. Nuku'alofa, Tonga, 13 – 21 August 2025

Punt, A.E., Maunder, M.N., and Ianelli, J.N. 2023. Independent review of recent WCPO yellowfin tuna assessment. WCPFC-SC19-2023/SA-WP-01. Koror, Palau, 16 – 24 August 2023

Scott, F., Scott, R., Wickens, M., and Yao, N. 2025a. Evaluation of candidate management procedures for South Pacific albacore. WCPFC-SC21-2025/MI-WP-04, Nuku'alofa, Tonga, 13-21 August 2025.

Scott, R., Scott, F., Yao, N., Wickens, M. and Pilling, G. 2025b. Operating models for bigeye tuna in the WCPO. WCPFC-SC21-2025/MI-WP-05, Nuku'alofa, Tonga, 13-21 August 2025.

Scott, R., Scott, F., Yao, N., Wickens, M. and Pilling, G. 2025c. Impacts of changes to the FAD closure period on the expected performance of the WCPO skipjack tuna management procedure. WCPFC-SC21-2025/MI-WP-02, Nuku'alofa, Tonga, 13-21 August 2025.

Teears, T., Davies, N., Hampton, J., Magnusson, A., Vidal, T., and Hamer, P. 2025. Stock assessment of skipjack tuna in the western and central Pacific Ocean: 2025. WCPFC-SC21-2025/SA-WP-02. Nuku'alofa, Tonga, 13 – 21 August 2025

Yao, N., Nishimoto, N., Teears, T., Aoki, Y., Scott, R., Scott, F., Wickens, M. and Pilling, G. 2025. Skipjack MP estimation method analysis: P&L CPUE. WCPFC-SC21-2025/MI-WP-01. Nuku'alofa, Tonga, 13 – 21 August 2025

10 TABLES

Table 1. The maximum percent difference in the sex aggregated catches: observed versus predicted; for the extraction fisheries in any individual model time period.

Fishery	Maximum percent difference in aggregated catch
1	0.98
2	0.80
3	3.33
4	1.24
5	1.01
6	1.70
7	0.93
8	2.11
9	1.07
10	0.59
11	1.23
12	0.69
13	0.56

Table 2. Component terms of the integrated total negative log-likelihood for the catch-errors and catch-conditioned models for the SWO201 example.

	catch-errors	**catch-cond_nomiss_bzero**	**catch-cond_qregrssn**
effort_dev_penalty	32.314	-	-
total_catch	5.529	-	-
Length frequency	-12892.677	-12847.071	-12725.213
Weight frequency	-40510.417	-40520.611	-40502.503
CPUE	-	-39.878	-40.113

Table 3. Modifications to MULTIFAN-CL with respect to their state of completion as of July 2025.

2011 Bigeye Tuna Peer review recommendations		
Task	Description	Status of completion
b. Non-uniform size bins	Allow the length bins to be of different widths. One might, for example, want many narrow length bins for the smaller lengths, but fewer but wider length bins for the larger lengths.	Development 0%
d. Tags inform movement	Include an option which allows the tagging data to inform movement only rather than movement and mortality.	Development 100%; Testing 90%
Other developments (* those added to the workplan after July 2024)		
Task	Description	Status of completion
Catch-conditioned model and projections	Document the catch-conditioned method, and flags for Manual	Complete 100%
	Fishing mortality estimation for multi-species/sexes	Development 100%; Testing 100%
	Projections of the catch-conditioned model often employ effort-conditioned fisheries, for which catch is unknown in <u>each projection time period</u>, and only the "observed" effort is known*	Development 100%; Testing 100%
CPUE likelihood consolidation	Enable for multi-species/sexes with aggregated indices*	Development 100%; Testing 100%
	Change the expression of fish_flags(92) for the non-concentrated CPUE likelihood to be the same as that of the concentrated form, i.e., as defining the sigma value	Development 100%; Testing 100%
Independent variables report	Add index values: 'recr', 'diff_coffs', 'region_rec_diffs', and 'tag_fish_rep' indices into the parameter names*	Development 100%; Testing 100%
Constrain deviates	Apply constraints on the recruitment deviates such that the $\bar{x}$ = 0. Apply also to the effort deviates for fisheries with missing effort data for the complete time series.	Development 10%; Testing 0%
Tags inform growth	Development of a feature that incorporates size data from tag recaptures to inform growth estimation.	Development 0%; Testing 0%
MSE Team support	Tutorial on catch-conditioned method calculations of fishing mortalities and catchabilities*	Complete 100%
Hessian operations	Debug the running of the Hessian calculations that interact with the test_plot_output report; replaces 0s in for all of the length comp likelihood entries	Development 100%; Testing 100%
EM fit only projection pars	For the "assessment" estimation model (EM) embedded in a management procedure, only fit parameters relating to the "new" data provided for the projection time periods, i.e. for effort devs, catchability devs, recruitment devs, while holding all other parameters fixed at the initial values.	Development 80%; Testing 0%
OM size comps	Generate a report of the OM size compositions for projection period without error at the end of the projection period as required for deriving economics-based indicators.	Development 0%; Testing 0%
Turing test	Ensure the quality of pseudo-observations to be made more realistic by:	Development 0%; Testing 0%

	• Including the sel_dev_coffs and eff_devs estimates in applying process error in projection size compositions and effort • Including over-dispersion error in tagging data	
Stochastic projection functionality	• Implement process error in future recruitments with application of the derived autocorrelation coefficient in historical recruitment estimates • Fix a bug in generating inputs for stochasticity in $N_{terminal}$ (more stable method is to use terminal year less 5 as the period for obtaining variance) and eff_devs	Development 0%; Testing 0%

Table 4. Proposed workplan for MULTIFAN-CL in 2025-26 and subsequent years, and those for which implementation and testing is to be completed.

Peer review recommendations		
Task	Description	Implementation
b. Non-uniform size bins	Allow the length bins to be of different widths. One might, for example, want many narrow length bins for the smaller lengths, but fewer but wider length bins for the larger lengths.	2025-26
d. Tags inform movement	Testing for the case of multi-species/stocks/sexes.	2025-26; Development 100%; Testing 90%
Developments carried over from 2024-25		
Task	Description	Implementation
Catch-conditioned method	Allow the fml_effort_rltnshp penalty calculation to be conditional on a fish_flags(fi) that facilitates it being disabled, or specified, only for particular fisheries.	2025-26
	Review the operation of existing control phase routines undertaken in Phase 1 in respect of their suitability for a catch-conditioned model, and draft a new control phase specific to the catch-conditioned model as needed.	2025-26
Constrain deviates	Apply constraints on the recruitment deviates such that the $\bar{x}$ = 0. Apply also to the effort deviates for fisheries with missing effort data for the complete time series.	2025-26
Tags inform growth	Development of a feature that incorporates size data from tag recaptures to inform growth estimation.	2025-26
CPUE likelihood	Review the formulation of the concentrated log-normal likelihood formulation as used in CASAL (Bull et al. 2012) for its suitability for implementation in MULTIFAN-CL.	2025-26
Outstanding testing of existing features	Multi-sex model projections	2025-26
EM fits only projection parameters	For the "assessment" estimation model (EM) embedded in a management procedure, only fit parameters relating to the "new" data provided for the projection time periods, i.e., for effort devs, catchability devs, recruitment devs, while holding all other parameters fixed at the initial values.	post-2025-26
OM size comps	Generate a report of the OM size compositions for projection period without error at the end of the projection period as required for deriving economics-based indicators.	post-2025-26
Stochastic projection functionality	- implement process error in future recruitments with application of the derived autocorrelation coefficient in historical recruitment estimates - stochastic variability in terminal numbers at age - consolidate the generation of stochasticity in effort_dev_coffs	post-2025-26
Turing test	Ensure the quality of pseudo-observations to be made more realistic by: - Including the sel_dev_coffs and effort_dev_coffs estimates in applying process error in projection size compositions and effort - Including over-dispersion error in tagging data	post-2025-26
Recruitment random effects	Report on the feasibility of its implementation in MULTIFAN-CL.	post-2025-26
Length-based selectivity	Resolve the anomalies that produce undesirable discrepancies in predicted weight frequency compositions.	post-2025-26
Self-scaling multinomial with random effects	Complete draft paper for peer review.	post-2025-26
Recruitment correlates	Region-specific environmental recruitment correlates estimated within the orthogonal polynomial parameterisation for recruitments	post-2025-26

Movement correlates	Add a time-series structure (e.g., random walk, time blocks or using environmental correlates) to movement coefficients	post-2025-26
Recruitment deviate penalties	Allow for time-variant penalties on recruitment deviate estimates	post-2025-26
Tagging multi-sex	Account for instances of differences between size composition the tag releases and the sex-specific populations	post-2025-26
Region specific SRR	Allow that region-specific spawning biomass is responsible for recruitment within that region. This is consistent with the assumption that stocks may not be truly panmictic. This would estimate region-specific SRRs.	post-2025-26
Report comments	Add comment descriptions of the selectivity parameter configurations in the output .par and .rep reports	post-2025-26
Developments for 2025-26		
Task	Description	Implementation
Catch-conditioned method	Enable the estimation of selectivity deviate coefficients sel_dev_coffs	2025-26
Growth estimation	Implement the linear relationship for standard deviation of mean length-at-age and length for the Richards parameterisation and for multi-species/sex instances	2025-26
BH-SRR	Ensure robustness when steepness approaches a value = 1	2025-26
Terminal constant recruitment	Add the option for specifying the range of years for calculating the mean value to which the terminal recruitments are constrained	2025-26
Variance estimation	Restrict the variance estimation to a defined subset of time series dependent variables	2025-26
Repository	Complete development of a public version of the MULTIFAN-CL github repository.	2025-26
Tasks from the Yellowfin Tuna Independent Peer Review Panel 2022		
Length-weight variance	Extend MULTIFAN-CL so that variability in weight-at-length can be taken into account	2025-26
Selectivity splines	Extend MULTIFAN-CL so that it is possible to specify the number of spline knots when defining selectivity and where they are located with respect to age (length) as the current approach means that the selectivity for some knots is constrained to zero.	2025-26
Age-reading error	Extend MULTIFAN-CL so that account can be taken of age-reading error when fitting to conditional age-at-length data.	2025-26
CPUE overdispersion	Add the ability to specify overdispersion in CPUE as an additive rather than multiplicative factor.	2025-26
Natural mortality at age	Integrate the calculation of M-at-age from the sex-ratio data into MULTIFAN-CL unless a sex-specific assessment is used.	2025-26
Tasks newly added		
PDH diagnostics	Refine and describe the algorithm of positive definite Hessian (PDH) diagnostics to be done for an assessment; add a unique identifier to the Hessian file, therefore its parallelised components, and possibly to the *.par, to ensure continuity among them when stitching parallel *.hes files.	post-2025-26
Evaluations report	Report the number of function evaluations completed during the minimisation in an output file.	post-2025-26
Simulation pseudo-observations	Correction to the generation of simulation pseudo-observations of tagging data when employing the catch-conditioned model	post-2025-26
Variance report	Resolve the discrepancy between F_{recent}/F_{msy} in the dependent variables variance report and the Fmult in the plot.rep report	post-2025-26

11 FIGURES

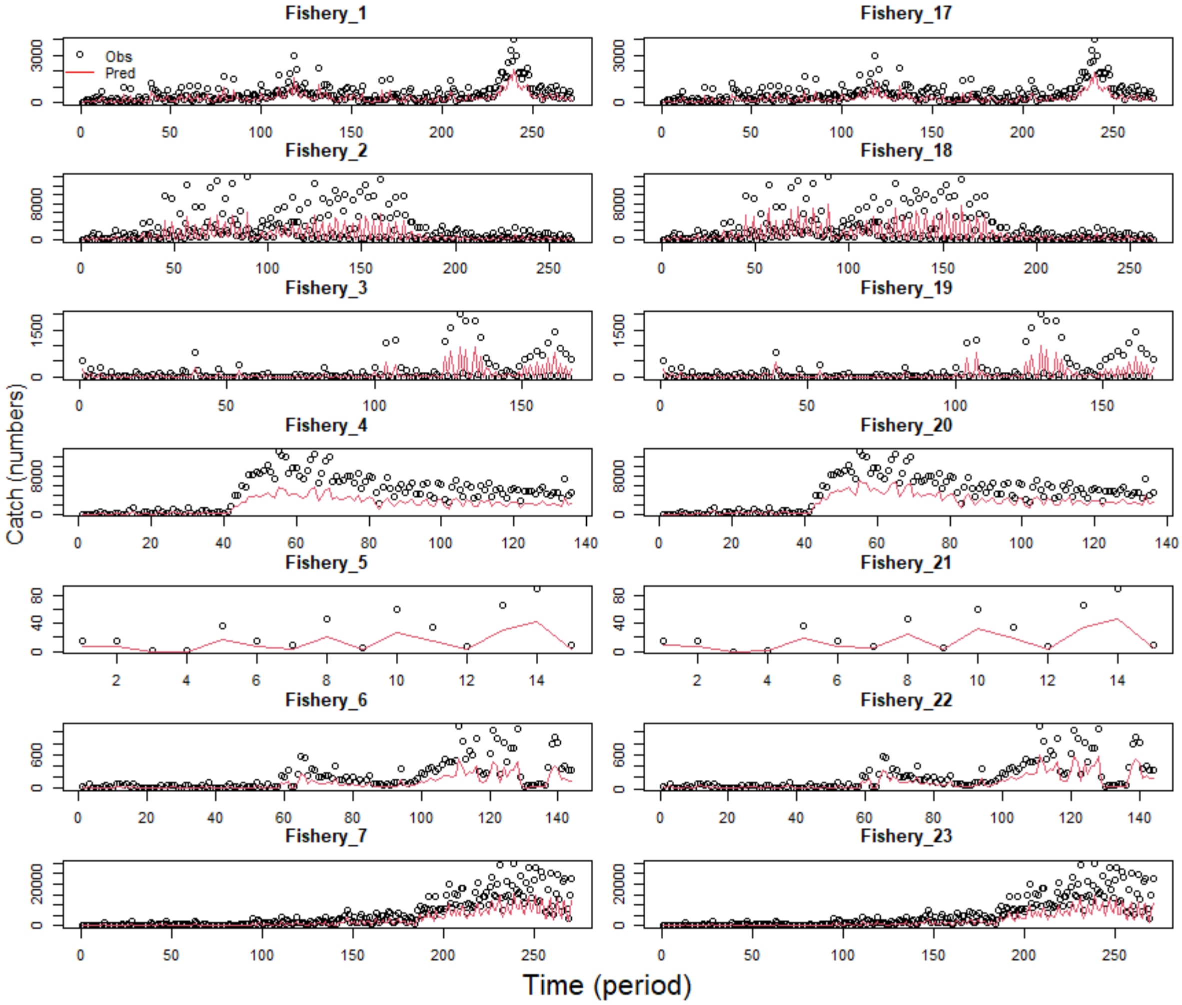


Figure 1. Observed and predicted catches for fisheries defined for sex 1 (left panels) and sex 2 (right panels).

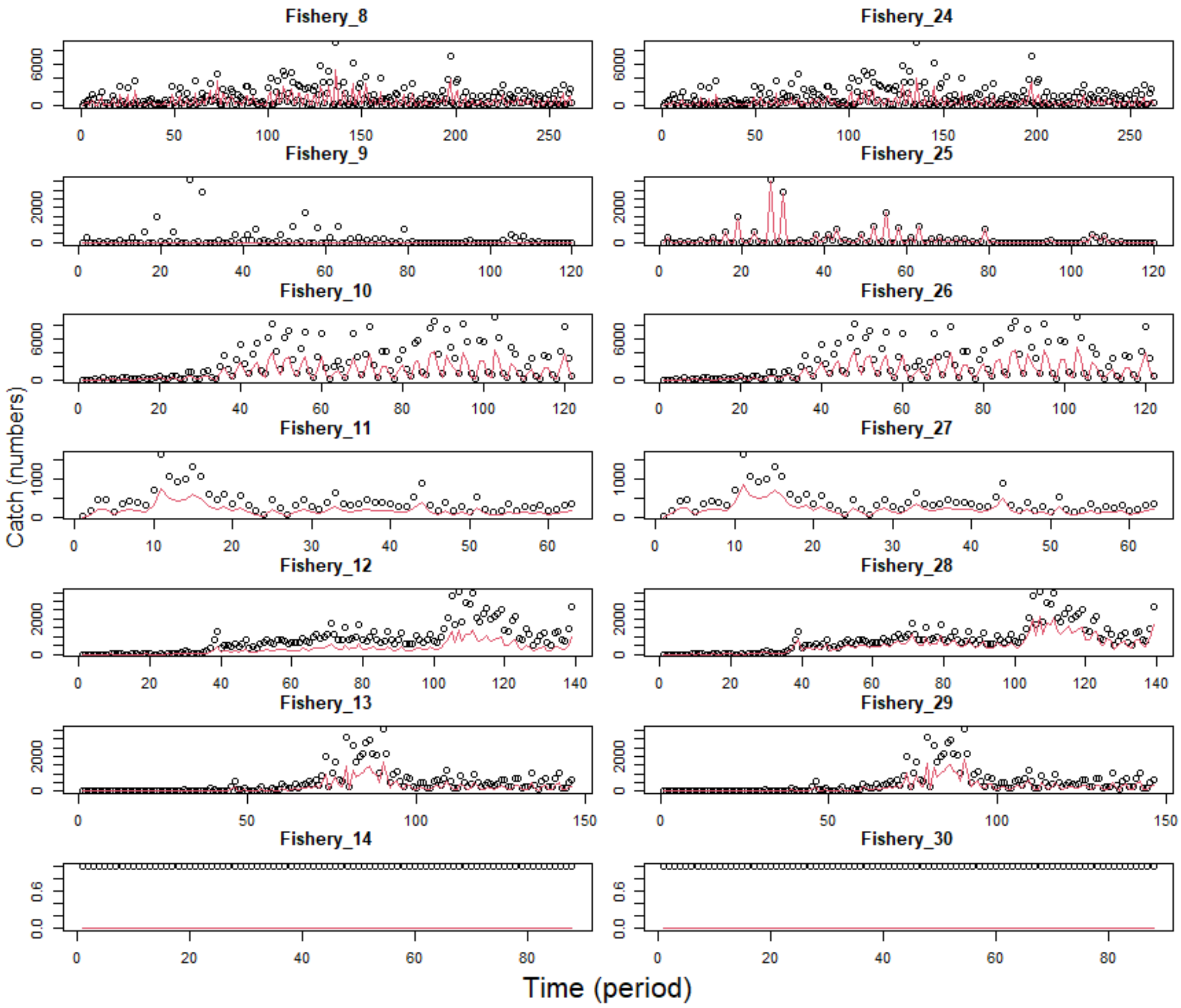


Figure 1 cont.: Observed and predicted catches for fisheries defined for sex 1 (left panels) and sex 2 (right panels).

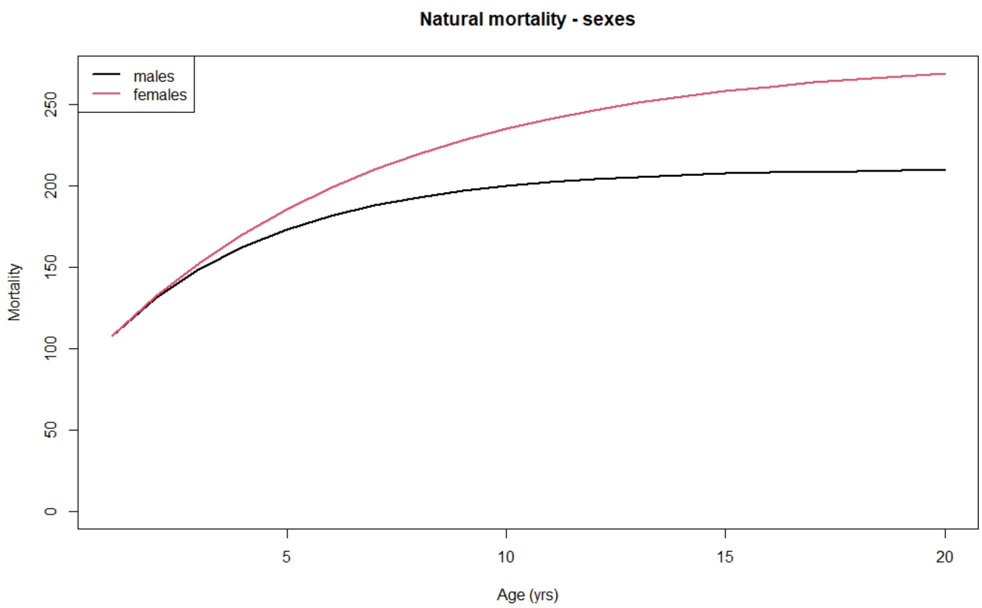


Figure 2. Growth expressed as mean length-at-age for males (top panel) and females (bottom panel).

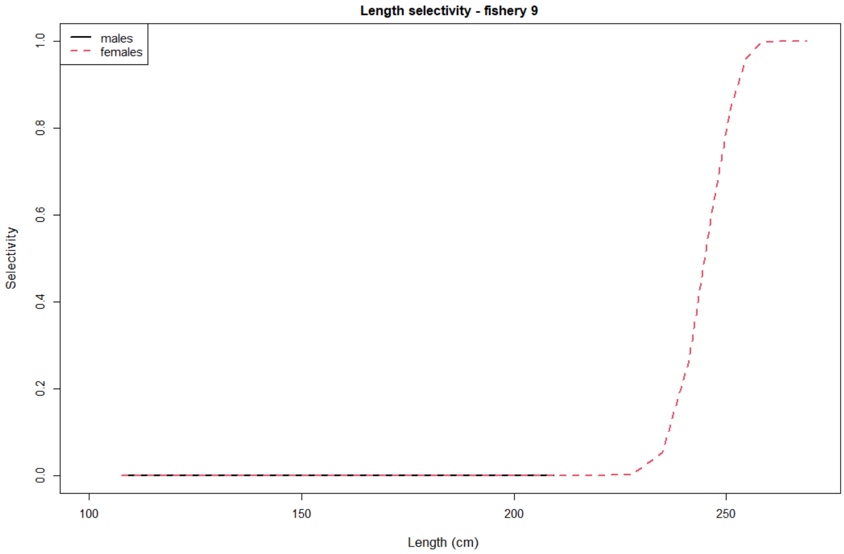


Figure 3. Estimated selectivity at length for males (yellow) and females (green) for SWO model fishery 9.

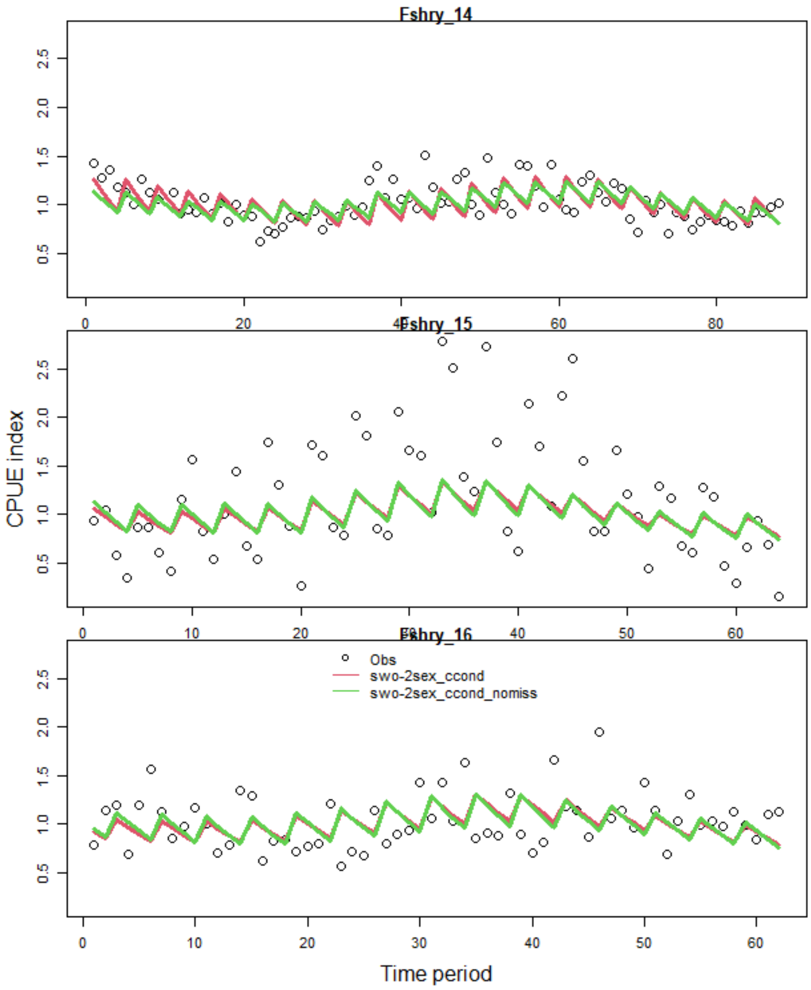
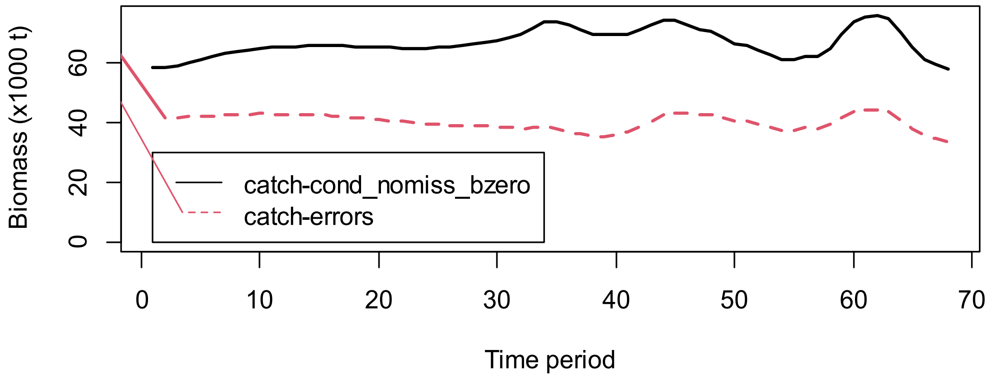


Figure 4. Observed and predicted CPUE indices for the survey fisheries for the fit of the multi-sex catch-conditioned models: without the catchability-regression (green line - swo-2sex_ccond_nomiss), and with the catchability-regression (red line - swo-2sex_ccond).

Multi-sex catch-errors vs catch-cond_nomiss_bzero Total Biomass: se



Multi-sex catch-errors vs catch-cond_nomiss_bzero Total Biomass: se

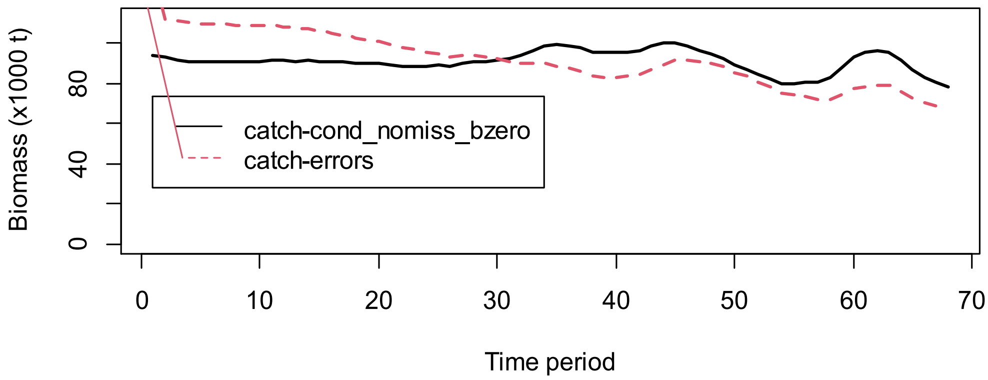


Figure 5. Estimated sex-specific absolute biomass (sex 1 top panel, sex 2 bottom panel) for the catch-errors model (dashed red line), and catch-conditioned model without the catchability-regression (black line – catch-cond_nomiss_bzero).

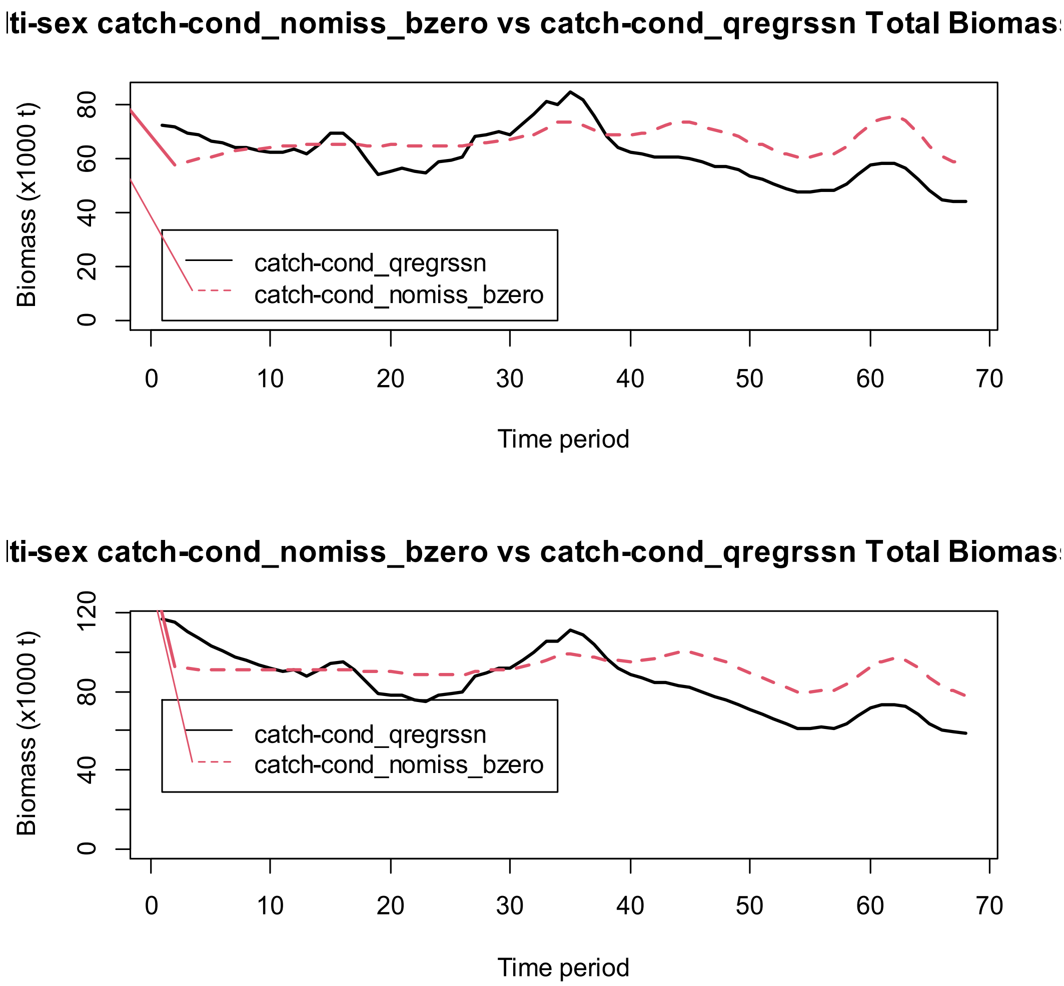
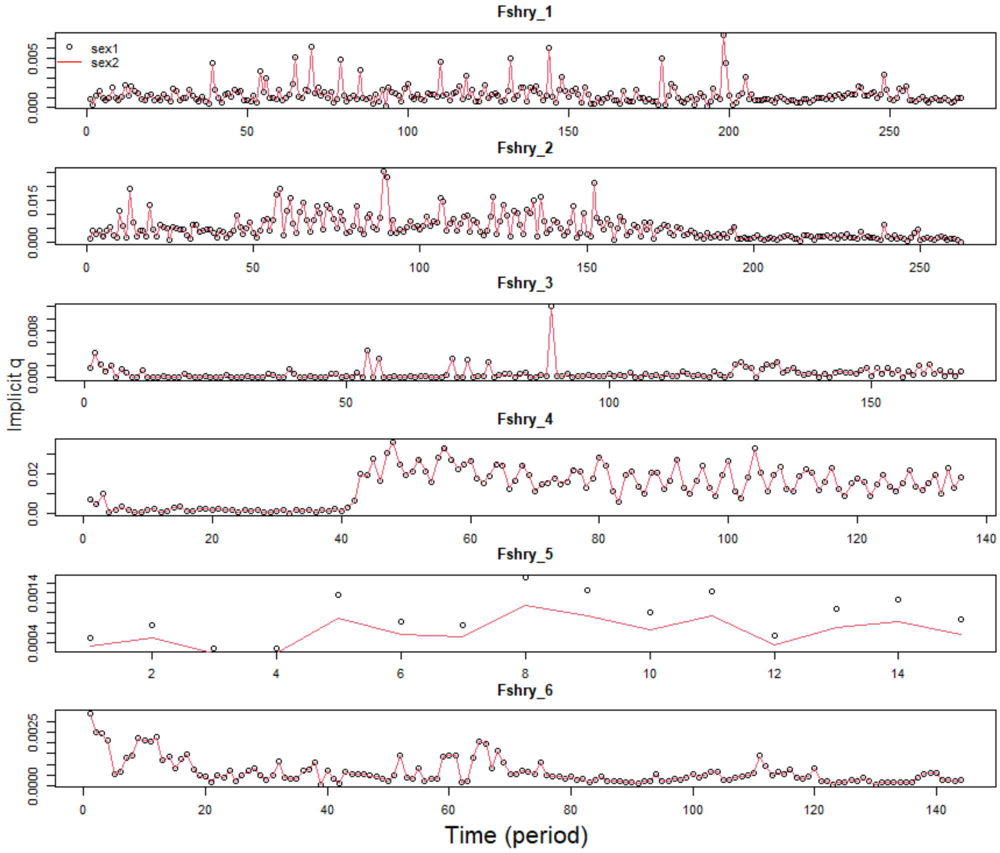


Figure 6. Estimated sex-specific absolute biomass (sex 1 top panel, sex 2 bottom panel) for the catch-conditioned model without the catchability-regression (catch-cond_nomiss_bzero – dashed red line), and the catch-conditioned model with the catchability-regression (black line – catch-cond_qregrssn).



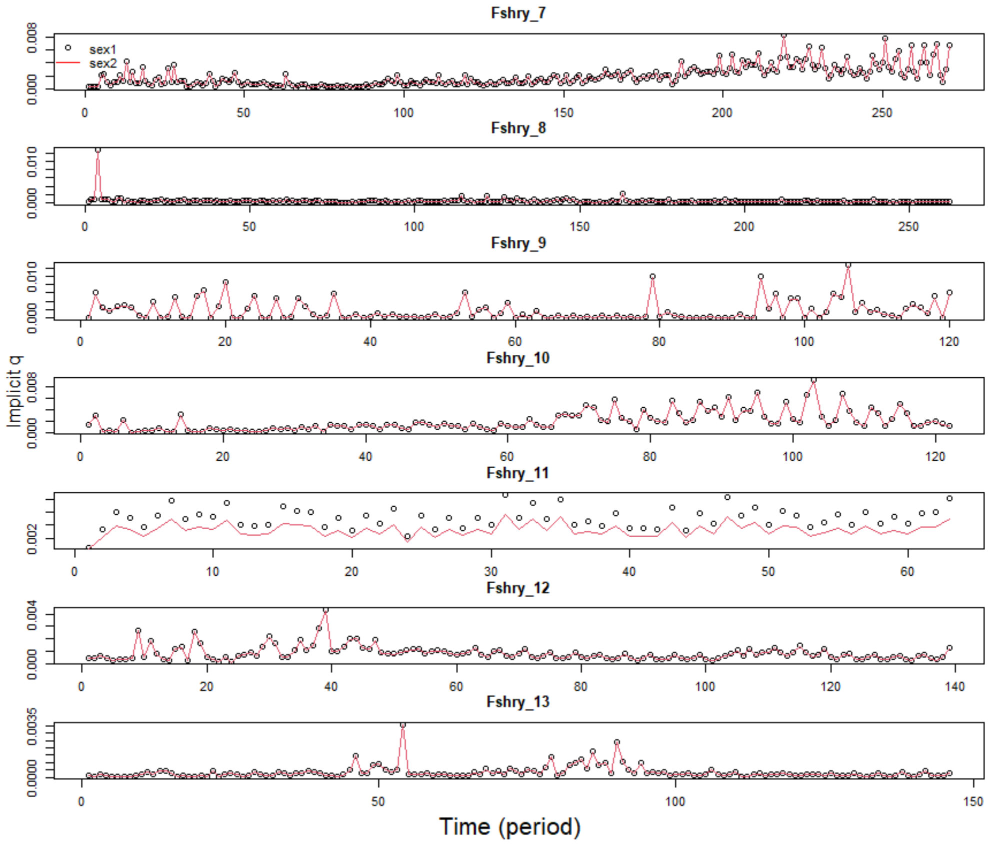


Figure 7. Implicit catchabilities for the catch-conditioned model without the catchability-regression (catch-cond_nomiss_bzero) for the extraction fisheries, for sex 1 (circles) and sex 2 (red line).

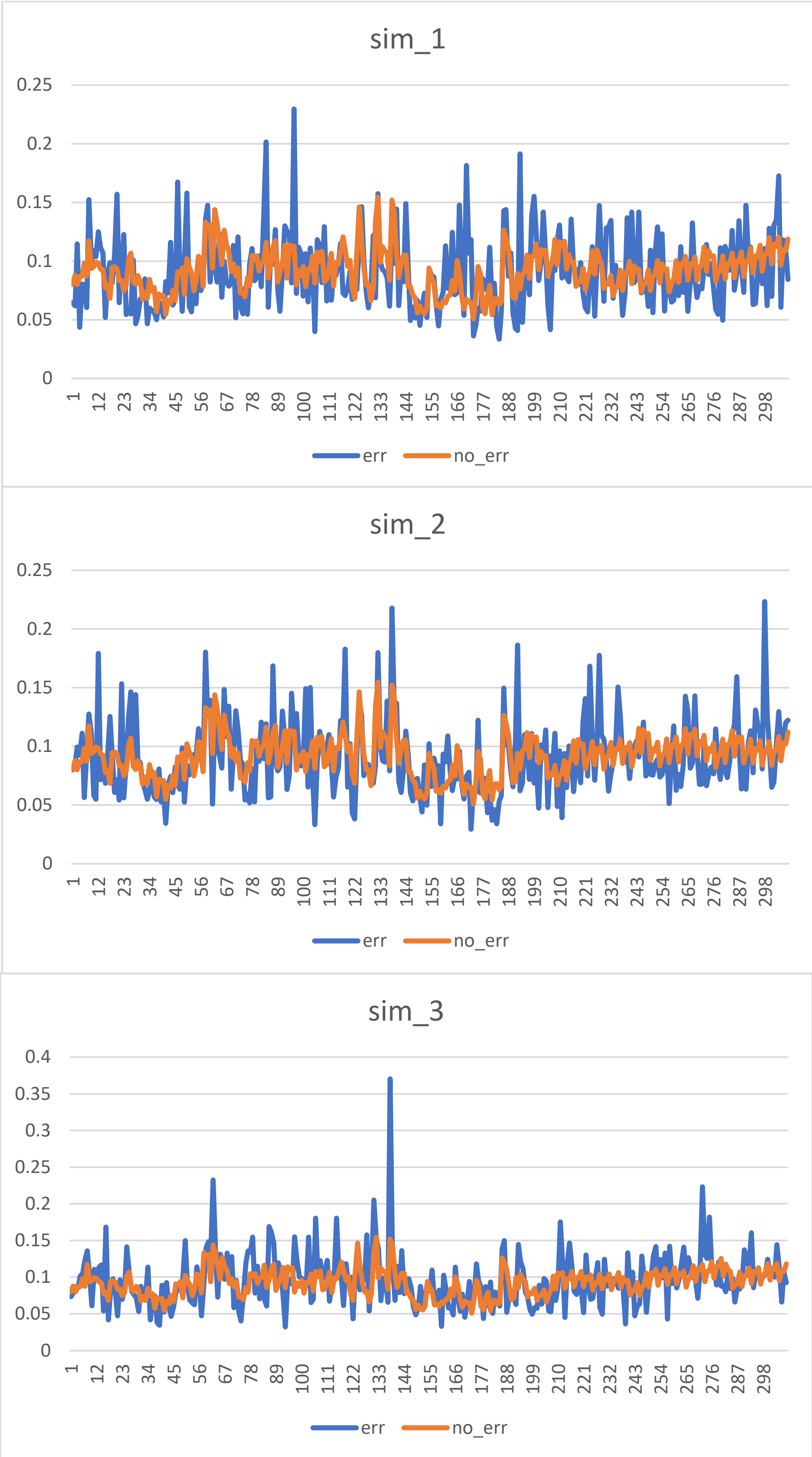


Figure 8. Comparison between the CPUE pseudo-observations with and without observation error (err and no_err) for a single fishery over three simulations (sim_1, …).

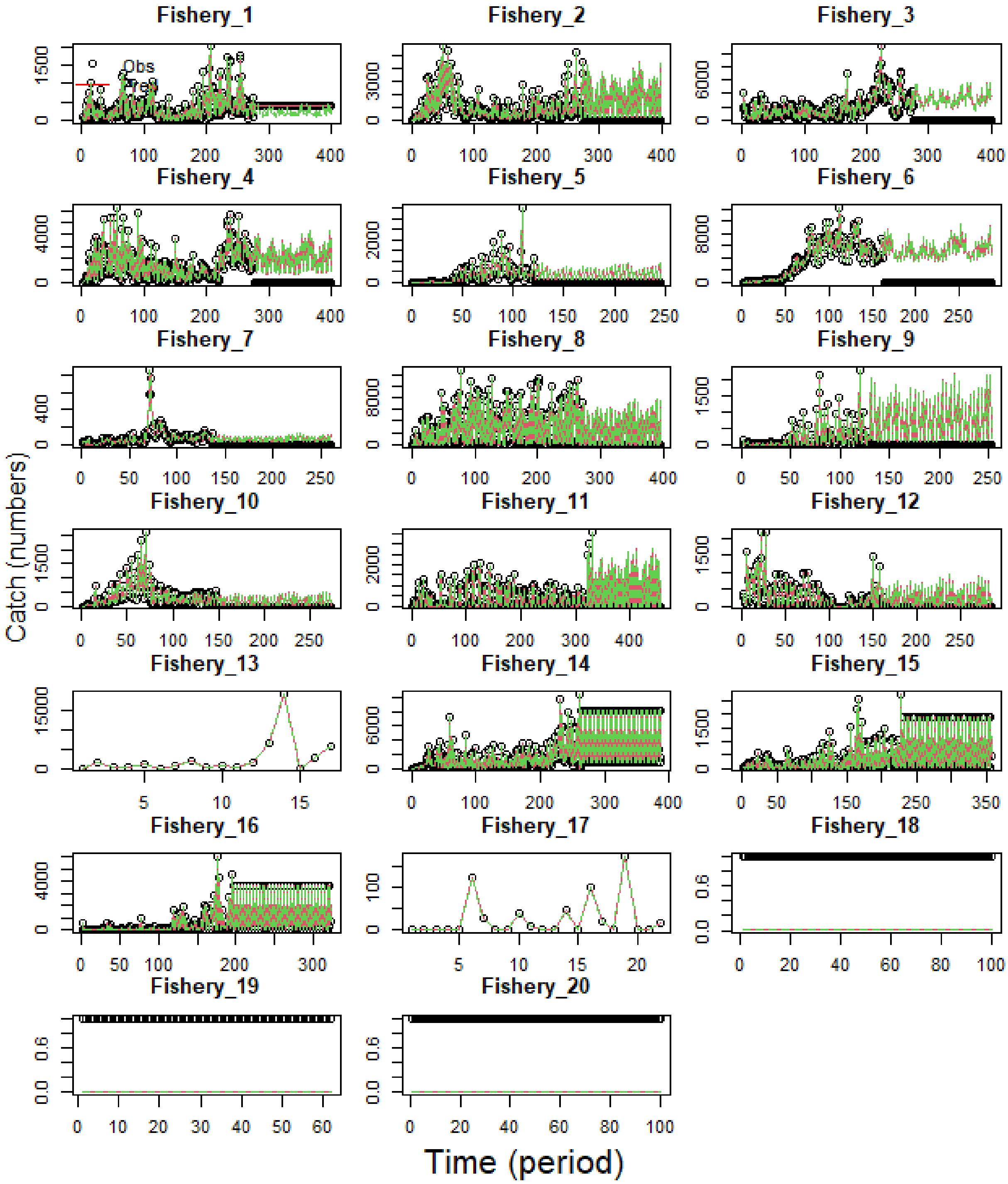


Figure 9. Predicted catches for the catch-conditioned OM for two scenarios: projection fisheries with Fishery 1 being catch-conditioned, all others effort-conditioned (F1catch – solid red line); and, projection fisheries are all effort-conditioned (alleffort – dashed green line).

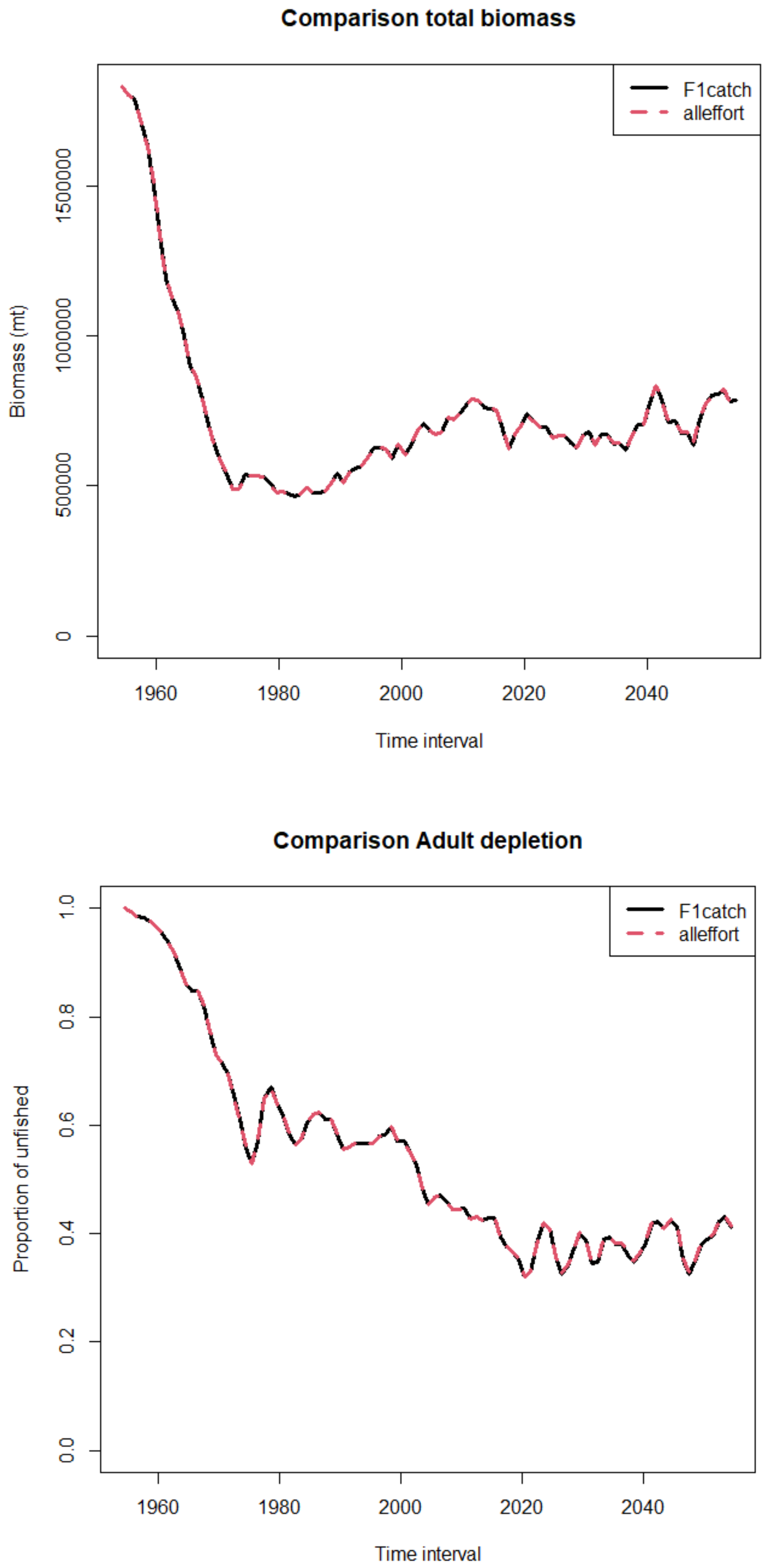
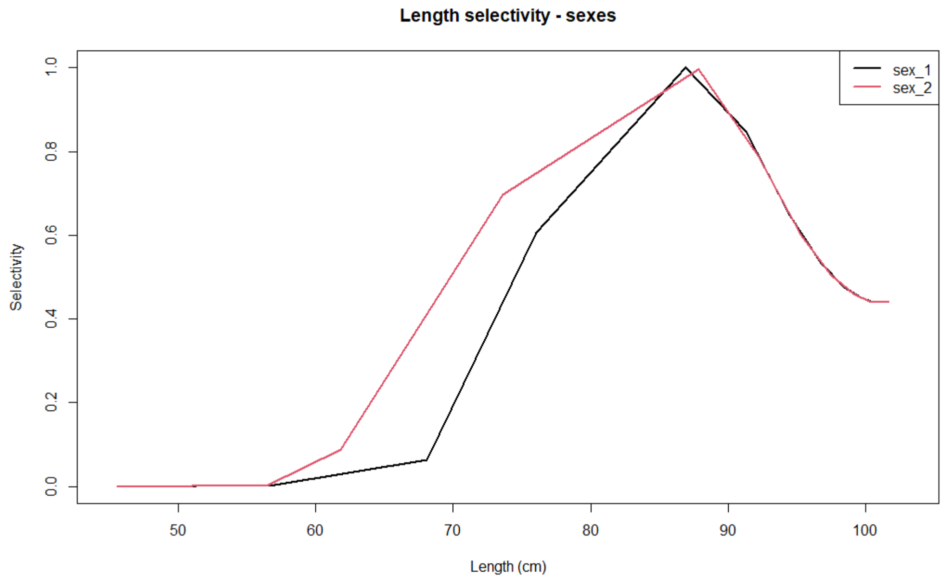


Figure 10. Predicted total biomass (top panel), and depletion (bottom panel) for the catch-conditioned OM for two scenarios: projection fisheries with Fishery 1 being catch-conditioned, all others effort-conditioned (F1catch – solid black line); and, projection fisheries are all effort-conditioned (alleffort – dashed red line).



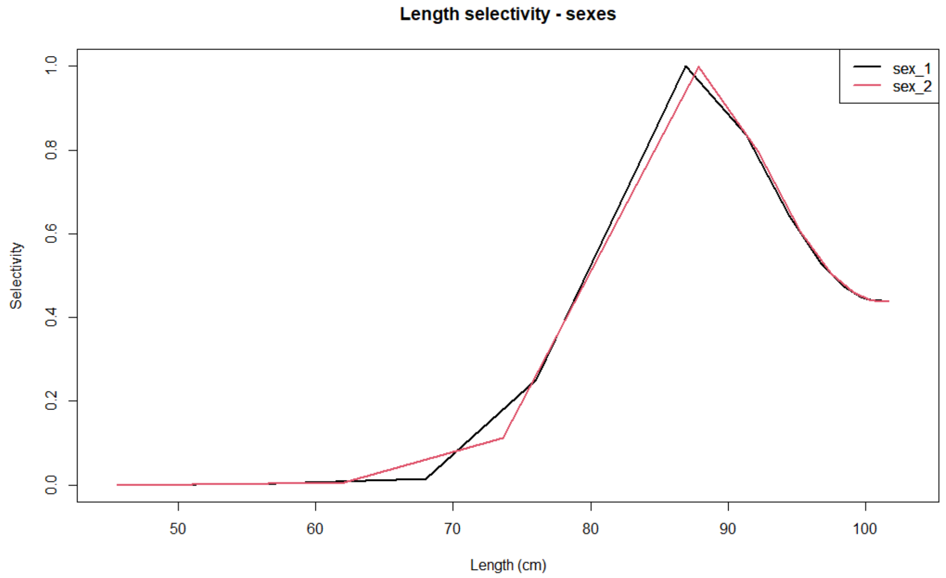


Figure 11. Selectivity-at-length that is shared among the sexes of the ALB2024 sex-structured model as derived from the estimated selectivity-at-age either: without accounting for the estimated growth offsets (top panel); or, with accounting for the offsets (bottom panel).

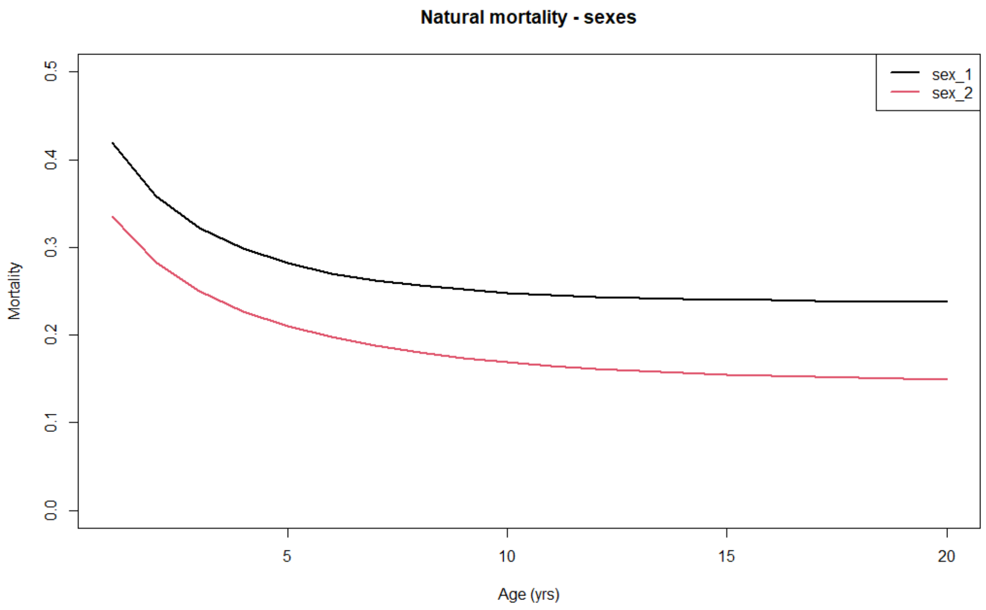


Figure 12. Sex-specific natural mortality at age estimated for the swordfish sex-structured model using the Lorenzen functional form.

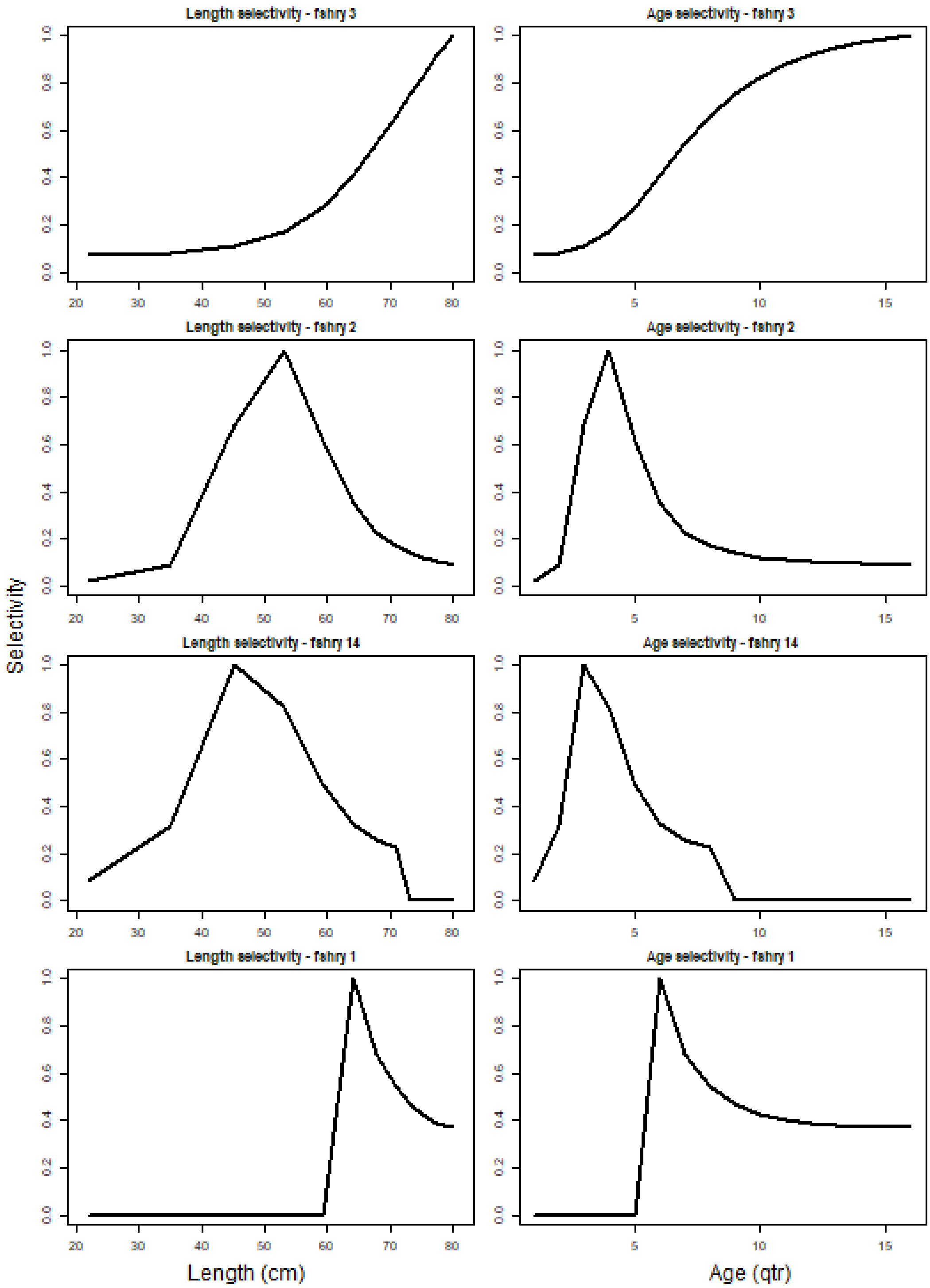


Figure 13. Length-based selectivities (left panels) with age-specific constraints applied for: non-decreasing right-hand limb (fshry_3); common selectivity above a specified age (fshry_2); zero selectivity above a specified age (fshry_14); and, zero selectivity below a specified age (fshry_1); with the underlying age-based selectivities (right panels).

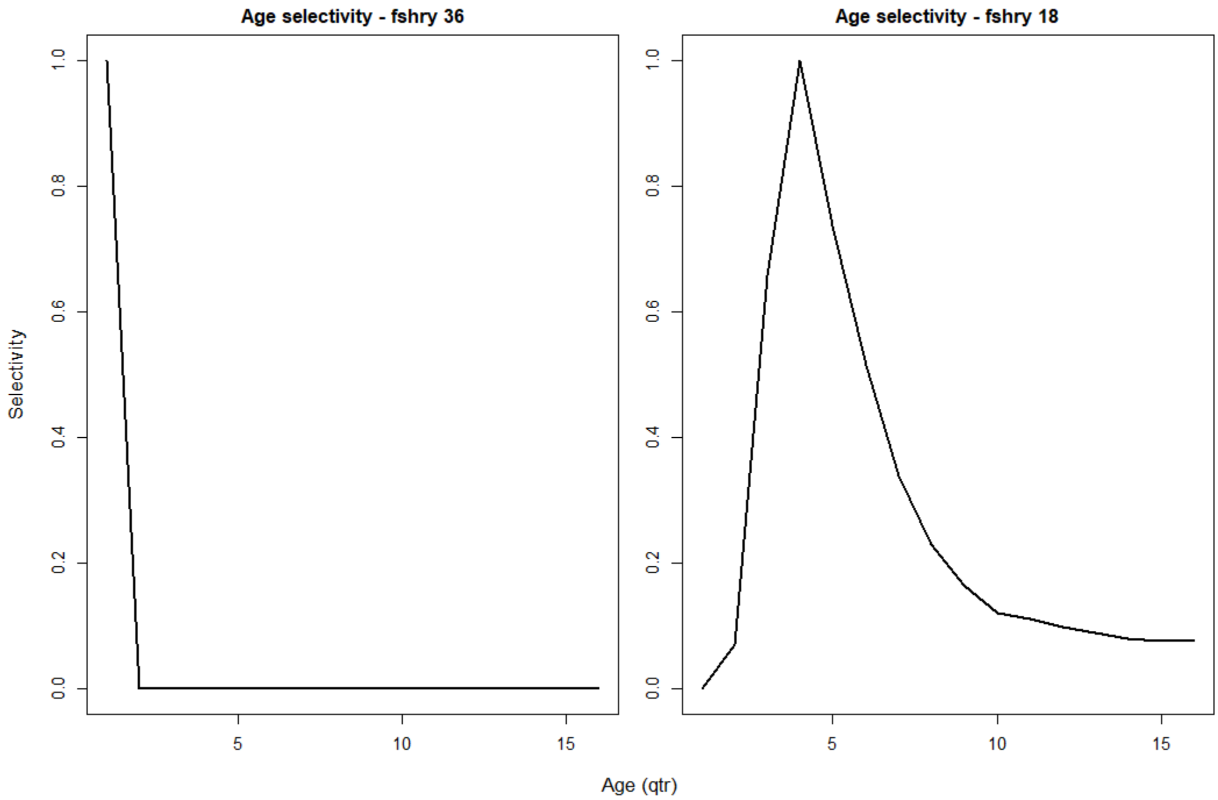


Figure 14. Non-functional forms of age-based selectivities with age-specific constraints applied for: the youngest age class = 1, while the selectivity for all other age-classes is assumed to be zero (fishery 36 left panel); and, no application of common selectivity above a specified age ((fishery 18 right panel).

12 ANNEX 1

Modified source code files (67) during 2024-25:

agelength.cpp all.hpp alldevpn.cpp alllengthsel.cpp ddnrc3.cpp do_all_for_empirical_autocorrelated_bh.cpp eq2.cpp equilib.cpp ests.cpp incident_calc.cpp indepvars.cpp lbselclc.cpp lesmatrix.cpp lmul_io2.cpp lmul_io4.cpp lmult.cpp lognormal_multinomial4.cpp lwsim.cpp makebig2.cpp mfcl_thrd_linux64_debug.mak mfcl_thrd_linux64_opt.mak mfcl_thrd_mac64.mak myorth.cpp natmort.cpp natural_mortality_spline.cpp new_cross_derivs.cpp new_incident_calc.cpp new_lognormal_multinomial5.cpp newl2.cpp newl5.cpp newl9.cpp newlbsel.cpp newm_io3.cpp newmau5a.cpp	newmovement2.cpp newmult.cpp newmult.hpp newrshimp_experiment.cpp nnewlan.cpp no_spline.cpp nrcatch3.cpp nrcatch4.cpp old_new_cross_derivs.cpp plot.cpp popes_approx.cpp print_survey.cpp real_ddnrc3.cpp recinpop_orth.cpp recrpen.cpp rsh3imp.cpp selbreaks.cpp setcomm3.cpp setuppvm.cpp sim_realtag_pd.cpp simulation_mode.cpp spline.cpp tag3.cpp tagfit_ss3.cpp tc_length_logistic.cpp testeq1.cpp variable.hpp VERSION version.h version3_len_self_scaling_multinomial_re_multi_rho_multi_var.cpp version3_wght_self_scaling_multinomial_re_multi_rho_multi_var.cpp win4opt_nick.mak xml.cpp

One source code file was renamed during 2024-25:

multspp_tagfit.cpp