*Earth’s Future*

Supporting Information for

**Detecting, attributing, and projecting global marine ecosystem and fisheries change: FishMIP 2.0**

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**Introduction**

The following Supplementary Information is to provide more details on the development of our FishMIP 2.0 protocols.

In FishMIP 1.0 we did not collect detailed information and metadata from modellers regarding the fishing assumptions and calibration data used. In Text S1 we show the Model Template that modellers have used to provide this information in FishMIP 2.0 for their models. This information is then catalogued and available as living documents for regional (https://github.com/Fish-MIP/Regional\_MEM\_Model\_Templates) and global (https://github.com/Fish-MIP/Global\_MEM\_Model\_Templates) modelling teams. These documents provide detailed information such as the assumptions regarding fishing the types of climate variables used, and information on calibration procedures and metrics. A summary of the fishing inputs typically used for a range of FishMIP models is provided in Table S2.

A list of GitHub repositories and their descriptions that have been developed specifically for the FishMIP 2.0 protocols is provided in Table S3.

Our Track A model evaluation experiment for marine ecosystem models contains two sensitivity tests related to climate forcing inputs. The first sensitivity test assesses the effect of including temporal dynamics linked to land-use change, which is not typically included in all Earth System Model experimental simulations. We show the global gridded differences between the default core historical forcing (obsclim), which includes dynamic changes in riverine inputs, primarily associated with land-use change, relative to the assumption of fixed riverine nutrients (ctrlclim) held constant at 1955 levels (Figure S1). Example differences in the spatially averaged temporal dynamics of lower trophic level biomass is shown in Figure S2 for the Canary Current large marine ecosystem. The second sensitivity test is a resolution test, mostly for global models, to determine the sensitivity of using a coarser remapping of our default 0.25 degree inputs. Spatially explicit regional ecosystem models will likely need to focus on 0.25 resolution default runs only, as these demonstrate oceanographic features much better than at one degree resolution (Figure S3). Aspatial regional ecosystem models will only need to use spatially averaged inputs derived from the default 0.25 resolution. Full list of climate variables available to force marine ecosystem models is given in Table S1.

To enable a standardized and systematic analysis of the effects of fishing across models, our Track A “model evaluation” experiment specifically provides fishing effort forcing, which used a published database (Rousseau et al. 2022, 2024) from 1950-2010 and carries out reconstruction to provide a gradual increase that occurs in the transition period towards the experiment. A description and example of the fishing effort reconstruction is shown in Figure S4, all code and data details provided in *https://github.com/Fish-MIP/FishingEffort.*

**Text S1. Model Template circulated to the FishMIP community for participating models**

**Model name**

*[put your model name here]*

**Contacts**

*[name of people running model]*

**Spatial scale forcing**

*[For example: scale: global or region, resolution: ¼ and 1 degree model runs]*

**Levels of gear disaggregation**

*[Which gears are used in the model, how was the effort aggregated or disaggregated?]*

**Levels of functional group disaggregation**

*[Which functional groups are used in the model, how was effort allocated across groups?]*

**Spatial grid-cell allocation method**

*[How was fishing effort allocated across grid-cells? Please provide equations as well as description]*

**Fishing mortality rate equation**

*[How are fishing mortality and catch rates calculated in your model? Please provide equations as well as description]*

**Selectivity (size, age, species)**

*[If you have a selectivity term please describe it, with equation]*

**Model calibration**

*[Catchability terms can be used to calibrate the model to catches, using data ONLY UP TO 2004. Please state how you estimate these parameters and the metrics and criteria you use to calibrate your model. Please provide details and equations]*

**Catchability and Creep (yearly rate of change catchability) Estimates**

*[Please provide details on the specific estimated parameters from the calibration, e.g. range of creep of 2-5% per year; and catchability coefficients per gear / functional group as necessary]*

**Further details on calibration**

*[Have you used other metrics or data in your calibration?]*

**Statistical metrics**

*[Please provide detail on the statistical method used in your calibration - E.g. optimisation, error terms]*

**Statistical results (summary)**

*[Please provide a summary of the metrics and results associated with your model calibration - E.g. RMSE with observed catches and any other process-based or theoretical criteria used to calibrate the model, comparison of modelled biomass, growth rates, P”B ratios etc]*

**Model changes or  improvements(s) made as a result of calibration**

*[Please provide detail of any other parameters or model changes since the last round as a result of this calibration]*

**ADDITIONAL DETAILS FOR REGIONAL MODELS ONLY:**

**Downscaling method**

[Please describe further details how the LME level fishing effort was downscaled to your region, providing further information on what data, if any were used, E.g. ]

**The “base” year range of the regional model**

*[If you expressed effort relative to the effort in your base model, which year was the base year and how was this done]*

**Environmental and biogeochemical variables and equations**

*[Please provide details about which climate forcing variables you use and how you integrate these into your model*

* *which primary/ secondary producers variables*
* *which temperature and other environmental variables]*

*[Please also provide equations for how temperature and primary/secondary producer or other variables are used in your model]*



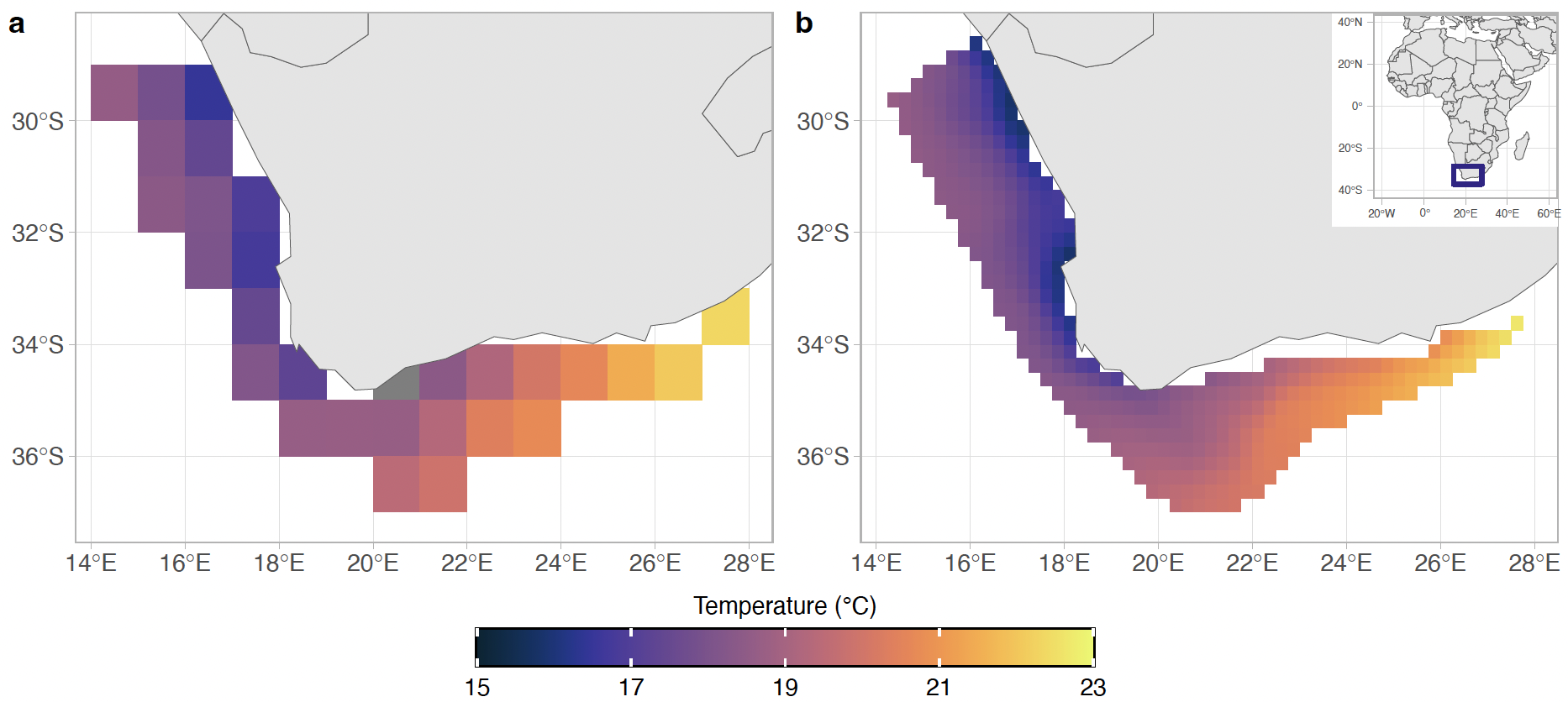
**Figure S1.** Difference between the default 3a GFDL ESM model reanalysis-based forcing (mapped to 1/4 degree) with changing climate and land-use river inputs through time (obsclim) and the sensitivity simulation forcing (controlclim) where riverine inputs are held fixed at 1950-1959 levels. Differences shown for the following ESM variables, all time averaged across 2000-2010: A) Sea-surface temperature, B) depth integrated primary productivity (gN/m2/dau), C) phytoplankton carbon biomass density, D) zooplankton carbon biomass density. The differences generally show higher productivity in coastal regions (Liu et al. 2019).

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Chart

Description automatically generated

**Figure S2.** Example experimental forcings from GFDL ESM reanalysis for Track A (ISIMIP 3a) simulation experiment.Time series of large phytoplankton biomass spatially averaged for the Large Marine Ecosystem. Light green shading shows the transition from spin-up to experimental period for MEMs (additional spin-up may be carried out prior to 1841 by repeating the cycle shown, if needed). The transition from spin-up to experiment is a repeat cycle of the 1961-1981 “ctrlclim” period (fixed 1955 riverine inputs), prior to detectable climate change signal.



**Figure S3.** Resolution improvement in temperature and depth contours visible at regional scales.Example showing mean sea surface temperature climatologies over 1961-2010 using Track A (3a ) climate forcing from GFDL coupled Earth System Model. a) 1 degree and b) 0.25 resolution for southern Benguela Current. Code and data are available here: [*https://github.com/Fish-MIP/FishMIP\_Input\_Explorer*](https://github.com/Fish-MIP/FishMIP_Input_Explorer)*.*

Graphical user interface

Description automatically generated

**Figure S4.** Example showing reconstruction of fishing effort data using generalised additive models. To capture the increase in the pre-industrial transition period prior to the start of the evaluation experiment, we reconstructed fishing effort for each of the 66 large marine ecosystems , FAO areas for High Seas, and each regional model spatial model domain in one of two ways: 1) If there was pre- 1950 catch reconstruction data available for the regions, a logistic model was fit using gam, as shown in panel A for the Patagonian Shelf. 2) If no pre 1959 catch data existed, the effort data were directly extrapolated using generalised additive models, as shown in panel B for the Canary Current. Each reconstruction was discussed with FishMIP modelling groups and adjusted where needed, usually this was addressed. Code and data are available here: [*https://github.com/Fish-MIP/FishingEffort*](https://github.com/Fish-MIP/FishingEffort)

|  |  |  |
| --- | --- | --- |
| **Variable** | **Specifier** | **Unit** |
| Mass Concentration of Total Phytoplankton Expressed as Chlorophyll | **chl** | kg m-3 |
| Sea Floor Depth | **deptho** | m |
| Downward Flux of Particulate Organic Carbon | **expc-bot** | mol m-2 s-1 |
| Particulate Organic Carbon Content | **intpoc** | kg m-2 |
| Primary Organic Carbon Production by All Types of Phytoplankton | **intpp** | mol m-2 s-1 |
| Net Primary Organic Carbon Production by Diatoms | **intppdiat** | mol m-2 s-1 |
| Net Primary Mole Productivity of Carbon by Diazotrophs | **intppdiaz** | mol m-2 s-1 |
| Net Primary Mole Productivity of Carbon by Picophytoplankton | **intpppico** | mol m-2 s-1 |
| Maximum Ocean Mixed Layer Thickness Defined by Sigma T | **mlotst-0125** | m |
| Dissolved Oxygen Concentration | **o2, o2-bot, o2-surf** | mol m-3, mol m-2 |
| pH | **ph** | 1 |
| Phytoplankton Carbon Concentration | **phyc** | mol m-3 |
|  | **phyc-vint** | mol m-2 |
| Mole Concentration of Diatoms expressed as Carbon in sea water | **phydiat** | mol m-3 |
|  | **phydiat-vint** | mol m-2 |
| Mole Concentration of Diazotrophs Expressed as Carbon in Sea Water | **phydiaz** | mol m-3 |
|  | **phydiaz-vint** | mol m-2 |
| Mole Concentration of Picophytoplankton Expressed as Carbon in Sea Water | **phypico** | mol m-3 |
|  | **phypico-vint** | mol m-2 |
| Sea Water Salinity | **so, so-bot, so-surf** | ‰ |
| Sea Water Potential Temperature | **thetao** | °C |
| Ocean Model Cell Thickness | **thkcello** | m |
| Sea Water Potential Temperature at Sea Floor | **tob** | °C |
| Sea Surface Temperature | **tos** | °C |
| Sea Water X Velocity | **uo** | m s-1 |
| Sea Water Y Velocity | **vo** | m s-1 |
| Mole Concentration of Mesozooplankton expressed as Carbon in sea water | **zmeso** | mol m-3 |
|  | **zmeso-vint** | mol m-2 |
| Mole Concentration of Microzooplankton expressed as Carbon in sea water | **zmicro** | mol m-3 |
|  | **zmicro-vint** | mol m-2 |
| Zooplankton Carbon Concentration | **zooc** | mol m-3 |
|  | **zooc-vint** | mol m-2 |
| Net Downward Shortwave Radiation at Sea Water Surface | **rsntds** | W m-2 |
| Sea Ice Area Fraction | **siconc** | % |

***Table S1.*** *List of climate forcing variables from Earth System Models used in FishMIP 2.0 simulation protocols. Specific details for each protocol*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Model short name* | *Type* | *Mortality* | *Effort* | *Catch* | *Fleet Dynamics* |
| *APECOSM* | *Global* |  |  |  | • |
| *BOATS* | *Global* |  | (•) |  | • |
| *DBEM* | *Global* | (•) |  | • |  |
| *DBPM* | *Global* | • | (•) |  |  |
| *EcoOcean* | *Global* |  | • |  |  |
| *EcoTroph* | *Global* | • | (•) |  |  |
| *FEISTY* | *Global* | • | (•) |  |  |
| *Atlantis* | *Regional* | • | (•) |  | • |
| *EwE* | *Regional* | • | (•) | • |  |
| *mizer* | *Regional* | • | (•) |  | • |
| *OSMOSE* | *Regional* | • | (•) |  |  |

***Table S2****. Summary of typical fishing inputs for a range of FishMIP model types. Mortality refers to fishing mortality rates derived externally from assessment time series or assumed as fixed in (). Fishing effort can be input in absolute terms or expressed relative as a multiplier of fishing mortality rates in (). Note that both effort and mortality inputs also require group specific parameters that relate to catchability and/or selectivity of different gears/groups. Marine ecosystem models that include fleet dynamics can take economic variables (price, costs) as inputs and use biomass from models in two-way coupling to determine fishing effort and mortality dynamically in these models. Modellers have provided details on how these assumptions have been modified for standardised fishing effort inputs under the Track A marine ecosystem model evaluation protocol (ISIMIP3a) in model templates provided here:* [*https://github.com/Fish-MIP/Global\_MEM\_Model\_Templates*](https://github.com/Fish-MIP/Global_MEM_Model_Templates) *and* [*https://github.com/Fish-MIP/Regional\_MEM\_Model\_Templates*](https://github.com/Fish-MIP/Regional_MEM_Model_Templates) *.*

|  |  |
| --- | --- |
| ***Repository Name*** | ***Description*** |
| *https://github.com/Fish-MIP/FishMIP2.0\_ISIMIP3a* | *Overall description of the simulation experimental protocols for Track A - Past Change.* |
| *https://github.com/Fish-MIP/FishMIP2.0\_OSP* | *Overall description of the simulation experimental protocols for Track B - Future Scenarios.* |
| *https://github.com/Fish-MIP/Global\_MEM\_Model\_Templates* | *Detailed descriptions of global models participating in FishMIP to date 2.0, with a focus on Track A.* |
| *https://github.com/Fish-MIP/Regional\_MEM\_Model\_Templates* | *Detailed descriptions of regional models participating in FishMIP to date 2.0, with a focus on Track A.* |
| *https://github.com/Fish-MIP/Fish-MIP.github.io* | *Website for communication with participating modellers and public* |
| *https://github.com/Fish-MIP/FishingEffort* | *Methods and code for spatial aggregation and reconstruction of fishing effort and large marine ecosystem scales and for regional model domains* |
| *https://github.com/Fish-MIP/FishMIP\_regions* | *Code for mapping regional ecosystem model domain shapefiles and creation of netcdf masks* |
| *https://github.com/Fish-MIP/FishMIP\_Input\_Explorer* | *Code for R Shiny app to explore, visualise, and download, regional model climate forcing inputs* |

***Table S3.*** *Summary table of the relevant https://github.com/Fish-MIP repositories that have been specifically used for the development of FishMIP 2.0 protocols, including detailed model protocol descriptions, fishing forcing data, and tools for extracting and visualizing inputs. Maintainers and contributing authors are listed on each repository on GitHub.*