Task 2.1. Marine ecosystem models (MEM) intercomparison

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1. Introduction

Funded by Ifremer, the FORESEA project (*French seafOod pRoduction Scenarios in 2050*) aims at integrating available knowledge across disciplines and scales and filling knowledge gaps in order to build plausible foresight scenarios of French commercial fisheries under global change by 2050 and predict possible pathways of domestic marine ecosystems based on those scenarios. While contrasted foresight scenarios are build following a prospective methodology, another task of the project is to review existing marine ecosystem models (MEMs) applied to French sea waters to assess the modelling capacity at hand for this project.

Over the past decades several MEMs ranging from statistical Niche Models, Dynamic Energy Budget (DEB), Individual Based Models (IBMs: e.g. Osmose, Ev-Osmose), mass balanced (e.g. Ecopath with Ecosim, Ecospace, Ecotroph), and End-to-End (e.g. Atlantis) models were developed in French marine ecosystems to assess anthropogenic and/or environmental stressors impacts on marine ecosystems and answer ecological and management questions. **The main objective of Task 2.1 is to list and compare the structure and capabilities of the different MEMs.** As each MEM was developed to answer specific objectives, they will most likely vary considerably in model structure, underlying assumptions, taxonomic, time and spatial resolutions, ecological and environmental processes included as well as human activities explicitly considered. A particular interest will be put on *a priori* knowledge gaps, i.e. the description of zooplankton and fishery implementations in the selected MEMs, and on the abilities of MEMs to forecast future ecosystem dynamics under climate change scenarios.

2. Method

The methodology envisioned was to circulate an online survey to be filled by the experts/modellers. A first list of questions has been draft and discussed within the ForeSea consortium. A revised version of the questions has been tested by few colleagues, to assess the clarity of the questions, their generality (targeting different models) and the duration required to fill the online survey (estimated to be around 30-45 minutes).

Regarding the type of models we were targeting, we aimed at gathering as many models as possible, so we put very few constraints on the type of models listed, except that they must be able to make projections. We therefore specified that we aim to identify all the models that can project the impacts of climate change and/or that can project the impacts of fishing on all or part of the socio-ecosystems in 2050. We target French marine ecosystems (part of the model includes all or part of the French EEZ) for the review of existing models, and we limit ourselves to metropolitan ecosystems (North Sea, Channel, Celtic Sea, Bay of Biscay, Bay of Lions) for the projection of scenarios in the case of ForeSea. We therefore allow niche (statistical) models to be listed, and the same goes for socio-eco and bio-eco models if they can project the state of the system in 2050 (alone or through coupling/forcing with other models).

The questionnaire was available online (https://forms.ifremer.fr/foresea/models-review/) and is reported in Appendix. It is structured in 5 pages. The first one is about model presentation, and list model name, reference, and main characteristics. The second page focuses on model details (components, processes). The third page questions how fishing and climate are modelled (if applicable). The fourth page is about model calibration and output. The fifth page asks about contact information and capabilities of the model to be used within ForeSea.

3. Results

3.1 Overview of the models

A total of 35 entries were collected from the online survey, covering a wide variety of models and areas. Among those, three situations where two entries were concerning the same model applications were encountered and have been merged. The 32 resulting model entries were then grouped into 8 categories according to their characteristics and the ecosystem components they explicitly represent (Figures 1 and 2). The information gathered through the online survey is presented based on these categories in the following Tables 1 to 9. Some model details are presented prior to each table. All information displayed in the following table have been provided by the model experts, but different understanding of the questions and/or time available to fill the online survey might result in different levels of details provided to each question, or missing information.

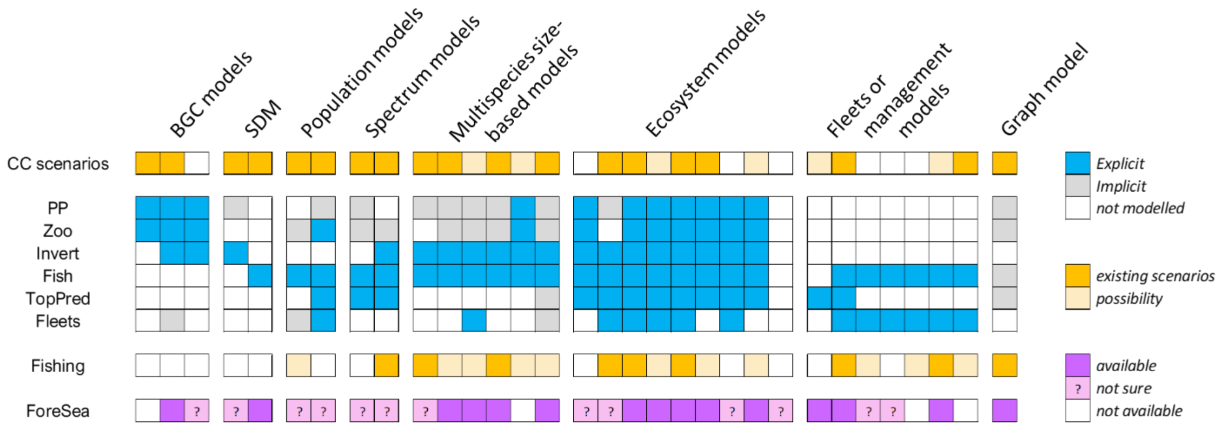

Figure 1*: Overview of the ecosystem components (with PP: primary production; Zoo: Zooplankton; Invert: Invertebrates; TopPred: top predator) represented by the set of models (with: BGC biogeochemical ; SDM, species distribution models) described in this document (central part of the figure, in blue). The possibility to explore climate change (CC) and/or fishing scenarios is also indicated (orange boxes). Finally, the possibility to use the models to run new foresight scenarios to be defined within the ForeSea project is indicated through purple boxes.*

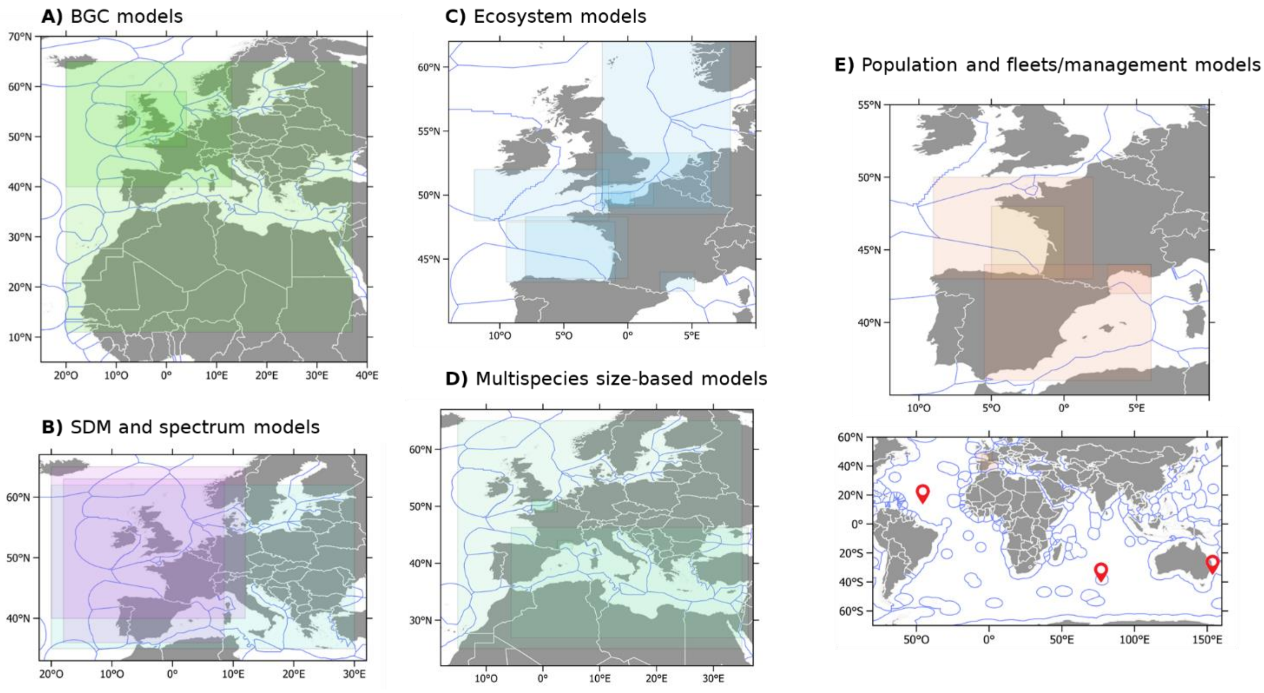

Figure 2 *: Overview of the spatial extent of ecosystems studied by the set of models described in this document, when coordinates were available. A) biogeochemical models in green (BGC, Table 1) ; B) species distribution models in green (SDM, Table 2) and spectrum models in purple (Table 4) ; C) ecosystem models in blue (Tables 6 and 7) ; D) multispecies size-based models in green (Table 5) ; E) population model in yellow (Table 3) and fleets/management models in orange and red dots (Table 8). Note that only the minimum and maximum latitude have been represented (i.e. larger than the exact grid of spatially explicit models).*

3.2 Details of the models

3.2.1 Biogeochemical models

Three applications were filled in, all based on the biogeochemical model **ERSEM** (European Regional Seas Ecosystem Model), but forced by different physical models (POLCOMS, NEMO or FVCOM). ERSEM is a 3D mechanistic models based on functional groups, designed to simulate the cycles of key elements (carbon and the major nutrient elements nitrogen, phosphorous, silicon and iron) within the marine environment (pelagic and benthic ecosystems). It assumes variable stoichiometry in most of its functional types. Written within the Framework for Aquatic Biogeochemical Models (FABM), it has a modular structure, hence the number of functional type can be adapted to the question studied.

***Table 1** : Answers to the ecosystem models survey received for biogeochemical models*

Model's name	**POLCOMS-ERSEM** (v15.06)	**NEMO-ERSEM**	**FVCOM-ERSEM**
Modelled ecosystem	European seas, except the Baltic	North Western European Shelf (or Atlantic Margin Model)	British Coast (include French coast of the English Channel)
Main reference	**Kay, S., (2020)**, Butenschön et al. (2016), Holt et al. (2009), Holt and James (2001)	**Butenschön et al. (2016)** Lessin et al. (2020), Artioli et al. (2014)	
Spatial resolution	0.1 x 0.1° 43 vertical levels	0.111 x 0.1666 ° 50 vertical levels	Non-regular grid (142090 elements) 25 vertical levels
Period represented	2006-2099	up to 2100	
Time step	Minutes (output saved monthly/daily for some variables)	Minutes (outputs saved daily at best)	Minutes
Phytoplankton	diatoms; pico-phytoplankton; nano-phytoplankton; micro-phytoplankton. *(see Note below the table)*	diatoms, nanoplankton, picoplankton, microplankton	
Zooplankton	heterotrophic nanoflagellates; micro-zooplankton; meso-zooplankton. *(see Note below the table)*	bacteria, heterotrophic nanoflagellates, microzooplankton and mesozooplankton	
Invertebrates (cephalopods, benthos)	*Not modelled/considered*	meiofauna, filter feeders, deposit feeders	

Fishing fleets	*Not modelled/considered*	beam trawlers; otter trawlers; otter trawlers targeting nephrops	*Not modelled/considered*
Socio-economic system	*Not represented*	*Implicitly represented* -Riverine discharge (nutrients and contaminant) -Atmospheric deposition of N, atmospheric CO2 (including anthropogenic emissions) -Trawling on benthic communities	
Ecological processes considered	Growth, Reproduction, Movement (horizontal or vertical migration, foraging movement, dispersal), Predation	Growth, Predation , Natural mortality	Growth, Reproduction, Movement (horizontal or vertical migration, foraging movement, dispersal), Predation
Pressures that can be addressed	Climate change, Environmental variability	Climate change, Environmental variability, Eutrophication , Aquaculture , Pollution (including plastic)	Environmental variability, Eutrophication , Aquaculture , Pollution (including plastic)
How environmental variability is implemented ?	Daily or sub-daily forcing is applied at the atmospheric and ocean boundary, giving intra- and inter-annual variability.	Temperature affects all metabolic processes as well as dissociation constants and air-sea gas exchange ; Oxygen affects metabolism of most hetetrophic groups ; pH affects nitrification rates and (optionally) phytoplankton carbon fixation ; light affects photosynthesis and Chl:C ratio and photochemistry (of terrigenous DOC) ; dissolved inorganic nutrient concentrations (and indirectly their ratio) affect metabolic rate of phytoplankton and bacteria ; salinity affects dissociation constants as well as air-sea gas exchange and flocculation of terrigenous DOC ; current velocity affect sinking of all particulates as well as resuspension	
Can the model be used for climate change projections ?	Yes, this has already been simulated	Yes, this has already been simulated	
How the model projects ecosystem state, e.g. in 2050 ?	Through a trajectory (every year between now and then is simulated)	Through a trajectory (every year between now and then is simulated)	
Existing climate change scenarios	RCP4.5 and RCP8.5, driven by a CMIP5 model (MPI-ESM-LR). 2006-2099.	RCP8.5 (up to 2100) driven by different ESM RCP4.5 and 8.5 (up to 2050) forced by HadGEM2-ES	
How Climate Change is implemented ?	Outputs from a CMIP5 global climate model (MPI-ESM-LR) were used to provide	Climate change is implemented by forcing the model with atmospheric	

	atmospheric forcing and open ocean boundary conditions. The atmospheric conditions came from a regional, dynamically-downscaled model, the open ocean conditions from the original global model: both are spatially explicit. Atmospheric CO2 concentrations were varied in line with the two RCP scenarios used. ERSEM processes are directly affected by temperature, salinity and (for some processes) alkalinity. Changes in circulation associated with the climate model forcing are modelled by POLCOMS, and this then affects the advection of ERSEM variables.	and lateral boundary condition from Earth System models. as a consequence, the environmental condition will change and so the ecosystem based on all the processes mentioned above (and more)	
Requirements for projecting ecosystem under climate change	Surface meteorological conditions and atmospheric CO2 concentration. Ocean boundary temperature, salinity, currents, nutrient and dissolved inorganic carbon concentrations.	Standard atmospheric forcing needed to drive physical oceanographic model (T, precipitation, SWR, LWR, humidity...). Spatially ideally at <1 degree (but they can be downscaled), temporally at least monthly, but higher resolution (e.g. daily) are preferable.	
Is the model coupled to another model?	Yes, one-way coupling (i.e. forcing) with the regional ocean circulation models POLCOMS (the Proudman Oceanographic Laboratory Coastal Ocean Modelling System), which provides temperature, salinity, currents etc to ERSEM.	Yes, one-way coupling (i.e. forcing) with the physical oceanographic model NEMO (forcing from reanalysis products publicly available) It can also be coupled to Higher trophic level model like SS-DBEM and CSSM/Mizer	Yes, one-way coupling (i.e. forcing) with the coastal physical oceanographic model FVCOM. Given the high resolution, we have dynamically downscaled atmospheric forcing from publicly available reanalysis

Is the model fitted / calibrated to represent the ecosystem?	No calibration performed	No calibration performed	No calibration performed
Which type of data are required to fit the model?		The model was calibrated in 1D context (see main reference)	
On which processes/parameters is the calibration performed?		main state variables (nutrients, oxygen phytoplankton,....)	
Which method/procedure is used for calibration?		combination of genetic algorithm and by hand	
Outputs and indicators related to fishing and catches		none directly, but it can inform HTL models to provide these	
Other outputs and indicators	temperature; salinity; current speeds; net primary production; secondary production; phytoplankton biomass, zooplankton biomass; dissolved oxygen; pH.	nutrients, oxygen, pH, phytoplankton/zooplankton/benthic fauna biomass, net Primary Production...	
Is the model ready to simulate new scenarios?	Yes, ready to run	Yes, ready to run	Runnable within a year
Able to run ForeSea scenarios if relevant ?	No, I cannot run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios	I don't know if I can run simulations of ForeSea scenarios
Comments on the possibility to run ForeSea scenarios	The POLCOMS-ERSEM model would need significant effort to update and run it, however the dataset on the Copernicus Climate Data Store is available and ready for use.	obviously this would depend on timing and resources needed	obviously this would depend on timing and resources needed

Note : The POLCOMS-ERSEM model has already been used to project ecosystem dynamics under greenhouse gas concentration scenarios RCP4.5 and RCP8.5, with the resulting dataset available on the Copernicus Climate Data Store. The published dataset includes only the total biomass and primary production for the four phytoplankton groups, and only the total biomass and secondary production for the three zooplankton groups. For these scenarios, the details are :
Atmospheric forcing: 6 hourly 10 m wind components, sea level pressure, 2 m air temperature and relative humidity, daily precipitation, shortwave and longwave radiation flux and cloud cover, from the CORDEX regional atmospheric model MPI-ESM-LR_RCA4. The regional climate model is the Swedish Meteorological and Hydrological Institute Rossby Centre Regional Atmospheric Model. Further information regarding the model is available here: https://www.smhi.se/en/research/research-departments/climate-research-at-the-rossby-centre/rossby-centre-regional-atmospheric-model-rca4-1.16562
Open ocean boundaries: daily temperature, salinity, currents, nutrients and carbon from Max Planck Institute-Earth System Model-Low Resolution (MPI-ESM-LR). Further information regarding the model is available here: https://www.mpimet.mpg.de/en/science/models/mpi-esm/

3.2.2 Species Distribution models (SDMs)

Two applications were filled in, based on species-based statistical models. Species Distribution Models allow to characterise the current distribution of species of interest based on recent climatologies and then to project climate-driven changes of these spatial distributions based on IPCC scenarios (typically at 2050 or 2100 horizons).

***Table** 2: Answers to the ecosystem models survey received for species distribution models*

Model's name	**Species Distribution Models**	**-**
Modelled ecosystem	Bay of Biscay / English Channel	Baltic Sea, North Sea, English Channel, Bay of Biscay, Mediterranean Sea
Main reference	**Curd et al. 2023** Different level of work in progress for different coastal habitat types including kelp, seagrass meadows, honeycomb reefs	No publication yet
Spatial resolution	2500 m No vertical dimension	0.25 x 0.25° No vertical dimension
Period represented	Climatological approach for the years 2010-2020 (for seagrass potential distribution)	1990-2020
Time step	No time step	

	Present and future (2050s / 2100s) climatologies	
Phytoplankton	Considered as forcing variable	Not modelled/considered
Invertebrate (cephalopods, benthos)	honeycomb reef-building worms	
Fish		355 demersal fish species (1 model per species) (list of studied species is based on DATRAS/MEDITS cruises)
Ecological processes considered	environmental niche / habitat suitability	
Pressures that can be addressed	Climate change, Environmental variability, Eutrophication	Climate change, Environmental variability
How environmental variability is implemented ?	as a forcing / predictor for the statistical model (standard deviation of certain predictors; such as temperature, coastal currents, etc..)	Environmental variability controls the species distribution (SDM)
Can the model be used for climate change projections ?	Yes, this has already been simulated	Yes, this has already been simulated
How the model projects ecosystem state, e.g. in 2050 ?	Through the simulation of the 2050 state alone (no trajectory)	Through a trajectory (every year between now and then is simulated)
Existing climate change scenarios	For certain habitats (e.g. honeycomb reefs), projections are available for 2050s and models are trained on records available across the whole biogeographical range. For seagrass meadows and kelp, it would be useful to extend the occurrence records (available only for French coastline) to the whole distribution of the species considered as current statistical models is skewed (as not capturing the full range of environmental conditions where the species can occur). Work in progress on commercial benthos group for the whole NE Atlantic (MAESTRO project with Arnaud Auber) including nephrops, crabs, lobster etc..	We will use 3 scenarios (details to be determined), to predict occurrence probability for the period 2020-2100 for each species
How Climate Change is implemented ?	statistical projection of environmental suitability under IPCC scenarios 4.5 and 8.5	forecast of the future species distribution based on climate change forecast (CMIP6)

Requirements for projecting ecosystem under climate change		temperature, salinity, mixed layer depth, sea level anomaly (from ARMOR3D) and chlorophyll, NPP, pH (from NEMOPISCES forced by Glorys ocean data and ERA-Interim atmospheric data) for climate change forecast, we extract these variables from CMIP6 (6 models identified), we calculate anomalies with the CMIP6 (future - present) and we add these anomalies to the variables cited above.
Is the model coupled to another model?	No, it is a stand-alone model	Yes, one-way coupling (i.e. forcing) using variables from CMIP6 models
Is the model fitted / calibrated to represent the ecosystem?	Calibration of an average state (or climatology)	No calibration performed
Which type of data are required to fit the model?		Two data sources are used : GBIF in one hand (models fit at global scale on occurrences) and DATRAS/MEDITS (models fit at north east atlantique scale, based on occurrences and abundance from trawl data in this case)
On which processes/parameters is the calibration performed?	cross-validation training and assessment of model skills using k-folds (test statistics on independent data)	no calibration
Outputs and indicators related to fishing and catches		
Other outputs and indicators	percentage cover of key coastal habitats	probability of occurrence
Is the model ready to simulate new scenarios?	Runnable within a year	Yes, ready to run
Able to run ForeSea scenarios if relevant ?	I don't know if I can run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios

3.2.3 Population models

Two applications were filled in regarding population models, the first one focusing on a single forage fish population while the second one focusses on top predator populations (table 3). The first model is a single-species mechanistic bioenergetic (Dynamic Energy Budget theory) individual-based model (IBM) that can run in 0D (spatially averaging food and temperature forcing) or 3D (not published on that form with population dynamics). The included mechanisms are: larval drift, adult movement, bioenergetics for growth and reproduction, mortalities. This model has already been applied to small pelagic fish (anchovy and sardine) and seabass (ongoing). The second model uses a set of physical, biogeochemical and biological environmental variables are used to describe fish habitat and define conditions for spawning, feeding, survival and movement. The model is resolved in four dimensions – twodimensional space (latitude and longitude and three vertical layers), time and fish species age, aggregated to four life stages (larvae, small juveniles, autonomous juveniles and adults). Model parameters, including the fishery-related parameters (age selectivity and catchability) are estimated using a maximum likelihood estimation (MLE) approach by fitting to catch, length composition and if available conventional tagging data acoustic biomass estimates, larvae densities.

***Table** 3: Answers to the ecosystem models survey received for population models*

Model's name	**DEB-IBM**	**SEAPODYM**
Modelled ecosystem	Bay of Biscay	GLOBAL/OCEAN/REGIONAL
Main reference	**Bueno-Pardo et al. (2020).** Gatti et al. (2017), Politikos et al. (2015), Huret et al. (2010)	**Lehodey et al. (2008)** Hampton et al. (2023), Nicol et al. (2022), Senina et al. (2008, 2019, 2020), Lehodey et al. (2010, 2018), Dragon et al. (2018)
Spatial resolution	2.5km 40 vertical layers	from 2° to 1/12° 3 vertical layers
Which period is represented?	hindcast 2000-2020	hindcast 1979-2022
Time step	minute (3D) to hour (0D)	week, month
Phytoplankton	Not modelled/considered	Considered as forcing variable (1 group)
Zooplankton	Considered as forcing variable (1 group ; size distribution)	1 explicit group; ongoing work to include migrant mesopelagic zooplankton
Fish	single species ; anchovy ; sardine	6 functional groups of micronekton and then target exploited pelagic species (tunas, mackerel)
Top predators		skipjack, yellowfin, albacore, bigeye, swordfish, mackerel
Fishing fleets	Considered as forcing variable (seasonal catches)	longline; pole and line; purse seine; by gear type, fishing nation, target species, fishing strategy

Ecological processes considered	Growth, Reproduction, Movement (horizontal or vertical migration, foraging movement, dispersal), Fishing mortality, Natural mortality	Growth, Reproduction, Movement (horizontal or vertical migration, foraging movement, dispersal), Fishing mortality, Natural mortality
Pressures that can be addressed	Climate change, Environmental variability, Commercial fishing/harvest	Climate change, Environmental variability, Commercial fishing/harvest
How environmental variability is implemented ?	Effect of temperature and zooplankton on bioenergetics. Effect of physical parameters (mixing, temperature, salinity, currents) on dispersal.	Forcing variables are temperature, horizontal currents, and dissolved oxygen concentration in three vertical layers dynamically defined using the euphotic depth. Total primary production is the energy source. 1 zooplankton and 6 micronekton functional groups are simulated based on temperature-time of development relationships and currents (passive movements) All these variables are used to simulate feeding and spawning habitats and movement of predator target populations. A seasonal cycle in is implemented for subtropical and temperate species that creates feeding and spawning migrations.
Can the model be used for climate change projections ?	Yes, this has already been simulated	Yes, this has already been simulated
How the model projects ecosystem state, e.g. in 2050 ?	Through the simulation of the 2050 state alone (no trajectory)	Through a trajectory (every year between now and then is simulated)
Existing climate change scenarios	2040-2060 and 2080-2100 were simulated based on POLCOMS-ERSEM Climate simulation outputs.	with CMIP5: scenario RCP8.5 (2010-2100)
How Climate Change is implemented ?	Effect of temperature and zooplankton on bioenergetics. Effect of physical parameters (mixing, temperature, salinity, currents) on dispersal.	The same forcing variables used for hindcast simulations are obtained from Earth Climate models (CMIP) to project the modelled fish populations using the parameterisation achieved with historical data and hindcast. A bias-correction method is applied to atmospheric climate forcing variables before running coupled physical-biogeochemical model used to produce the forcing variables

Requirements for projecting ecosystem under climate change	Temperature and zooplankton with daily resolution and spatially averaged over a given area. Could be run on a long term trajectory or for 2050 state (over few years)	Forcing variables (temperature, currents, primary production, dissolved oxygen, euphotic depth) from physical-biogeochemical models. Resolution is linked to the resolution of the forcing variables
How fishing activity is described in the model?	Through global catches only	Through global fishing mortality only, Through fishing vessels or fleets
Please provide information about variables and processes	Fishing catches based on assessment reports	Fishing mortality can be deduced directly from observed catch or by predicting catch from the fishing effort (with parameterisaiton of catchability and selectivity)
How fishing management is modelled?	HCRs	MPA / closure area can be tested with or without redistribution of catch/ effort outside the closed area
Can the model be used for projections of potential fisheries catch in 2050?	Yes, it has the capabilities to do so (but projections have not been run yet)	No
Requirements for projecting potential fisheries catch	Projection of fishing catches or HCRs	There is ongoing work to generate future fishing scenarios, until now only a projection of historical average effort/catch was used.
Is the model coupled to another model?	Yes, one-way coupling (i.e. forcing) ECO-MARS3D (Climatology) and POLCOMS-ERSEM (2000-2015) have been used with temperature and zooplankton. SEAPODYM is now being used with same variables	Yes, one-way coupling (i.e. forcing) NEMO-PISCES.; any physical-biogeochemical models; Primary production and euphotic depth can be derived from satellite ocean color data.
Is the model fitted / calibrated to represent the ecosystem?	Calibration of an average state (or climatology), Calibration of a time series (hindcast)	Calibration of a time series (hindcast)
Which type of data are required to fit the model?	Size/weight/energy-at-age ; population biomass/abundance	Catch by fleet and species; size frequencies of catch; tagging data; acoustic biomass estimates; larvae density
On which processes/parameters is the calibration performed?	natural mortality terms ; bioenergetics ; density dependence	natural mortality, recruitment, habitat and movement, fishing selectivity and catchability

Which method/procedure is used for calibration?	simplex or evolution strategies depending on the number of parameters ; first bioenergetics parameters, second mortality parameters for population dynamics	Maximum Likelihood Estimation approach, gradient based with adjoint code.
Outputs and indicators related to fishing and catches	No prediction for fishing	predicted catch by species by size for each fleet
Other outputs and indicators	recruitment : abundance per age class, size/weight/energy per age class ; reproduction success	abundance per age class
Is the model ready to simulate new scenarios?	Runnable within a year	Runnable within a year
Able to run ForeSea scenarios if relevant ?	I don't know if I can run simulations of ForeSea scenarios	I don't know if I can run simulations of ForeSea scenarios
Comments on the possibility to run ForeSea scenarios	Will depend on advances of an ongoing PhD who work on density-dependent processes	

3.2.4 Spectrum models

Two applications were filled in, based on mechanistic spectrum models with the first one modelling biomass fluxes through size bins while the other models biomass fluxes through trophic levels bins. FABM-MIZER is a community size spectrum model for higher trophic levels (1 mg – 1000 kg in wet mass) that uses phytoplankton and zooplankton biomass as inputs, as well as temperature to calculate the wet mass of fish with time. In addition to the impact of plankton on fish biomass, the two-way coupling between the models allows the impact of fish on plankton and biogeochemical processes of the system via feeding of fish, excretion of nutrients, particulate organic matter and carbon dioxide through respiration. One-way coupling can also be used for this model where there is no feedback on fish on plankton/biogeochemical components. In the trophic spectrum application presented, a new two pathways version of the EcoTroph model is implemented, forced by a regional high resolution coupled hydrodynamic-ecosystem model, within each of the 15 ICES divisions considered in the NE Atlantic.

***Table** 4: Answers to the ecosystem models survey received for spectrum models*

Model's name	**FABM-MIZER**	**EcoTroph**

Modelled ecosystem	North West European Shelf	NE Atlantic - ICES Division 4 to 9
Main reference	Bruggeman, J. (2021).	du Pontavice et al. (submitted)
Spatial resolution	The model can be run for whatever grid the biogeochemical model is run on (when coupled to NEMO-FABM-ERSEM it is ~7km by 7km or 1/9th degree by 1/6th degree) No vertical layers	Non-regular grid (15 boxes) No vertical layers
Period represented	Hindcast 1981-2017 Climate simulation 1981-2100	Forecast 2020-2099
Time step	5 minutes (output daily or monthly)	year
Phytoplankton	4 phytoplankton groups considered as forcing variable (diatoms, picophytoplankton, nanophytoplankton, microphytoplankton)	Not modelled/considered
Zooplankton	3 zooplankton groups considered as forcing variable (nanozooplankton, microzooplankton, mesozooplankton)	3 groups of Ersem, agregated in trophic classes, considered as forcing variable
Invertebrate (cephalopods, benthos)	Not modelled/considered	Yes, implicitly modelled
Fish	100 bins of size spectrum	Implicitly modelled, based on trophic classes of 0.1 TL wide
Top predators	Top of size spectrum of fish	Yes, implicitly
Ecological processes considered	Growth, Predation , Fishing mortality, Natural mortality, Fish recruitment, calculated by extrapolating the linear slope of the plankton spectra	Predation
Pressures that can be addressed	Climate change, Environmental variability, Eutrophication , Commercial fishing/harvest, Pollution (including plastic)	Climate change, Commercial fishing/harvest
How environmental variability is implemented ?	Temperature dependency on predator-prey interactions and background mortality of fish	
Can the model be used for climate change projections ?	Yes, this has already been simulated	Yes, this has already been simulated
How the model projects ecosystem state, e.g. in 2050 ?	Through a trajectory (every year between now and then is simulated)	Through a trajectory (every year between now and then is simulated)

Existing climate change scenarios	The model has been run two-way coupled with NEMO-FABM-ERSEM using environmental forcings (temperature and physical) from the IPSL-CMR5a-MR (RCP 8.5) climate simulation (Dufresne et al., 2013; WCRP, 2016) from 1981-2100	RCP 4.5 and 8.5
How Climate Change is implemented ?	Temperature dependency on predator-prey interactions and background mortality of fish	Model forced by the following outputs of Polcoms/Ersem : SST, SBT, zooplancton production and Benthic invertebrate production
Requirements for projecting ecosystem under climate change	Temperature, phytoplankton and zooplankton (as function of depth)	
How fishing activity is described in the model?	Through global fishing mortality only Fishing was modelled assuming a knife edge approach (Scott et al., 2014) where fishing occurs at a constant rate (0.8 yr-1) for all fish above 80g wet mass (WM) across the entire domain and is constant throughout space and time	Through global fishing mortality only
Can the model be used for projections of potential fisheries catch in 2050?	No	Yes, this has already been simulated
Existing fishing scenarios		Only F=cts, at the moment
Requirements for projecting potential fisheries catch	It is possible to calculate total fish landings and we do have model output for fish landings in 2050, but at this stage, fishing is constant throughout the time and space so I would argue that it is not suitable to project a realistic potential fisheries catch	
Is the model coupled to another model?	Yes, two-way coupling (with feedbacks) and one-way coupling (i.e. forcing) between MIZER and NEMO-FABM-ERSEM (providing temperature, phytoplankton and zooplankton biomass). Thus we can model impact of fish on phytoplankton and zooplankton biomass as well as fish excretion of nutrients	Yes, one-way coupling (i.e. forcing) with Polcoms/Ersem

	and particulate organic matter and fish respiration of CO2. Note the impact of climate change has only been assessed using the two-way coupled model.	
Is the model fitted / calibrated to represent the ecosystem?	Calibration of an average state (or climatology), Calibration of a time series (hindcast)	Calibration of an average state (or climatology)
Which type of data are required to fit the model?	annual fish landings, mesozooplankton data (for two-way coupling)	Annual landing by species and ICES subdivision
On which processes/parameters is the calibration performed?	fishing mortality, size of fish fished, parameters associated with the volumetric search rate of food of fish	Fishing mortalities by trophic level
Which method/procedure is used for calibration?	by hand	
Outputs and indicators related to fishing and catches	total fish landings (for all size spectra)	TL-based indicators
Other outputs and indicators	total fish wet mass (and fish wet mass per each size class), fish predation of phytoplankton/zooplankton, fish excretion of nutrients, fish respiration, fish recruitment	
Is the model ready to simulate new scenarios?	Yes, ready to run	Runnable within a year
Able to run ForeSea scenarios if relevant ?	I don't know if I can run simulations of ForeSea scenarios	I don't know if I can run simulations of ForeSea scenarios
Comments on the possibility to run ForeSea scenarios	Yes, if there is time and cost renumeration. New simulations are likely to be simple if coupled to NEMO-FABM-ERSEM but will require more time to setup if use any other biogeochemical model to give forcing to FABM-MIZER	

3.2.5 Multi-species size-based models

Seven applications were filled in, based on size-based and species based models, among which two were corresponding to the same application (OSMOSE in the eastern English Channel) and have been merged in Table 5. This six applications rely on two different modelling frameworks : SS-DBEM and OSMOSE.

The Size Spectra – Dynamic Bioclimate Envelope Model (SS-DBEM) is a mechanistic model, which means that it takes into account aspects of ecology (e.g. habitat preference, migration) and physiology (e.g. growth and reproduction) to determine biomass and distribution of fish species in response to changes in the environment (e.g. temperature, competition with other species, food availability). It projects the impact of changes in the environment (e.g. warming, deoxygenation) and human activity (fishing pressure) on the abundance, biomass and catch of modelled species. Whilst the model units are expressed as "Number of individuals", they are not to be used to predict actual future stocks but rather numbers relative to the initial starting values of the model, to show temporal and geographical trends in response to changes in the climate and fishing activity scenarios (MSY).
OSMOSE is a multispecies, spatial, individual-based model (IBM) which focuses on fish species and their trophic interactions, and representing the whole life cycle of several fish species from eggs and larvae up to juveniles and adults. It assumes opportunistic predation based on spatial co-occurrence and size adequacy between a predator and its prey (size-based opportunistic predation). Size-structure and age-structured, the model represents fish individuals grouped in schools, which are characterized by their size, weight, age, taxonomy and geographical location, and which undergo different processes of fish life cycle (growth, explicit predation, natural and starvation mortalities, reproduction and migration) and possibly fishing mortality. Based on life-history traits, the model needs biological parameters for growth and reproduction processes and it is forced by spatial distribution maps for each species. In output, a variety of size-based and species-based ecological indicators can be produced at different levels of aggregation, from the species to the comunity levels. The Eastern English Channel OSMOSE application has been further developped through coupling with the DSVM agent-based model (ABM) in order to explicitly represent fishers behavior (specifically the French exclusive bottom trawlers (>18m), the other fleets being still represented through a fishing mortality). The North Sea application uses a bioenergetic version of OSMOSE and allows simulation of evolutionary dynamics.

***Table** 5: Answers to the ecosystem models survey received for size-based and species-based models*

Model's name	**SS-DBEM**	**OSMOSE**	**OSMOSE-DSVM**	**OSMOSE**	**Osmose coupled with ECO3M-S**	**Ev-OSMOSE-NS**
Modelled ecosystem	Northeast Atlantic, European Shelf Seas	Eastern English Channel	Eastern English Channel	Mediterranean Sea	Gulf of Lions	North Sea and East English Channel
Main reference	Cheung et al (2009) Sailley et al. (2020)	Travers-Trolet et al. (2019)	Bourdaud et al. (In Prep)	Moullec et al. (2019a,b, 2022, 2023)	Banaru et al. (2019), Diaz et al. (2019)	Morell et al. 2023a,b
Spatial resolution	0.5 x 0.5° No vertical layers	0.1 X 0.1° No vertical layers	0.1 x 0.1° No vertical layers	20 x 20 km No vertical layers	3 km No vertical layers	0.25° x 0.5° No vertical layers
Period represented		average state 2000-2009	average state 2008-2015	average state 2006-2013	2000-2004	average state 2010-2019
Time step	year	2 weeks	2 weeks	15 days	15 days	Two weeks

Phytoplankton	Forcing model has 4 phytoplankton groups: Diatoms, macro, micro and nano phytoplankton, aggregated to forcing primary production	2 groups (dinoflagellates and diatoms) considered as forcing variable	2 functional groups considered as forcing variable	3 groups (pico; nano, micro) considered as forcing variable	3 explicitly modelled	Considered as forcing variable
Zooplankton	Not modelled/considered	3 groups (microzooplankton, mesozooplankton, macrozooplankton) considered as forcing variable	8 functional groups considered as forcing variable	3 groups (nano; micro; meso) considered as forcing variable	3 explicitly modelled	Considered as forcing variable
Invertebrate (cephalopods, benthos)	2 octopus and 1 shrimp species	1 explicit squid group 5 benthic invertebrate groups depending on size considered as forcing variables	2 explicit cephalopods species	5 cephalopods; 10 crustaceans ; 1 group of benthos	Krill and cuttlefish	1 explicit group (shrimps)
Fish	28 explicit species	13 explicit species	13 explicit fish species	100 explicit species; 85 fish species, 5 cephalopods; 10 crustaceans	8	15 explicit fish species
Top predators						Considered as forcing variable
Fishing fleets	Not modelled/considered	Not modelled/considere d	2 fleet defined per port	Not modelled/consider ed	Not modelled/considere d	Considered as forcing variable
Socio-economic system	Not represented	Not represented	Yes, implicitly through the price of	Not represented	Not represented	Not represented

			all species and quota of 2 species			
Ecological processes considered	Growth, Movement (horizontal or vertical migration, foraging movement, dispersal), Fishing mortality, Natural mortality	Growth, Reproduction, Movement (horizontal or vertical migration, foraging movement, dispersal), Predation , Fishing mortality, Natural mortality, Starvation mortality				Growth, Reproduction, Movement (horizontal or vertical migration, foraging movement, dispersal), Predation, Fishing mortality, Natural mortality, Evolution, Phenotypic plasticity, Maturation, Physiological response to temperature and oxygen
Pressures that can be addressed	Climate change, Environmental variability, Eutrophication , Commercial fishing/harvest	Climate change, Environmental variability, Eutrophication , Commercial fishing/harvest, Recreational fishing/harvest, Pollution (including plastic)	Climate change, Environmental variability, Commercial fishing/harvest, Costs (fuel, etc.)	Climate change, Environmental variability, Eutrophication , Commercial fishing/harvest, Recreational fishing/harvest	Climate change, Commercial fishing/harvest	Climate change, Environmental variability, Eutrophication , Commercial fishing/harvest, Predation
How environmental variability is implemented ?	Effect of temperature on growth and distribution (thermal preference) Oxygen availability for metabolism Available resource to	Environmental variability is taken into account mostly through bottom-up effect, via forcing by plankton and benthos prey field.	Boundaries of seasonal spatial distribution of species can be provided; Abundance of Lower Trophic	through spatio-temporal variability of primary and secondary productions through HTL species		Effect of temperature on metabolism (and then on growth, maturation and fecundity), on low trophic level which are seasonally organized, and potentially the

	sustain the population		Levels can be modified	distributions (from SDM)		spatial distribution of the fish can be seasonally organized
Can the model be used for climate change projections ?	Yes, this has already been simulated	Yes, this has already been simulated	Yes, it has the capabilities to do so (but projections have not been run yet)	Yes, this has already been simulated	Yes, it has the capabilities to do so (but projections have not been run yet)	Yes, this has already been simulated
How the model projects ecosystem state, e.g. in 2050 ?	Through a trajectory (every year between now and then is simulated)	Through the simulation of the 2050 state alone (no trajectory) Through a trajectory would be possible but not simulated yet	Trajectory, but years between now and then not explicit	Through the simulation of the 2050 state alone (no trajectory)	Through a trajectory (every year between now and then is simulated)	Through a trajectory (every year between now and then is simulated), Through the simulation of the 2050 state alone (no trajectory)
Existing climate change scenarios	RCP8.5 and RCP4.5 for 2000-2098. Forced with POLCOMS-ERSEM model RCP4.5 and RCP8.5 for 2000-2050. Forced with NEMO-ERSEM	RCP4.5 and RCP8.5 have been run, using average outputs from the POLCOMS-ERSEM model over the period 2050-2059		RCP8.5; NEMOMED8-ECO3M-S model for physical (temperature and salinity) and biogeochemical variables (phyto and zooplankton); 2021-2050 and 2071-2100 periods		2020-2100 under scenario RCP 8.5 The simulations under scenarios RCP 4.5 will be run soon. The 2050 state alone could be easily run too.
How Climate Change is implemented ?	Effect of temperature on growth and distribution (thermal preference) Impact of change in environment	Climate change is taken into account mostly through bottom-up effect, via forcing by plankton and	Boundaries of spatial distribution of species can be provided; Growth can be modified; Reproduction can	spatial distribution of HTL species; Primary and secondary productions	Effects on pk groups	Effect of temperature and deoxygenation on metabolism (and then on growth, maturation and fecundity), modification of the

	production Change in distribution as a result of change in environment (temperature, salinity, pH, oxygen are the main environmental forcings in the model)	benthos prey field. Temperature effects can be indirectly taken into account by modifying growth and reproduction parameters (including spawning seasonality) and/or by changing distribution maps.	be modified; Abundance of Lower Trophic Levels can be modified			primary and secondary production and potentially the spatial distribution of the fish can be impacted by temperature and oxygen Fish can evolve in response to climate change
Requirements for projecting ecosystem under climate change	Variables from biogeochemical climate model (at the original resolution): Surface variables: SST, salinity, oxygen, pH, primary production. Bottom variables: temperature, salinity, oxygen, pH Other: currents, sea ice cover (if working in polar sub-polar areas) Choice of species to be modelled (different if in Europe or South East Asia for example)	Prey fields are required, i.e. 2D maps biomass of plankton and possibly benthic preys, every time step (15 days). New spatial distribution maps possibly by age/season are required.	New spatial distribution of species; New growth; New reproduction; New abundances of Lower Trophic Levels	Need abiotic variables (salinity and temperature) at different depth (to project future species distributions (SDM)) Need projections of primary (phytoplankton) and secondary (zooplankton) productions (same resolution than model configuration)		

How fishing activity is described in the model?	Through global fishing mortality only	Through global fishing mortality only	Through global fishing mortality only, Through global fishing effort, Through fishing vessels or fleets	Through global fishing mortality only	Through global fishing mortality only	Through global fishing mortality only
Please provide information about variables and processes	Global fishing mortality applied as a multiple of the MSY	In the current version of the model, a global fishing mortality F is applied by species (to individuals older than age at recrutement) and could be structured by age/size, space and season. The new version of the model (OSMOSE 4.3) has the capabilities to describe the fishing activity using fleets.	Fishing mortality and spatial accessibility of non-explicit fleets for the 15 species; Effort, fish prices, costs, values, quotas, spatial accessibility, discard ban, gear selectivity for the explicit fleets	fishing mortality on targeted species only	Fishing mortality on target species	Fishing mortality per size class per species.
Is fishing management taken into account?	No	No	Yes HCRs, quotas, minimal landing size, MPA, spatial closures	No	No	No
Can the model be used for projections of potential fisheries catch in 2050?	Yes, this has already been simulated	Yes, it has the capabilities to do so (but projections have not been run yet)	Yes, it has the capabilities to do so (but projections have not been run yet)	Yes, this has already been simulated	Yes, it has the capabilities to do so (but projections have not been run yet)	Yes, it has the capabilities to do so (but projections have not been run yet)

Requirements for projecting potential fisheries catch	Same as for climate projections along with a value for MSY	Estimation of fishing mortality per species in 2050 compared to past fishing mortalities. Or rules to change the current F towards a particular target to be reached in 2050	Yearly values of management tools if modified (discard ban, etc.); Fishing mortality for non-explicit fleets.	Same than for "ecosystem projection"; statu quo for fishing effort/mortality		Depending on the complexity of the tested scenario, the model could be used in its current version or through modules available in the OSMOSE modeling framework such as spatialization of fishing effort, multiple fleets, marine protected areas...
Existing fishing scenarios	These were done in combination with RCPs (see climate runs(to approximate SSPs RCP4.5 MSY0.6 RCP8.5 MSY0.8 RCP8.5 MSY1.1	Fishing mortality scenarios targeting LTL, HTL and ALL species, using a multiplier of FMSY between 0 and 2. The species that were not targeted in the scenarios were fished at their current fishing mortality.	Business-as-Usual; Discard ban; MPAs; spatial closures; selectivity change; (+ mix of scenarios: e.g. MPAs + selectivity)	Same than for ecosystem		
Is the model coupled to another model?	Yes, one-way coupling (i.e. forcing) with biogeochemical simulations available on the Copernicus CDS. POLCOMS-ERSEM product (Kay et al.	Yes, one-way coupling (i.e. forcing) with the biogeochemical model ECOMARS3D, not really available for new runs. But applying ratio of	Yes, one-way coupling (i.e. forcing) using Lower Trophic Level fields provided by ECO-MARS-3D	Yes, one-way coupling (i.e. forcing) with NEMOMED12-ECO3M-S for present period (NEMOMED8-ECO3M-S for	Yes, two-way coupling (with feedbacks) with Eco3Ms	Yes, one-way coupling (i.e. forcing) with POLCOM-ERSEM

	2020) or NEMO-ERSEM product (Galli et al. 2020)	changes from other models (eg ERSEM) have been done in the past		climate change projections) 3 groups of phyto- and 3 groups of zoo-plankton (link to HTL species through predation process)		
Is the model fitted / calibrated to represent the ecosystem?	No calibration performed	Calibration of an average state (or climatology)	Calibration of an average state (or climatology)	Calibration of an average state (or climatology)	Calibration of a time series (hindcast)	Calibration of an average state (or climatology)
Which type of data are required to fit the model?		The common method consists of using : stock biomass estimates from stock assessment ; annual catches ; catch-at-size (at lesser extent)	Average landings or catches (when available); average biomasses (when available)	Total biomass per species (from stock assessment models); Biomass indices from surveys (MEDITS); Total catch per species (from FAO and SAU)		Annual catches, annual estimated biomasses, length-at-age
On which processes/parameters is the calibration performed?		larval mortalities; plankton accessibility; fishing mortality	Lower Trophic Levels accessibilities; larval mortality rates; fishing mortality rates; natural mortality rates; catchabilities for explicit fleets	Plankton accessibility; larval mortality; fishing mortality		Natural mortality, larvae mortality, a parameter to calibrate the accessibility of fish species to planktonic prey and the maximum of the fishing mortality per size curve.
Which method/procedur		semi-automatic method (evolutionary	optimization method/algorithm + "by hand"; "by	Evolutionary algorithm (Calibrar package)		evolutionary algorithm (optimization method) was performed with

e is used for calibration?		algorithm, Oliveiros et al. Calibrar R package), usually with 2 or 3 phases	hand" for catchabilities			four phases, one per parameter type.
Outputs and indicators related to fishing and catches	potential catch (in grams of fish) per fish species per year per model grid square	- Total catches (biomass, abundance) - Trophic level of catches - Mean size of catches - Fishing mortality	Catches per species for non-explicit fleet; Landings and Discards per species for explicit fleets; Fixed costs for explicit fleets; Variable costs (fuel, landings, crew salaries and other variable costs) for explicit fleets; Income for explicit fleets; Profit for explicit fleets; Quota for explicit fleets	Total catch per species/size/age (spatial outputs available)	See Osmose V3	landings per species, landings per species per size and age, mean size of the landing, mean trophic level of the landing
Other outputs and indicators	Abundance (# of fish) per fish species per year per model grid square Biomass (in grams of fish) per fish species per year per model grid square	- Diet composition - Biomass - Abundance - Additional Mortality - Trophic level Every level of aggregation is possible (individuals, cohort, per size class, per	Abundance per age class; Abundance per size class; Abundance per trophic level; Biomass per age class; Biomass per size class; Mortalities per stage; Biomass per trophic level; Mean Size; Mean Size of	All standard outputs available from OSMOSE		numerous output including biomass, abundance, landings, trophic level, mean size, mortality. Each outputs can be explored by size or by age or spatially. Emerging diet. Physiological outputs (resting metabolism, ingested energy rate,

		age class, species, community).	catches; Mean trophic level; Mean trophic level of catches; SSB; etc.			growth rate, energy allocated to reproduction). emerging mean maturation size and age, and their variability. Genotypic outputs (mean and variance of genotypic values the life history traits, and diversity of the allele coding for this trait).
Is the model ready to simulate new scenarios?	Yes, ready to run	Yes, ready to run	Runnable within a year	Yes, ready to run	No	Yes, ready to run
Able to run ForeSea scenarios if relevant ?	I don't know if I can run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios	No, I cannot run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios
Comments on the possibility to run ForeSea scenarios	This will be dependent on the work needed to run the scenario and resulting time demand		I put "Runnable within a year" if some scenarios require small modifications of code or inputs format, but I hope it would be less	OSMOSE-MED model will be updated in 2023 (with osmose version 4). New configuration ("multi-fisheries") available soon.	Contact Nicolas Barrier and Yunne Shin for the code of the couples model made by Frédéric Diaz.	

3.2.6 Ecosystem models

Eleven applications were filled in, based on ecosystem models, among which four were corresponding to two similar applications (Ecopath with Ecosim in the Bay of Seine, and Ecopath with Ecosim and Ecospace in the Celtic Sea) and have been merged. Among these 9 applications, represented in two tables (Table 6 and 7) for sake of clarity, 7 are based on the Ecopath modelling framework, with some specificities depending on the studies.

Ecopath is a mechanistic ecosystem model structured in functional groups (including non living groups such as detritus and possibly fishing discards) with possibility to include fleets representation depending on case studies. Living groups typically include single species groups and multi-species groups, from bacteria and phytoplankton to seals and dolphins. Species are aggregated based on their trophic and ecological traits. Single species groups can be defined, and even discretized into multi-stanza groups (to represent different age classes for instance), in order to study species specific issues like the effect of fishing on specific species. Different currencies (e.g., wet weight, carbon) can be used depending on the applications. Ecopath with Ecosim is a dynamic framework based on the mass-balanced Ecopath model, which relies on two master equations and a resulting set of linear equations to describe the trophic interactions among functional groups of organisms. The first one describes the production and the second equation ensures energy balance for each functional group. The dynamic component can be driven by time-series of fishing effort and primary production or other abiotic environmental variables (possibly through coupling with a physical-bioegeochemical model), and is usually fitted to abundance and fisheries catch data. Ecopath with Ecosim with Ecospace is a spatio-temporal trophic model which, in the application presented here, was parameterized using statistical habitat models fitted to presence-absence data collected by multiple fisheries-independent surveys and ecological-niche approach based on satellite remote sensing data. This model is also forced by several abiotic environmental variables (including, among others, temperature, salinity and dissolved oxygen concentration, both at the surface and at the bottom). Non indigenous species can be modelled in this framework, usually using information from distribution species models, either by considering the spatial dimension implicetly (including non indigenous species as functional groups) or explicitly (proving maps to an Ecospace model).

Atlantis is a mechanistic size-structured and age-structured model, based on biochemical cycle of nitrogen, tracking nutrient flow through the food web up to fishery. Invertebrates are modeled as biomass pools or stages and vertebrates are represented as size/age structured and their condition are recorded. Food wed interaction are forced by an availability matrix and then governed dynamically by spatial co-occurrence and size relationship between prey and predator.

RCaN is a mass-blanced model.

***Table** 6: Answers to the ecosystem models survey received for ecosystem models (1/2)*

Model's name	**Ecopath with Ecosim**	**Ecopath with Ecosim (with Ecospace)**	**Ecopath with Ecosim (with Ecospace)**	**EwE-ERSEM-SDM**
Modelled ecosystem	Gironde estuary	Celtic sea	Bay of Seine	ICES area 7d and 4c

Main reference	Lobry et al. 2008 Chevillot et al. 2019	Hernvann et al. (2020), Pottier et al. in prep	**Halouani et al. (2020)** Nogues et al. (2022)	Araignous et al. in prep
Spatial resolution	Not spatially explicit	0.125 x 0.125° No vertical layers	0.015 x 0.015° No vertical layers	0.02 x 0.02° No vertical layers
Period represented	Chevillot et al. provided 3 Ecopath models representing 3 periods from the 1980's to the early 2010's	Hindcast 1985-2016 or 2003-2020 depending on the version, Forecast 2017-2099	hindcast 2000-2015	2006-2018
Time step	year	year	year	monthly
Phytoplankton	1 group of phytoplankton ; 1 group of microphytobenthos	2 phytoplankton groups considered as forcing variable; including large (>5µm) and small(<5µm)	1 group of phytoplankton	Pico-nanophytoplankton ; microphytoplankton
Zooplankton	2 groups of zooplankton	4 functionnal groups considered as forcing variable (macrozooplankton, large mesozooplankton, small mesozooplankton and microzooplankton)	3 groups of zooplanton (Microzooplankton, Mesozooplankton and Macrozooplankton)	Microzooplankton ; Mesozooplankton
Invertebrate (cephalopods, benthos)	2 goups of macrobenthos; 2 groups of suprabenthos; 1 group of shrimps	11 invertebrate groups; including 2 cephalopod groups and 9 benthos groups; 3 forcing variables for benthic production	10 groups on invertebrates (benthos groups and cephalopods)	10 groups: meiofauna; suprabenthos; Benthic Inv. suspension feeders ; Benthic Inv. suspension feeders specific to biofouling; Benthic Inv. deposit feeders (Surface); Benthic Inv. deposit feeders (sub-Surface); Benthic Inv. Pecten maximus; Benthic Inv. suspension feeders ; Benthic Inv. predators ; Shrimps; Lobster/crabs

Fish	11 explicit species ; 4 functional groups	15 explicit fish species and 16 additional functional groups	15 explicit species; 5 functional groups	10 explicit species ; 14 functional groups
Top predators	1 bird group	2 birds groups ; 2 groups of mammals	3 birds group; 3 groups of mammals	1 birds group ; 1 group of toothed whales; one group of seals
Fishing fleets	Not modelled/considered	In the latest version, 44 fleets defined per Country x Gear Type x vessel length category	6 fleets defined by gear and targeting species	9 fleets: beam trawl; Danish seine; demersal trawl; dredge; nets; pelagic trawl; pots/traps; seine; others
Socio-economic system			Implicitly represented through market prices of exploited species, driving the profitability of fishing fleets.	
Ecological processes considered	Predation , Fishing mortality, Natural mortality	Movement (horizontal or vertical migration, foraging movement, dispersal), Predation , Fishing mortality, Natural mortality	Movement (horizontal or vertical migration, foraging movement, dispersal), Predation , Fishing mortality, Natural mortality	Predation , Fishing mortality
Pressures that can be addressed	Commercial fishing/harvest, Mechanical mortality by nuclear power plant	Climate change, Environmental variability, Commercial fishing/harvest	Climate change, Environmental variability, Commercial fishing/harvest, Recreational fishing/harvest, RME (renewable marine energies, mainly offshore wind farm), Marine aggregate extraction	Climate change, Commercial fishing/harvest, Offshore windfarms
How environmental variability is implemented ?		Through temperature forcing functions (SBT and SST/ polcoms-ersem). Those annual temperature time series are coupled with functional responses of species (niche model) for temperature, directly	Environmental drivers (such as T°, O2, pH) could be implemented into Ecospace to drive species/functional groups distribution through their foraging response.	

		affecting the consumption of species within the ecosystem and thus their biomass.		
Can the model be used for climate change projections ?		Yes, this has already been simulated	Yes, this has already been simulated	Yes, it has the capabilities to do so (but projections have not been run yet)
How the model projects ecosystem state, e.g. in 2050 ?		Through a trajectory (every year between now and then is simulated)	Through a trajectory (every year between now and then is simulated)	Through a trajectory (every year between now and then is simulated), Through the simulation of the 2050 state alone (no trajectory)
Existing climate change scenarios		RCP 4.5 and RCP 8.5	In Nogues et al. 2022, Ecospace was used to simulate the effects of RCP 8.5 forcing scenario in 2050 and 2100.	
How Climate Change is implemented ?		Niche models forced by SST or SBT, and forcing by time series of the plancton and benthic producers abundance	Through future distribution maps (from SDM models) as a new set of suitability index maps. Possibly through projections of Production/Biomass or the Consumption/Biomass ratios.	Through spatial distribution maps of indigenous and non indigenous species (at different time steps under scenario RCP8.5) ; Change in physiologic parameter with the rising temperature (P/B) Distribution of biomass forced by ERSEM simulation under rcp 8.5 from 2006 to 2050
Requirements for projecting ecosystem under climate change		THe EwE model is forced by the ouputs of Polcoms/Ersem (plancton, benthos, and temperature)	- The Ecopath spatial-temporal framework. - Future maps of species distributions under climate change projections scenarios from SDM models. - Future environmental conditions.	the trajectory could be assessed using only the monthly distribution of biomass of low trophic levels from ERSEM under RCP8.5 over the whole period. only the simulation for 2050 state integrates SDM for fish groups
How fishing activity is described in the model?	Through global fishing mortality only	Through global fishing mortality only	Through global fishing mortality only, Through global fishing effort, Through fishing vessels or fleets	Through global fishing mortality only, Through fishing vessels or fleets

		Lastest version: through global fishing effort, fishing vessels or fleets		
Please provide information about variables and processes	global catches by professional fishery	Initial year: landings and discards are entered by fleets and functional groups. Then: fleets are driven by relative effort forcing time series and catches are driven by catches time series by functional group.	In Ecospace The spatial fishing mortality depends on fishing fleet distribution. The gravity model spreads the fishing effort inherited from Ecosim across all habitats open to fishing. In Ecosim a fishing mortality rate F is estimated during the calibration process to fit the catch and/or the biomass. It also possible to provide time series of F by species/functional group and/or time series of fishing effort by fleet.	fishing mortality on targeted species, bycatch included discards included
Is fishing management taken into account?	No	No	Yes, In Nogues 2022, Fishing management is modelled through MPAs, discards and fishing time series	No
Can the model be used for projections of potential fisheries catch in 2050?	No	Yes, this has already been simulated. Latest version : projections have not been run yet	Yes, this has already been simulated	Yes, it has the capabilities to do so (but projections have not been run yet)
Requirements for projecting potential fisheries catch			To run projections of potential fisheries it's required to have scenarios of fishing effort (and eventually climate change scenarios).	
Existing fishing scenarios			The simulated fishing scenarios are very simple and arbitrary, they consist in : 1/ a progressive decrease of fishing pressure (e.g -20% for trawling activities, -5% for other fishing fleets)	Scenario of fishery restrictions inside the limits of offshore windfarms in the area

			2/ a progressive increase of fishing pressure (e.g +20% of pelagic and bottom trawls, +5% for "other fishing fleets)	
Is the model coupled to another model?	No, it is a stand-alone model	Yes, one-way coupling (i.e. forcing) with Polcoms/Ersem	No, it is a stand-alone model. In Nogues et al. (2022) one-way coupling (i.e. forcing) Forcing was made using species distribution models (SDM) output. Suitability index maps computed by SDM were used to define the habitat suitability of the different groups in the ecosystem model.	Yes, one-way coupling (i.e. forcing) ERSEM : monthly data of biomass, production, distribution of biomass from 2006 to 2050 under rcp 8.5 SDM: distribution maps for fish groups currently in the area of the model and non indigenous species two period : 2066-2018 and 2040-2050
Is the model fitted / calibrated to represent the ecosystem?	No calibration performed	Calibration of a time series (hindcast)	Calibration of a time series (hindcast)	Calibration of a time series (hindcast)
Which type of data are required to fit the model?	annual landings ; biomass surveys		Time series of : catches, biomass, fishing mortality, fishing effort by fleet	nominal catches ; annual biomass ; fishing mortality ; monthly data of biomass for low trophik levels
On which processes/parameters is the calibration performed?	Mass balance is checked	Mass balance is checked for the base ecopath model. Then, a certain number of vulnerability parameters are estimated to improve the fit of the model to observed data (on the hindcast period).	During the calibration procedure, the best values of vulnerability were estimated to improve the fit of Ecosim predictions to the observed data. This parameter describes the predator-prey interaction.	diet
Which method/procedure is used for calibration?	by hand	The "Stepwise Fitting Procedure" will be used.	There is an automatic optimization method/algorithm called "the Stepwise Fitting Procedure".	by hand

Outputs and indicators related to fishing and catches			Catches (volume and value) by species and fleet, Discards and biomass by species Fishing effort by fleet	landing per species per fleet and discards
Other outputs and indicators	Trophic flows and trophic indicators		Trophic level based indicators (TL catch, MTI, TL community), Ecological Network Analysis indices	Trophic levels; keystone species; ecological network analysis indicators
Is the model ready to simulate new scenarios?	Runnable within a year	Runnable within a year	Runnable within a year	Runnable within a year
Able to run ForeSea scenarios if relevant ?	I don't know if I can run simulations of ForeSea scenarios	I don't know if I can run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios
Comments on the possibility to run ForeSea scenarios		I think I can potentially run ForeSea scenarios depending on the scenarios elected and the deadline. The hindcast model might be ready next month for running simulations.		maybe best to wait for the paper to be at least submitted

***Table** 7: Answers to the ecosystem models survey received for ecosystem models (2/2)*

Model's name	**Ecopath with Ecosim**	**Ecopath with Ecosim**	**Ecopath**	**Atlantis**	**RCaN**
Modelled ecosystem	Bay of Biscay - ICES area 8abc	Bay of Biscay	Gulf of Lions	Eastern English Channel, ICES area 7d	Brouage intertidal mudflat in the bay of Marennes-Oléron
Main reference	Corrales et al. (2022)	Le Marchand et al. (2022)	Banaru et al. 2013 in JMS	Girardin et al. (2018)	

Spatial resolution	Not spatially explicit	Not spatially explicit	Not spatially explicit	Non-regular grid (35 boxes) 3 vertical layers	Not spatially explicit
Period represented	average state 2000-2003; hindcast 2003-2019	2007-2016		2002-2011	
Time step	year	year	Year	day	year
Phytoplankton	Small phytoplankton (<20µm); large phytoplankton (>20 µm)	Small and large phytoplankton groups. One primary benthic producers group.		1 group of phytoplankton	
Zooplankton	Gelatinous plankton; Macrozooplankton (>2000 µm); Mesozooplankton (<2000 and >200 µm); Microzooplankton (<200 µm)	microzooplankton (<200 µm), mesozooplankton (200–2000 µm), and macrozooplankton (>2000 µm).		small zooplanktons ; carnivorous zooplanktons ; gelatinous zooplanktons	
Invertebrate (cephalopods, benthos)	16 groups of invertebrates, both benthic (e.g., bivalves, polychaetes, echinoderms, cephalopods and decapods) and pelagic (e.g., squids, shrimps, pelagic crab, gelatinous plankton and zooplankton)	8 benthic invertebrate groups (Norway lobster, lobsters/crabs, shrimps, carnivorous and necrophagous benthic inv., subsurface deposit feeding inv., surface suspension and deposit feeders, benthic meiofauna, and suprabenthic inv.). Cephalopods are separated into two groups: benthic and pelagic.		1 cephalopods ; 3 crustaceans ; 2 bivalves; 1 whelks ; 1 echinoderms ; 2 benthos	

Fish	23 functional groups of fish	There are 21 groups of fishes: two groups of chondrichthyans (large piscivorous sharks and small sharks and rays), 11 monospecific groups of fishes targeted by fisheries (seabass, blue whiting, hake, whiting, megrim, sole, plaice, horse mackerel, sardine, anchovy, and pout) and 8 multispecific groups: anglerfishes (two species), mackerels (two species), flatfishes (benthos feeders), demersal benthos feeders, demersal piscivores, demersal planktivores, pelagic piscivores, and pelagic planktivores.	7 explicit species ; 10 functional groups	
Top predators	2 groups of seabirds; 1 group of marine mammals (i.e., dolphins), 2 groups of sharks (i.e., demersal and pelagic sharks); and 7 groups of fishes (i.e., bluefin tuna, albacore, other large pelagic fishes, anglerfish, sea bass,	Marine mammals are divided into two groups according to their size. Seabirds are also divided into two groups, according to their feeding strategies.	1 birds group ; 2 mammals groups	

	large hake and large demersal fishes)			
Fishing fleets	The model comprises 13 fishing fleets from Spain and France: Spanish demersal trawl; Basque demersal trawl; Spanish purse seine; Spanish coastal fishery; Spanish offshore fishery; French demersal trawl; French pelagic trawl; French nephrops trawl; French purse seine; French coastal fishery; French offshore fishery; Spanish recreational fishery; and French recreational fishery.	10 main French fleets operating in the area: bottom trawlers targeting demersal fishes, purse seiners, bottom trawlers targeting Norway lobster, gillnetters >15m, pelagic trawlers targeting small pelagic fishes, gillnetters <15m,pelagic trawlers targeting demersal fish, long-liners and line vessels, pelagic trawlers targeting tuna, and Danish seine. Other European fleets were also included, mostly from Spain (29% of catches from foreign ships), the United Kingdom (10%), and Belgium (6%).		
Ecological processes considered	Predation , Fishing mortality, Natural mortality	Predation , Fishing mortality, Natural mortality	Predation , Fishing mortality, Natural mortality	Growth, Reproduction, Movement (horizontal or vertical migration, foraging movement, dispersal), Predation , Fishing mortality, Natural mortality, nutrient recycling, vertebrates

				conditions (structure versus reserve biomass), movement is forced using maps
Pressures that can be addressed	Climate change, Environmental variability, Commercial fishing/harvest, Recreational fishing/harvest	Climate change, Commercial fishing/harvest	Commercial fishing/harvest, Recreational fishing/harvest	Climate change, Environmental variability, Commercial fishing/harvest, Recreational fishing/harvest
How environmental variability is implemented ?	Time series of primary production are used to drive the dynamics of primary producers Time series of temperature (sea surface temperature and sea bottom temperature), together with environmental response functions (that link the species or functional groups dynamics with the environmental drivers) are use to drive the dynamic of specific groups (i.e., mackerel, horse mackerel, sardine, anchovy, anglerfish, sea bass, blue withing, hake, megrim, common sole and mullets). Specifically, the intercep between the environmental driver and the response function is used to estimate a multiplier factor that modifies the			Environmental variability is implemented using forcing. Seasonal maps of distribution are already used, change in river flow or temperature and salinity are also implemented. However at the moment, ecological processes are not influence by temperature or salinity but good be (growth, mortality or assimilation).

	consumption rate of the species or functional groups with a maximum value of 1 and and a declining value as the environmental driver deviates from the optimum values. Remarkably, temperature response functions has been obtained using using shape-constrained generalized additive models (SC-GAMs) and data from the North-Atlantic using GBIF and OBIS datasets.		
Can the model be used for climate change projections ?	Yes, this has already been simulated	Yes, this has already been simulated	Yes, it has the capabilities to do so (but projections have not been run yet)
How the model projects ecosystem state, e.g. in 2050 ?	Through a trajectory (every year between now and then is simulated)	Through the simulation of the 2050 state alone (no trajectory)	Through a trajectory (every year between now and then is simulated)
Existing climate change scenarios	The model has been used to assess the impact of three scenarios of greenhouse emissions (RCP-2.6, RCP-4.5, and RCP-8.5) between 2019 and 2099. The projections came from an ensemble modelling of the CMIP6 models: MIROC-ES2L, MPI-ESM1-2-LR, CMCC-ESM2, IPSL-CM6A-LR, CMCC-CM2-		

	SR5, CanESM56-CanOE, UKESM1-0-LL, GFDL-ESM.				
How Climate Change is implemented ?	In our model changes in primary production and temperature (sea surface temperature and sea bottom temperature) due to climate change were assessed.	To study the effects of NIS arrivals, we compared the current situation (2007–2016) with five other Ecopath models (2041–2050) under the IPCC scenario RCP8.5 based on different community changes caused by the arrival of NIS. Into these models, we integrated (i) the evolution of fish and cephalopod biomass (based on Chaalali et al., 2016) due to the projected evolution (gain or loss) of their suitable habitat (calculated in Le Marchand et al., 2020); and (ii) the changes in the organisms' production and consumption.		Effect on temperature on metabolism can be used, change in spatial distribution or pH can be also implemented. Change in primary production and/or river inputs	
Requirements for projecting ecosystem under climate change	In our model we need time series of primary production and temperature (sea surface temperature and sea bottom temperature). These			Spatial distribution maps should be used for every groups of interest. In term of temperature or pH this will require more investigation to	

	time series were obtained from monthly projections with a spatial resolution of 1/12th degree from the ensemble projections of CMIP6 data on the Bay of Biscay. However, any resolution can be used to estime time series of environmental parameters.			be able to use that functionality (calibration first) or use proxies for of the impact (scenario with change in growth rate or mortality linked to climate change). The easiest methods to implement climate change would be either to force primary production or change it's parameterization to mimic change in productivity induced by climate change. Change in rivers loads.	
How fishing activity is described in the model?	Through global fishing mortality only, Through global fishing effort	Through global fishing mortality only	Through global fishing mortality only, Through fishing vessels or fleets	Through global fishing mortality only	
Please provide information about variables and processes	Official landings were obtained from IEO and AZTI databases, Ministry of Agriculture, Fisheries and Food of the Spanish Government, and the Ministry of Agriculture and Food of the French Government. Landings for tuna species (bluefin tuna and albacore) came from ICCAT databases. The model considers discards, which were estimated from local estudies and the AZTI			At the moment, the final version is using one constant fishing mortality per functional groups with constant selectivity. Discards are considered as a constant proportion of the catch for each functional groups. Previous versions of the model were using several fleets; spatial effort distribution with constant selectivity by fleet and catchability per functional groups, a fleet dynamics model was also implemented for	

	database. Finally, recreational fisheries catch were obtained from natianal scale studies. The dynamic model used time series of fishing effort (expressed as number of trips for Spanish fishing fleets and for French fleets are expressed as) and time series of fishing mortalities for those species with available stock assessment.			some fleets. To use, fleets in the current version of the model would required updating the model.	
Can the model be used for projections of potential fisheries catch in 2050?	Yes, this has already been simulated	Yes, it has the capabilities to do so (but projections have not been run yet)	No	Yes, it has the capabilities to do so (but projections have not been run yet)	
Requirements for projecting potential fisheries catch	We have assessed the impact of fishing at the advised FMSY for the functional groups with available stock assessment			In the current version it would require fishing mortality trajectory or the use of constant fishing scenarios per functional groups. Dynamics management would require additional work, it's already implemented in the model framework but needs to be parameterized for the Eastern English Channel.	
Existing fishing scenarios	Fishing mortality were forced between 2019 and 2099	in progress		Most of the scenarios were exploratory ones, looking for Fmsy for each functional group or ecological indicators sensitivity/responsiveness runs	

				using different fishing strategies with runs of up to 60 years.
Is the model coupled to another model?	Yes, one-way coupling (i.e. forcing) The model has been calibrated with data from the POLCOMS-ERSEM model (Plymouth Marine Laboratory - PML) and the impact of climate change were assessed by using data from an ensemble modelling of the CMIP6 models: MIROC-ES2L, MPI-ESM1-2-LR, CMCC-ESM2, IPSL-CM6A-LR, CMCC-CM2-SR5, CanESM56-CanOE, UKESM1-0-LL, GFDL-ESM.	No, it is a stand-alone model	No, it is a stand-alone model	Yes, one-way coupling (i.e. forcing) Hydrodynamics in the model are forced using MARS3D ouputs from 2006. Current, salinity and temperature are used as forcing for Atlantis. River inputs and solar radiation are also forced but derived from observation.
Is the model fitted / calibrated to represent the ecosystem?	Calibration of a time series (hindcast)	Calibration of a time series (hindcast)	No calibration performed	Calibration of an average state (or climatology)
Which type of data are required to fit the model?	To calibrate an Ecosim model we need data to force the model (normally fishing effort/fishing mortality but also environmetal parameters such as temperature and primary production) and data to compare/calibrate the model (normally annual catch and	landings		Annual catch, catch-at-age, diet, biomass, size at age for vertebrates

	biomass). In our model we used time series of fishing effort, fishing mortalities for those species with available stock assessment, sea surface temperature, sea bottom temperature and primary production to drive the model while time series of biomass and catches were used to calibrate the model		
On which processes/parameters is the calibration performed?	the vulnerability parameter but also (not in our case) through the estimation of a primary production anomaly.		growth ; stock recruitment relationships ; natural mortality ; diet ; fishing selectivity
Which method/procedure is used for calibration?	The model was fitted by using the Stepwise Fitting Procedure, which automates testing of alternative hypotheses used for fitting EwE models This procedure can test alternative hypotheses related to the impact of fishing, changes in predator-prey dynamics (vulnerabilities), changes in primary production (production anomalies) or all of the above together. This procedure estimates different vulnerability parameters and primary		The model is calibrated by hand with usually several phases of calibration. First, focus on hydrodynamics and NPZD part of the model to make sure plankton groups blooms occurred and no major issue with water and nutrient flow happened. Then, other biological compartment are implemented using forced time series of catches, during that phase most of the biological parameters are tuned. Finally, the fishery is implemented using fishing mortality first and selectivity per functional

	productions anomalies to improve model fits by comparing model predictions to observed data using the sum of squares (SS) statistics and to find the statistically “best fit” model based on Akaike’s Information Criterion (AIC), which penalizes the overparameterization of the model. In our case, we only test for changes in predator-prey dynamics (vulnerabilities).			groups to try to reproduce observed catches. If more complex fisheries related processes are needed another phase of calibration can start (to implemented effort, fleets dynamics model, management...). Each phase are not compartmentalized, you sometime need to go back on previous phases tuned parameters even if you need to keep the change as minimal as possible.
Outputs and indicators related to fishing and catches	catches (landings and discards) per species/functional group and fleets; total mean trophic level of the catch; mean trophic level of the catch per fleet; primary production required to sustain the fishery; gross efficiency of the fishery; exploitation rate (fishing mortality/total mortality)	Mean Trophic Level 3.25	Landings	catches per fleets and functional groups
Other outputs and indicators	biomass per species/functional group; trophic level of species and/or functional groups; mean trophic level of the community; Finn's cycling		Trophic level	Biomass per age class and functional groups; abundance per age class and functional groups; diet per age class and functional groups; nutrients (organic and inorganic) ; fish

	index; path length; mean transfer efficiency; keystone index; Kempton's index			condition per age class and functional groups
Is the model ready to simulate new scenarios?	Yes, ready to run	Yes, ready to run	Yes, ready to run	Yes, ready to run
Able to run ForeSea scenarios if relevant ?	Yes, I can run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios	I don't know if I can run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios
Comments on the possibility to run ForeSea scenarios	Ecospace is not ready yet but will hopefully be ready in a year.		Une mise à jour du modèle est en cours de publication et un ecosim-ecospace-ecotracer en cours de réalisation	As part of ForeSea it's planned to run scenarios with the existing model that use fishing mortality, as new calibration is unlikely to happen in a short time. However, some modification could be tested to implement climate change scenarios

3.2.7 Fleet-oriented fisheries management models

Seven applications were filled in, based on fleet-oriented and/or management mechanistic models (Table 8). These applications are based on four different modelling frameworks.

The Scilab Integrated model is an integrated bio-economic fleet-based model applied to the French demersal longline fishery targeting Patagonian toothfish around Crozet and Kerguelen Islands. This fishery has one of the highest depredation rates worldwide, mainly due to interactions with killer whales and sperm whales. This population-based and age-structured model explicitly account for the fish and mammals population, as well as the depredation process (through depredation rates).

The MICE bio-economic model is species-based and fleet-based and simulates biomass dynamics, accounting for climate variability using SST. Evolution of price and cost are accounted for in the model, and fishing management is modelled through change in fleet capacity over time. This model can assess the impact of management strategy (MMSY, MMEY, no take...) on socio-ecosystem.

ISIS-Fish is a spatially-explicit population-based and fleet-based model. Population dynamics are age-structured and described through seasonally-explicit processes (growth, natural mortality, spawing stock-recruitement relationship, spatial distribution). Exploitation dynamics is characterized by several fishing activities with specific spatial and seasonal features, and practiced by several kinds of vessels with specific technical characteristics. Exploitation costs and revenues are considered at several levels: the fishing trip, the fishing unit (vessel and crew), and the vessel owner. The model is generic and can be used for different types of fisheries. A database is attached to the software for the storage and updating of information for each fishery. This includes the specification of model dimensions and of the parameters describing populations and exploitation (homogeneous fleet segments according to home harbor and vessel length). Several model assumptions regarding either population or exploitation may be adapted to suit a specific fishery. Both policies and corresponding fishers' response may be interactively specified through JAVA™ scripts. This version of ISIS-Fish allows for the calculation of biological and economic consequences of a range of policies, including conventional ones like catch and effort controls (e.g. effort reduction measures applied to one specific gear or all gears), and alternative policies such as spatial temporal closures (including marine protected areas). To facilitate policy-screening in a high-dimension parameter space, the software includes features, like interfaces for sensitivity analysis and simulation queues. http://isis-fish.org/v4/user/usermanual/introduction.html

IAM (Impact Assessment Model for fisheries management) is a bio-economic model developed as part of a partnership with stakeholders to support fisheries management. It is a tool for academic and non academic knowledge integration which models dynamics and interactions between fish stocks, vessels or fleets, fisheries governance and fish market. It is based on the Baranov production function for explicitly dynamic stocks. It is dedicated to scenario simulations and optimization, impact assessment of management strategies (transition to MSY, fisheries Management Plans, socio-economic consequences of alternative TAC and quotas allocation options) and exploration of conditions for fisheries viability and sustainability. It enables stochastic simulations of biological and socio-economic consequences of scenarios to compare trade-offs of alternative options from a multi-criteria perspective. It is a discrete time (yearly or quarterly time steps), multi-fleet or multi-vessel, multi-métier, multi-species bio-economic model with "age" components for the biological part, and "commercial category" components for the economic part. The framework is coded in R and C++ to take advantage of both languages, and has a modular structure (e.g. Individual Based Model option at vessel level). Free open-source software under French license CeCILL v2.1 (CeCILL compatible with the GNU GPL license and French law).

***Table** 8: Answers to the ecosystem models survey received for fleet-based / management models*

Model's name	Scilab Integrated model of sub-	MICE Guiana coastal	ISISFISH	ISIS-Fish	IAM-BoB	IAM-MED	IAM-SESSF

	antarctic socio-ecosystem						
Modelled ecosystem	TAAF, around Crozet and Kerguelen islands	French Guiana	Gulf of Lion (western Mediterranean)	Bay of Biscay	Bay of Biscay	EMU1 in Mediterranean sea (GSAs 1-2-5-6-7)	Australian Southern and Eastern Scalefish and Shark Fishery
Main reference	*No reference yet*	**Cissé et al. (2015,** 2013**).** Cuilleret et al. (2022), Gomez et al. (2021), Doyen et al. (2012)	**Leforestier et al. (2020)**	**Vigier 2022 Provot 2020** Pelletier et al. (2009) Mahévas et al. (2004)	**Merzereaud et al. (2022)** Bellanger et al. (2018), Briton et al. (2020, 2021), Guillen et al. (2013a,b, 2014, 2015), Macher et al. (2013, 2018), Nielsen et al. (2018), Raveau et al. (2012), STECF (2015, 2017)	**STECF (2021)** Merzereaud et al. (2022), STECF (2019, 2020, 2022).	**Briton et al. (2021, in revision)** Briton (2020) Merzereaud et al. (2022)
Spatial resolution	*Not spatially explicit*	*Not spatially explicit*	3' x 3' No vertical layers	Whatever No vertical layers	*Not spatially explicit*	*Not spatially explicit*	*Not spatially explicit*
Period represented	simulation/forecast (latest application : 2021 - 2056)	2006-2050	calibration period 2015-2017; hindcast 2015-2019; forecast 2020-2025	2010-2020 (hindcast)	simulation/forecast (latest application: param- 2016, forecast 2017-2025; under progress BoB Sole 2021)	simulation/forecast (latest application : 2021-2030)	simulation/forecast (Reference state: 2015; forecast 2016-2025)
Time step	year (with fishing effort expressed in week)	year	month	month	year and quarters for some	year	year and quarters for some

					population dynamics		population dynamics
Fish	2 populations of patagonian toothfish	12 species	one species only: Hake	9	4 species dynamically modelled + 18 “static species” modelled as a linear function of effort	Depends on STECF assessment group. Latest application: 10 stocks dynamically modelled + about 10 “static species” modelled as a linear function of effort	16 species dynamically modelled; 12 “static species” modelled as a linear function of effort
Top predators	2 groups of marine mammals, but only killer whales can by modelled, as no population dynamics for sperm whales	Yes, explicitly modelled	*Not modelled/considered*	*Not modelled/considered*	*Not modelled/considered*	*Not modelled/considered*	Four shark species included
Fishing fleets	1 fleet (as only one fleet is operating)	4 fleets	1 fleet of spanish long liners, 1 fleet of french gill-netters, 1 fleet of spanish trawlers and several fleet of french trawlers defined by vessel	10 fleets (vessel-length groups x North and South)	latest application: 710 vessels - 44 fleets/length classes - 13 métiers	Latest application: 14 french and spanish fleet segments and 11 métiers were explicitly modelled in IAM-Med	110 vessels, grouped in 9 fleets; 36 métiers

			size, port and gear type				
Socio-economic system	Yes, implicitly	Yes, explicitly	No	No	Yes, explicitly Fishing effort allocation: exogenous; quota allocation: exogenous; Fish prices: exogenous		
Ecological processes considered	Growth, Reproduction, Fishing mortality, Natural mortality	Growth, Predation , Fishing mortality	Growth, Reproduction, Fishing mortality, Natural mortality	Growth, Reproduction, Movement (horizontal or vertical migration, foraging movement, dispersal), Fishing mortality, Natural mortality	Growth, Reproduction, Fishing mortality, Natural mortality		
Pressures that can be addressed	Climate change, Environmental variability	Climate change, Environmental variability, Commercial fishing/harvest, Recreational fishing/harvest	Commercial fishing/harvest	Climate change, Environmental variability, Commercial fishing/harvest, Recreational fishing/harvest	Climate Change, Environmental variability, Commercial fishing/harvest, Recreational fishing/harvest		
How environmental variability is implemented ?	through stochasticity in recruitment of patagonian toothfish	Mangrove surface			Variability in recruitment, possible variability on other biological parameters (see ICES, 2013 special request)	Can be included directly in the annual recruitment estimations or in stock-recruitment relationship, possible inter-annual variability on other	Variability in recruitment of dynamically modelled species

						biological parameters	
Can the model be used for climate change projections ?	Yes, it has the capabilities to do so (but projections have not been run yet)	Yes, this has already been simulated			Yes, it has the capabilities to do so (but projections have not been run yet),	Yes, it has the capabilities to do so (but projections have not been run yet)	Yes, it has the capabilities to do so (but projections have not been run yet)
How the model projects ecosystem state, e.g. in 2050 ?	Through a trajectory (every year between now and then is simulated)	Through a trajectory (every year between now and then is simulated)			Through a trajectory (every year between now and then is simulated)	Through a trajectory (every year between now and then is simulated)	Through a trajectory (every year between now and then is simulated)
Existing climate change scenarios					see lagarde et al, 2018		
How Climate Change is implemented ?	through scenarios of recruitment of patagonian toothfish	SST			Not yet implemented.	Not yet implemented.	
Requirements for projecting ecosystem under climate change	assumptions on climate impacts on model parameters				assumptions on climate impacts on model parameters	assumptions on climate impacts on model parameters	assumptions on climate impacts on model parameters
How fishing activity is described in the model?	Through fishing vessels or fleets	Through fishing vessels or fleets	Through fishing vessels or fleets	Through fishing vessels or fleets	Through fishing vessels or fleets	Through fishing vessels or fleets	Through fishing vessels or fleets
Please provide information about variables and processes					Variables and processes of the model relate to the following dimensions: biological stock dynamics,	Variables and processes of the model relate to the following dimensions: biological stock dynamics,	Variables and processes of the model relate to the following dimensions: biological stock

					harvesting strategies by individual vessels / fleets, fish and management procedures. Evaluation of system performance relies on co-viability/ multicriteria assessment	harvesting strategies by individual vessels / fleets, fish and management procedures.	dynamics, harvesting strategies by individual vessels / fleets, fish market dynamics and management procedures. Evaluation of system performance relies on multicriteria / co-viability assessment.
Is fishing management taken into account?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
How fishing management is modelled?	TAC	licences	effort quotas and spatio-temporal closures. Assumption of effort redistribution outside closure areas but within initial fishing zones.		Input/output control - scenarios of quotas, HCR, discards, MSE, ITQ, MSY, MEY, alternative effort allocations, alternative allocations of quotas	Changes of fishing effort by fleet effort quota (corresponding to the regulation), eventually by fleet and gear, Maximum catch limit (MCL), Changes in gear (modelled through changes in selectivity),	Explicit modelling of the TAC and quota allocation management system

						HCR (target Fmsy)	
Can the model be used for projections of potential fisheries catch in 2050?	Yes, this has already been simulated	Yes, this has already been simulated	Yes, it has the capabilities to do so (but projections have not been run yet)		Yes, it has the capabilities to do so (but projections have not been run yet). *Technically, but would assume validity of the model over such a time horizon*.	Yes, it has the capabilities to do so (but projections have not been run yet) *Technically, but would assume validity of the model over such a time horizon*.	Yes, it has the capabilities to do so (but projections have not been run yet). *Technically, but would assume validity of the model over such a time horizon.*
Requirements for projecting potential fisheries catch	would require to include long term scenarios of evolution of prices, etc.		time (and faith since long term processes that may shape the population evolution are not accounted for)		would require to include long term scenarios of evolution of fuel price, climate change, fish demand....	Assumptions about the extent to which the structure of the bio-economic model would change.	Assumptions about the extent to which the structure of the bio-economic model would change.
Existing fishing scenarios			Simulated period = 2020-2025 (~actual EU management plan) ; combination of effort reduction (trawler specific or all gear) of 30 to 50% and spatio-temporal closures (trawler specific or all		status quo scenarios MSY, MSE scenarios Alternative TAc and quotas alternative selectivity scenarios, Co-viability generally simulated for 10 to 20 years	Different combinations of : trawlers/ longliners/ netters effort reduction, Combined catch limits for the 3 stocks of ARA - Blue and red shrimp, Selectivity measures and /or	Alternative TAC management plans associated with ITQs, to achieve Maximum Economic Yield; Co-Viability approach for multi-criteria TAC advice

			gear), yearly seasonal closure or permanent			Reduction in trawler number (See STECF report for more details)	
Is the model coupled to another model?	No, it is a stand-alone model	No, it is a stand-alone model	No, it is a stand-alone model	No, it is a stand-alone model	No, it is a stand-alone model	No, it is a stand-alone model	No, it is a stand-alone model
Is the model fitted / calibrated to represent the ecosystem?	No calibration performed	Calibration of a time series (hindcast)	Calibration of a time series (hindcast)	Calibration of a time series (hindcast)	Calibration of a time series (hindcast)	No calibration performed	Calibration of a time series (hindcast)
Which type of data are required to fit the model?			annual landings, catch-at-age, quaterly recruitment		Biological parameters from stock assessment, catches, landings, price per vessel/fleet/métier/species, effort per vessel/fleet/métier, cost structure per fleet	Biological parameters from stock assessment, catches, landings, price per vessel/fleet/métier/species, effort per vessel/fleet/métier, cost structure per fleet	Biological parameters from stock assessment, catches, landings, price per vessel/fleet/métier/species, prices flexibility coefficients, effort per vessel/fleet/métier, cost structure per fleet, quota trading and uptake, TAC information
On which processes/parameters is the calibration performed?			6 age catchability parameters, and 3 target factor per gear type parameters		fishing mortality at age by fleet or vessel and métier, production and	fishing mortality at age by fleet or vessel and métier, production	Existing calibration data is used to define parameters; segmentation

					price by commercial grades		analysis is used to define métiers / fleets
Which method/procedure is used for calibration?			Sequential calibration based on Latin Hypercube Sampling (initial step with 5000 nodes and 9 dimensions)				
Outputs and indicators related to fishing and catches	- catches by stock - depredated quantity - discards - number of additional longline by zone (Crozet and Kerguelen) due to depredation (a proxy of depredation cost)	Biomasses, Species Richness, MTI, efforts, catches, profits of fleets	hake catch and biomass at age		Standard bio-economic assesssment indicators are produced (e.g. - Fbar and SSB per stock - Landings per species, per age or commercial category - Per fleet : total landings per stock (modelled species + staticnon modelled species), fishing effort, - Per vessel : landings, gross value of landings,	Generally: - Fbar and SSB per stock - Landings per species, per age or commercial category - Per fleet : total landings per stock (modelled species + static species), fishing effort, - Per vessel : landings, gross value of landings, gross value added	Standard bio-economic assesssment indicators are produced (e.g. - Fbar and SSB per stock - Landings per species, per age or commercial category - Per fleet : total landings per stock (modelled species + staticnon modelled species), fishing effort, - Per vessel : landings, gross value of landings,

					gross value added and short and long-term profit), as well as co-viability assessment		gross value added and short and long-term profit), as well as co-viability assessment
Other outputs and indicators	- abundance at age by stock - gross value of landings by fleet (annual income)		revenues from hake and other species (static, no modelled)		Value Effectiveness : distance to objective Efficiency (CBA) Viability		
Is the model ready to simulate new scenarios?	Runnable within a year	Yes, ready to run	Yes, ready to run	Runnable within a year	Runnable within a year	Yes, ready to run	No
Able to run ForeSea scenarios if relevant ?	Yes, I can run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios	I don't know if I can run simulations of ForeSea scenarios	I don't know if I can run simulations of ForeSea scenarios	No, I cannot run simulations of ForeSea scenarios	Yes, I can run simulations of ForeSea scenarios	No, I cannot run simulations of ForeSea scenarios

3.2.8 Graph models

Semi-quantitative model of type Fuzzy Cognitive Mapping (graph theory), Key variables and drivers of the sustainable functioning of the social-ecological systems
Transdisciplinary models of key variables and drivers of the sustainable functioning of two social-ecological systems : the French fisheries of the North Sea and the Gulf of Lion. They are based on key stakeholders perceptions and consider Governance, Economy, Social, Technology and Environment dimensions. They focused mostly on pelagic and demersal fish resources and are not fleet-based.

***Table** 9: Answers to the ecosystem models survey received for the graph model*

Model's name	**Fuzzy Cognitive Mapping (with the software Mental Modeler)**
Modelled ecosystem	ICES Great North Sea, Gulf of Lion from Cerbère to Hyères
Main reference	Chevallier et al. (in prep)
Spatial resolution	Not spatially explicit
Period represented	Average state
Phytoplankton / Zooplankton	Considered as forcing variable (overall state of the ecosystem is considered)
Fish	main fish resources targeted, not explicit
Top predators	depredation is considered (predators' groups are not explicitly modelled)
Fishing fleets	Not modelled/considered
Socio-economic system	Explicitly considered, from fishing sector to sales and processing sector
Ecological processes considered	Movement (horizontal or vertical migration, foraging movement, dispersal), Fishing mortality
Pressures that can be addressed	Climate change, Eutrophication , Commercial fishing/harvest, Aquaculture , Pollution (including plastic), market forcing
Can the model be used for climate change projections ?	Yes, this has already been simulated
How the model projects ecosystem state, e.g. in 2050 ?	Through the simulation of the 2050 state alone (no trajectory)

Existing climate change scenarios	SSP1-RCP2.6, SSP2-RCP4.5, SSP3-RCP7.0 and SSP5-RCP8.5
How Climate Change is implemented ?	Climate Change is considered our main environmental driver : it has influence on the health status of the marine ecosystem and fishing resources, a synergistic effect with the negative impacts of fishing, pollution, and other negative anthropogenic impacts, positive impacts of some exotic species on fisheries, negative impacts of biological invasions. It has also influence on socio-economic and governance variables such as management efficiency, stability of sales turnover, sanitary crisis economic impacts, fisheries volume produced, working conditions, fishers' environmental awareness, EU decision-makers environmental awareness, social and territorial inequalities and conflicts among fishers and conflicts with other users.
Requirements for projecting ecosystem under climate change	main forcing variables states in 2050 to see what happens with all other variables.
How fishing activity is described in the model?	Through global fishing effort
Please provide information about variables and processes	Fishing mortality depends on fishing effort, gear selectivity, gear's environmental impact, technological overcapacity, climate change, health status of the marine ecosystem and resources, pollution, other negative anthropogenic impacts, negative impacts of biological invasions, positive impacts of exotic species on fisheries, and depredation rate.
Is fishing management taken into account?	Yes, through effort regulations, MPA, minimal landing size and other management actions aggregated into main management components
Can the model be used for projections of potential fisheries catch in 2050?	Yes, this has already been simulated
Requirements for projecting potential fisheries catch	main forcing variables states in 2050 to see what happens with all other variables.
Existing fishing scenarios	SSP1-RCP2.6, SSP2-RCP4.5, SSP3-RCP7.0 and SSP5-RCP8.5
Is the model coupled to another model?	No, it is a stand-alone model

Is the model fitted / calibrated to represent the ecosystem?	No calibration performed
Which type of data are required to fit the model?	a matrix of interactions (Likert scales) between variables
Outputs and indicators related to fishing and catches	Rate of changes of all variables, graph theory indicators (indegree, outdegree, centrality of each variable)
Other outputs and indicators	Sensitivity analysis
Is the model ready to simulate new scenarios?	Yes, ready to run
Able to run ForeSea scenarios if relevant ?	Yes, I can run simulations of ForeSea scenarios

4. Synthesis

4.1 Zooplankton representation

In general, zooplankton is explicitly modelled in BGC and ecosystem models, implicitely considered through forcing varibale in population models, spectrum models and multispecies size-based models, and not modelled in SDM or fleet/management models.

In the BGC models described here, all based on ERSEM, zooplankton is represented through three compartments: heterotrophic nanoflagellates, micro-zooplankton and meso-zooplankton. BGC model outputs often serve as forcing variables for spectrum models and multispecies size-based models, thus with the same zooplankton representation, i.e., three zooplankton groups based on size classes (either nano-, micro- and meso-zooplankton or micro-, meso- and macro-zooplankton). Population models presented here use one group of zooplankton, either explicitly or as forcing variable, but with information regarding size distribution or vertical migration type. In ecosystem models, zooplankton is represented by two, three or four functional groups, mostly based on size (microzooplankton: <200 µm, mesozooplankton: 200–2000 µm, and macrozooplankton: >2000 µm), but sometimes also based on feeding type (e.g. carnivorous zooplankton) or jellyness (e.g. gelatinous zooplankton).

In the models listed here, the zooplankton diversity is poorly represented and often limited to the size dimension, through 1 to 4 groups. This might be due to the specific objective of the questionnaire, as models with finer resolution of zooplankton exist but are absent from our results.

4.2 Fleet representation

Fishing fleets are modelled explicitly in ecosystem models and fleet/management models, and are rarely considered implicitly in other models. We can note the possibility of representing beam trawlers and otter trawlers as forcing variable in one BGC application, a detailed and explicit representation of fleets per gear type, fishing nation, target species and fishing strategy in one population model and an explicit representation of fleets defined by port in one multi-specied size-based model. Most of the time, when fleets are described as « not modelled/considered » in the model, fishing activity is represented by global fishing mortality applied to species or functional groups.

For ecosystem models and fleet/management models, the representation of fleets is quite variable. It can be either implicit (typically with global fishing mortality or fishing effort of separated theoretical fleets for each biological group) or explicit, with the number of fleets varying from 1 to 44. They are mostly defined using one or several of the following criteria: country, port, gear type, vessel size and target species.

The questionnaire outputs do not indicate any link between the number or types of fleets represented and the consideration of management. All fleet/management models take into account some management measures, from effort regulation and spatial closure to quota and minimal landing size. Management is rarely taken into acount in other models (only in one ecosystem model, one multi-species size-based model, and both population models).

4.3 Existing scenarios

Existing climate change scenarios are available for more than 50% of the models described in the review, but there are mostly available for biogeochemical models, species distribution models, spectrum models, population models, multispecies size-based models, and few ecosystem models. There are rarly available for fleets/management models.

Climate change scenarios are derived from a small number of models output, with a majority of them coming from the POLCOMS-ERSEM model, itself driven by data reanalysis and earth system model (from CMIP5, Coupled Model Intercomparison Project Phase 5). Simulating climate change scenarios often relies on a suite of models (coupled through either one-way forcing or two-ways coupling), starting from earth system models to regional physical model and population or ecosystem models. Models coupled directly to ESM can provide the most recent climate change scenario, but most models rely on a regional downscaling of climate scenario via physical and often biogeochemical models.

The RCP8.5 (RCP for Representative Concentration Pathway) is the main scenario available for the models described here, followed by RCP4.5. We can note that RCP2.6 is available for one ecosystem model and is also applied to the graph model, together with the associated SSP1 (SSP for shared socioeconomic pathways).

Fleet/management models allow the consideration of a variety of management measures to be tested, but so far only few scenarios have been run for projection of potential fisheries catch in 2050. Among those scenarios, we can identify three types of scenarios :

- fishing pressure (fishing mortality or effort) is kept constant relatively to the current situation
- fishing pressure (fishing mortality or effort) increases or decreases over time by a certain percentage (e.g. 20%)
- fishing pressure is set to sustainable reference point (FMSY), or set to a multiplier of FMSY in order to approximate SSPs

Other fishing scenarios, involving current management plans, are run on a shorter time period.

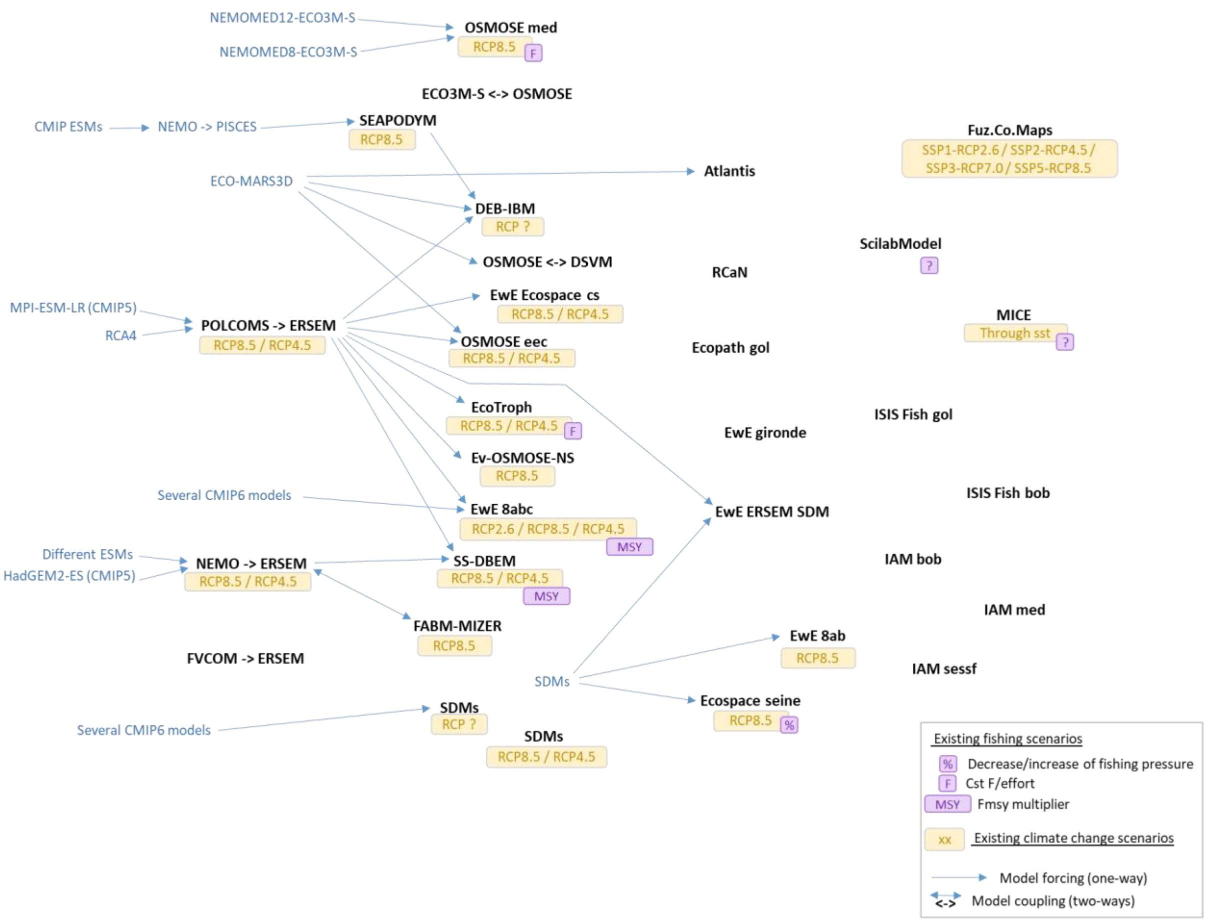

***Figure 3** : Overview of the links existing between the models presented in this review, including one-way forcing and two-ways coupling. Models in black are described in this review (Tables 1 to 9), models in blue are mentionned as they provide forcing variables for the former models. Existing climate change and fishing scenarios for 2050 are indicated in yellow and purple respectively (see Tables 1 to 9 for more details).*

4.4 Futures perspectives

Several models appear to be available to be used within ForeSea, with some well-defined climate change scenarios already available. Fishing scenarios for 2050 are less homogeneous, but several model developer are ready to make some runs and contribute to this initiative. Some areas are covered by several models, which will ensure both realization of the suite of models required for climate change scenarios and possibly multi-model approach.

Some models are existing in the French EEZ, and appear here as forcing variables, but were not described by their authors/developers. Several reasons can explain this situation: lack of time or interest to fill the questionnaire, models no longer supported/developped, models not perceived as fulfilling the questionnaire context. Further discussion with different scientist might help complete the list of models described here, which is therefore not exhaustive.

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https://catalogue.marine.copernicus.eu/documents/PUM/CMEMS-NWS-PUM-004-009-011.pdf

POLCOM-ERSEM:
https://confluence.ecmwf.int/pages/viewpage.action?pageId=283550184#NEMOERSEMandPOLCOMSERSEM:UserGuidesforProducts(v1.1)-2.1_The_ERSEM_ModelTheERSEMModel

6 Appendix

ForeSea Project

Models review ForeSea

FORESEA is a French scientific project funded by Ifremer which aims at exploring the futures of French commercial fisheries under global change. To do so, the project will build on existing modelling initiatives and will review available models of marine ecosystems within French Exclusive Economic Zone (EEZ), to assess their capabilities to project the future state of marine ecosystems and their living resources. Another distinct task of the project will be to build plausible foresight scenarios of the fisheries and predict possible pathways of domestic marine ecosystems based on those scenarios.

The aim of this questionnaire is to list **existing marine ecosystem models applied to French marine waters** (all/part of the model includes all/part of the French EEZ), **suitable for projecting impacts of climate change and/or impacts of fishing activities on all/part of the socio-ecosystem at the 2050 horizon**. The first objective is to get an overview of the modelling capacity at hand. The second objective is to identify which models could be possibly used within FORESEA at a later stage. We are targetting various kinds of models representing fish and fisheries, from statistical to mechanistic models, from population to end-to-end models. If a model has been independently applied to different ecosystems, please fill one questionnaire per application (modelled components/processes might change between applications).

The questionnaire is structured in 5 pages. The first one is about model presentation, and list model name, reference, and main characteristics. The second page focuses on model details (components, processes). The third page questions how fishing and climate are modelled (if applicable). The fourth page is about model calibration and output. The fifth page asks about contact information and capabilities of the model to be used within ForeSea. Filling this questionnaire takes approximately 30-40 minutes depending on the complexity of the model.

The questionnaire is build to be as generic as possible, but if one question does not apply to your model, please answer as best as possible and add a comment at the end of the questionnaire if needed. If you have any questions or comments, you can use the comment box at the end of the questionnaire, or send an email to Morgane Travers-Trolet (Morgane.travers@ifremer.fr) and Raphaël Girardin (Raphael.Girardin@ifremer.fr). You also have the possibility to contact us to modify an answer or provide additional information regarding the model.

Users have the right to access, correct, restrict, transfer, delete and dispute their personal data (and the right to specify instructions for holding, deleting and communicating their personal information after their death) by contacting the Data Protection Officer by email (dpo@ifremer.fr) or by writing to the following address: Institut Français de Recherche pour l'Exploitation de la MER (IFREMER) – délégué à la protection des données – 1625 route de Sainte Anne – Zone industrielle de la pointe du diable – CS 10070 – 29280 Plouzané – France or by email at dpo@ifremer.fr.
Important: any request sent by post or email must be supported by proof of identity and include details of the address to which responses should be sent. A response will be sent within three months of receiving the request. Exact timescales will vary depending on the complexity of the matter.

Users also have the right to submit a complaint to a supervisory body (CNIL for France).

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MODEL OVERVIEW

1. Model identification

Model's name (if any) ❓

e.g. Ecopath with Ecosim, FLBEIA...

Modelled area / name of the ecosystem ❓

e.g., North Sea, ICES area 8ab, Bay of Vilaine, Réunion island EEZ...

If the same model structure (e.g. same functional groups) covers several ecosystems, please separate them using semicolons

Type of ecosystem

Several choices are possible

- ☐ Estuarine
- ☐ Coastal
- ☐ Open Sea
- ☐ Pelagic
- ☐ Benthic
- ☐ Other(s)

Spatial coverage (lat/lon coordinates) ❓

e.g. 40 to 50°N , -8 to -2°E ; from 0 to 200m depth

Please separate latitude and longitude using a coma. You can provide additional information using semicolons

2. Main references

Main reference ❓

Is the seminal reference of the model published ?

- ○ Yes
- ○ Submitted
- ○ In revision
- ○ No

Other / additional references ❓

3. Model description

Model type

- ○ Statistical model
- ○ Mechanistic model
- ○ Other

Model structure ❓

Several choices are possible

- ☐ Individual-based or agent-based
- ☐ Population-based
- ☐ Species-based
- ☐ Functional groups
- ☐ Fleet-based
- ☐ Others

- ☐ Size-structured
- ☐ Age-structured
- ☐ Other trait(s) or characteristics

Brief description ❓

Please provide few words or sentences presenting the main characteristics or specificities or structural hypotheses of the model.

Spatio-temporal characteristics

Is the model spatially explicit ? ❓

Veuillez sélectionner

Is the model vertically explicit ?

Veuillez sélectionner

Which period is represented (average state / hindcast / theoretical)? ❓

e.g. average state 2000-2010 ; hindcast 1995-2020

Time step

e.g. day, year...

MODEL DETAILS

1. Information about modelled ecosystem components: how many and which types?

✱ Are fish explicitly considered in the model?

- Yes, explicitly modelled
- Considered as forcing variable
- Not modelled/considered

How many and which types of fish groups?

e.g., 5 explicit species ; 10 functional groups ; 20 bins of size spectrum

If several types are considered, please separate them using semicolons

✱ Are top predators explicitly considered in the model?

- Yes, explicitly modelled
- Considered as forcing variable
- Not modelled/considered

How many and which types of top predators' groups?

e.g., 2 birds group ; 1 group of mammals

If several types are considered, please separate them using semicolons

✱ Are fishing fleets explicitly considered in the model?

- Yes, explicitly modelled
- Considered as forcing variable
- Not modelled/considered

How many and which types of fishing fleets?

e.g., 5 fleets defined per vessel size and port

If several types are considered, please separate them using semicolons

✱ Are invertebrates (cephalopods, benthos) explicitly considered in the model?

- Yes, explicitly modelled
- Considered as forcing variable
- Not modelled/considered

How many and which types of invertebrate groups?

If several types are considered, please separate them using semicolons

✱ Are primary production or phytoplankton groups explicitly considered in the model?

- Yes, explicitly modelled
- Considered as forcing variable
- Not modelled/considered

How many and which types of phytoplankton groups?

If several types are considered, please separate them using semicolons

✱ Are secondary production or zooplankton explicitly considered in the model?

- Yes, explicitly modelled
- Considered as forcing variable
- Not modelled/considered

How many and which type of zooplankton groups?

If several types are considered, please separate them using semicolons

2. Ecological processes explicitly modelled

What are the ecological processes considered ?

- [ ] Growth
- [ ] Reproduction
- [ ] Movement (horizontal or vertical migration, foraging movement, dispersal)
- [ ] Predation
- [ ] Fishing mortality
- [ ] Natural mortality
- [ ] Other(s)

3. Socio-economic environment

Is the socio-economic system represented ?

e.g. markets, fish consumption ...

- ○ Yes, explicitly
- ○ Yes, implicitly
- ○ No

Short description of how the socio-economic environment is represented

4. Pressures addressed

What are the pressures that can/could be addressed (either directly or indirectly) with the model ?

- [x] Climate change
- [x] Environmental variability
- [ ] Eutrophication
- [x] Commercial fishing/harvest
- [ ] Aquaculture
- [ ] Recreational fishing/harvest
- [ ] Pollution (including plastic)
- [ ] Other

PRESSURES CONSIDERED

Environmental variability

How environmental variability is implemented ?

Please provide details about how environmental variability impacts ecosystem components or processes (effect of temperature on metabolism? on seasonality ? ...)

Climate Change

How Climate Change is implemented ?

Please provide details about how climate change impacts ecosystem components or processes (effect of temperature on metabolism? on spatial distribution? effect of pH? ...)

Can the model be used for climate change projections ?

- ○ Yes, this has already been simulated
- ○ Yes, it has the capabilities to do so (but projections have not been run yet)
- ○ No

How the model projects ecosystem state, e.g. in 2050 ?

- ☐ Through a trajectory (every year between now and then is simulated)
- ☐ Through the simulation of the 2050 state alone (no trajectory)
- ☐ Other

Requirements for projecting ecosystem under climate change

Please provide details about what is required to run a projection of climate change (which forcing variables with which resolution?)

Fishing activities

How fishing activity is described in the model?

- ☐ Through global fishing mortality only
- ☐ Through global fishing effort
- ☐ Through fishing vessels or fleets

Please provide information about variables and processes

e.g., fishing mortality on targeted species only, fishing pressure expressed by ports or fleets, spatialized fishing pressure, TAC by countries, consideration of discards ?

Is fishing management taken into account?

- ○ Yes
- ○ No

Can the model be used for projections of potential fisheries catch in 2050?

- ○ Yes, this has already been simulated
- ○ Yes, it has the capabilities to do so (but projections have not been run yet)
- ○ No

Requirements for projecting potential fisheries catch

Please provide details about what is required to run a projection of potential fisheries catch (which forcing variables with which resolution?)

Existing fishing scenarios

Please describe briefly the existing scenarios of potential fisheries catch (forcings, simulated period, ...)

MODEL COUPLING, CALIBRATION and OUTPUT

1. Model coupling

Is the model coupled to another model?

- ○ Yes, two-way coupling (with feedbacks)
- ○ Yes, one-way coupling (i.e. forcing)
- ○ No, it is a stand-alone model

Please provide details about the coupled models

e.g., name and type of the forcing model, availability of the forcing model, forcing variables used for coupling...

2. Calibration

Is the model fitted / calibrated to represent the ecosystem?

- ☐ No calibration performed
- ☐ Calibration of an average state (or climatology)
- ☐ Calibration of a time series (hindcast)

Which type of data are required to fit the model?

e.g. annual landings, catch-at-age, monthly temperature, diet...

Please separate the data required using semicolons

On which processes/parameters is the calibration performed?

e.g. specific natural mortality terms ; fishing selectivity by gear ; growth process (size at age)

Please separate the items using semicolons

Which method/procedure is used for calibration?

Please precise if there is an automatic optimization method/algorithm, if the calibration is performed "by hand", if several phases are required...

3. Output

Outputs and indicators related to fishing and catches

Please list the main indicators related to fishing (e.g. landings per species per fleets (volume and value) ; discards ; gross value added by fleet; salaries...)

Other outputs and indicators

Please list the main indicators produced by this model (e.g. abundance per age class ; reproduction success ; trophic level per group ...)

CONTACT INFORMATION

1. Main contact

Contact person

Name and affiliation of someone who could answer precise questions about the model and who could possibly run the model with scenarios defined within ForeSea

Email of the contact person

Are you the contact person?

- Yes
- No

Do you agree to the use of the information you provided in a review paper?

- Yes
- No

2. Next steps within ForeSea

Is the model ready to simulate new scenarios?

- Yes, ready to run
- Runnable within a year
- No

If the foresight scenarios defined in ForeSea are relevant for this model, are you willing to run some simulations to project the future of the ecosystem modelled?

- Yes, I can run simulations of ForeSea scenarios
- I don't know if I can run simulations of ForeSea scenarios
- No, I cannot run simulations of ForeSea scenarios

Comments on the possibility to run ForeSea scenarios

Would you like to have more information on the project

- Yes, I would like to follow the project regularly
- Yes, I would like to have information once the project is over
- No

We thank you warmly for the time you took to fill this questionnaire

If you have any comment you would like to send use, please use the box below