DTU

A Spatial Bio-Economic Model to support Economically Viable and Sustainable Fisheries – Application to Potential Mesopelagic Fishery

The DISPLACE Model

MEESO

Ecologically and Economically Sustainable Mesopelagic Fisheries

Outline of e-learning material

- Background and motivation for potential fisheries targeting species in the mesopelagic layer

- Bio-economic models for fishery management strategy evaluation (MSE)

- The DISPLACE model
  - Model structure
  - Input parameters
  - Output measures and estimates
  - Model demonstration

- Application of DISPLACE to evaluate different management strategies of potential mesopelagic fishery under biological uncertainty

The H2020 MEESO Project

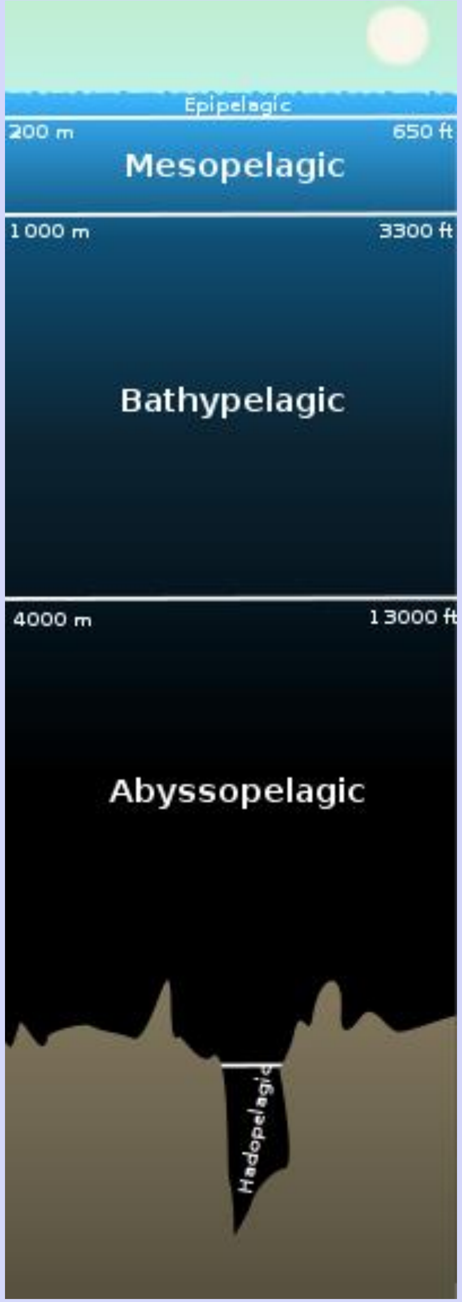
Ecologically and Economically Sustainable Mesopelagic Fisheries

Aim: Filling in major knowledge gaps on mesopelagic organisms and evaluating whether they can be exploited in an ecologically and economically sustainable way.

- New acoustic and trawling research survey technologies
- Development of new fishing and processing technologies
- Mapping of contaminant and nutrient content
- New tools for assessment of stocks/species
- Managing and assessing social, economic, and biological impacts and risks
- Governance: trade-offs between exploitation and changes in ecosystem service values

DISPLACE →

The mesopelagic zone



Water layer between 200-1000 m depth

Mixed species:

- Crustaceans
- Cephalopods
- Fish

Fish biomass estimates are high and variable:

~ 1 to 10 billion tonnes (e.g. Irigoien et al., 2014)

The mesopelagic zone & ecosystem services

Extensive diel vertical migrations
- Day: hide from predators in deeper layers
- Night: Feed in epipelagic surface layers

- **Carbon transport** to deep ocean from atmosphere and surface layers
  – 2 - 6 billion metric tonnes annually

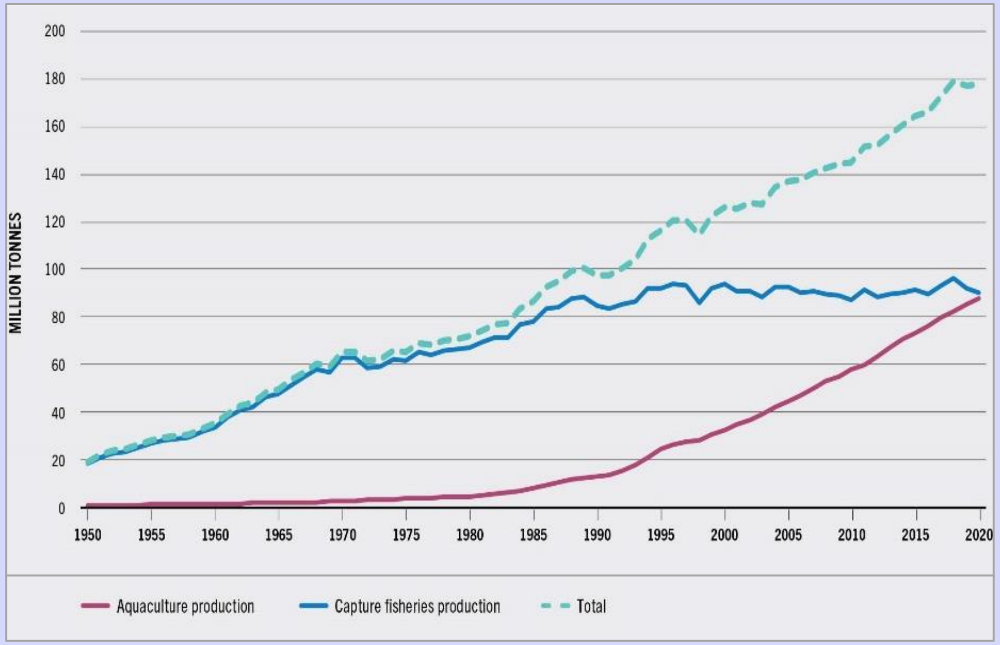
- **Resource** (prey) for higher trophic levels
  – E.g. marine mammals, tuna
  – More locally: e.g. blue whiting, saithe

A mesopelagic fishery?

- Increasing demand for food

- FAO (2017):
  - Approx. 66% of exploited fish and shellfish stocks fished sustainably
  - Approx. 34% fished above biological sustainable limits

- Industrial fishery
  - Fish meal
  - Fish oil

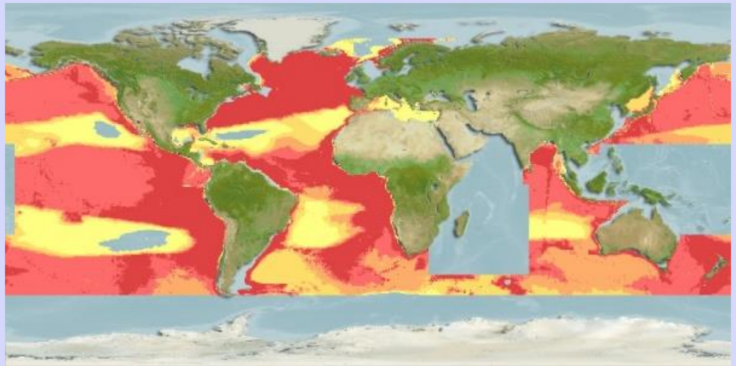


Source: FAO (2022)

The selected case study species

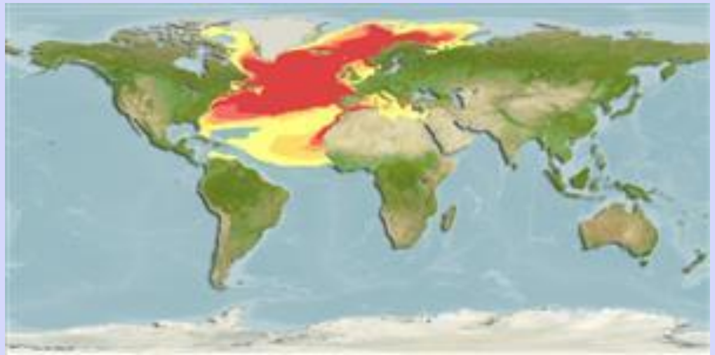
*Maurolicus muelleri (*Mueller's pearlside)

- Max 3 years
- Max 7 cm
- Maturation after 1 year
- Global oceans (mainly temperate Atlantic and Pacific waters)
- 50-400 m depth (dependent on life stage)



*Benthosema glaciale (*Glacier lantern fish)

- Max 8 years
- Max 10.3 cm
- Maturation after 2-3 years
- Atlantic Ocean



Source: Fishbase

The mesopelagic case study

Potential fishing in the mesopelagic zone can have a variety of social, economic, and biological impacts:

- **Positive**, e.g., increased supply of food for human consumption, aquaculture feed, and/or nutritional supplements (neutraceuticals, pharmaceuticals, etc.)
- **Negative**, e.g. ecological impacts, high investments, increased fuel use.

<u>Aim: Develop an evaluation framework and toolbox to evaluate scenarios of management strategies for potential mesopelagic fisheries under different sources of (biological) uncertainty such as variable population dynamics of the species.</u>

Bio-economic models for management strategy evaluation (MSE)

Sustainable fisheries management requires well-planned approaches and management scenarios

- Consider the socio-ecological costs and benefits of management options
- Minimize conflicts among fishing practices

Management Strategy Evaluation: Use simulation to compare the effectiveness (in terms of e.g. economic and ecological performance) of different management actions and scenarios, to achieve specific management objectives

Bio-economic models allow for the investigation of the interlinked effects on fish populations and fisheries caused by alternative management (and spatial) plans and strategies:

- – Simulation of the full fisheries system and each step in the management process
- – Feedback on the fish population model
- – Output is provided for economic and biological indicators to identify the ‘best’ management strategy on population and fleet/fishery/single fishing vessel level

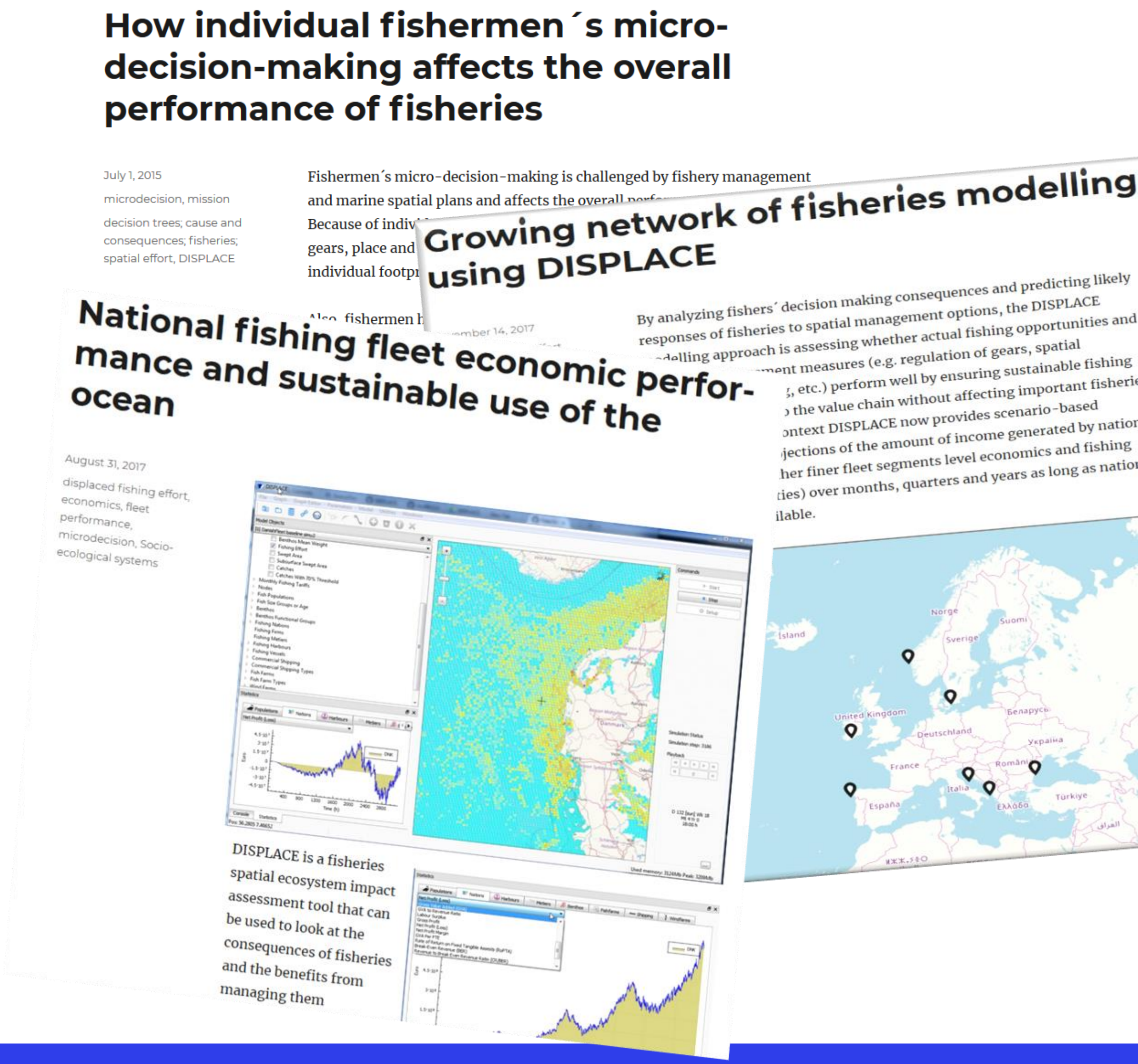
The DISPLACE model

- A spatial, dynamic individual-vessel-based model
- Linked to spatial population dynamics and other activities
- High time resolution as well (months, seasons, years)

Economic-Ecological indicators according to

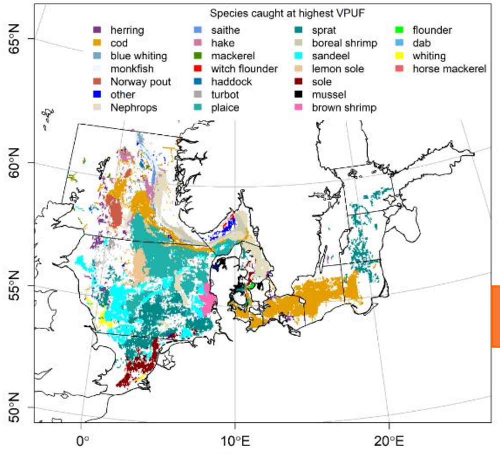
- Fishing Nations
- Fleet-segments or métiers or single vessels
- Harbour communities
- Fish communities and stocks
- Marine benthic communities

https://displace-project.org/



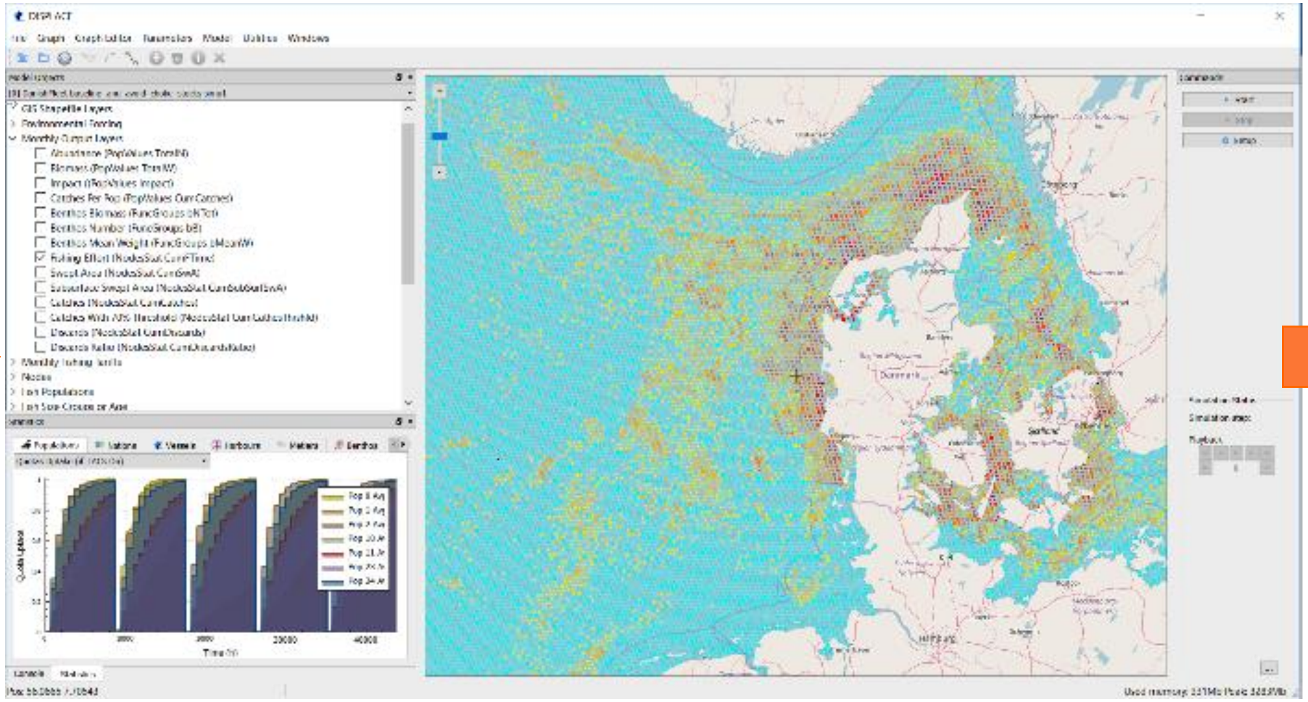
The DISPLACE model

INPUT: VMS, Logbooks, Sales slips, Cost structure per fleet

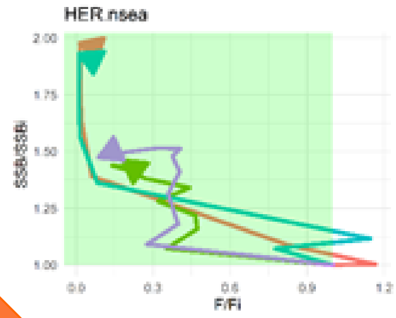


INPUT: gear specifications, biological parameters, foodweb

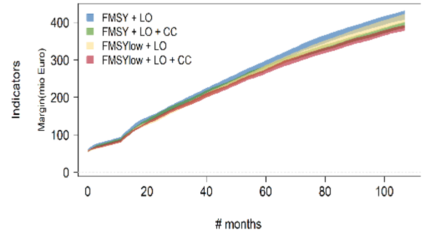
DISPLACE testing alternative worlds (policy options etc.)



OUTPUT: time series of biological stock indicators (F, SSB, R)

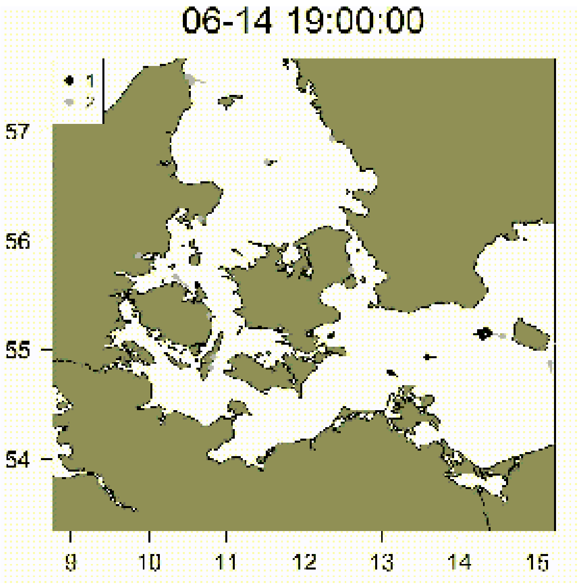


OUTPUT: time series of economic indicators (GVA, fuel efficiency, etc.) for vessels, fisheries , fleets.



It is possible to make each of the computer worlds slightly different to represent the uncertainty about the real-world system dynamics and project forward to a 10 year horizon for each alternative scenario evaluated.

The DISPLACE model



Accounting for real-case individual vessel based footprints & using best available fisheries-related science

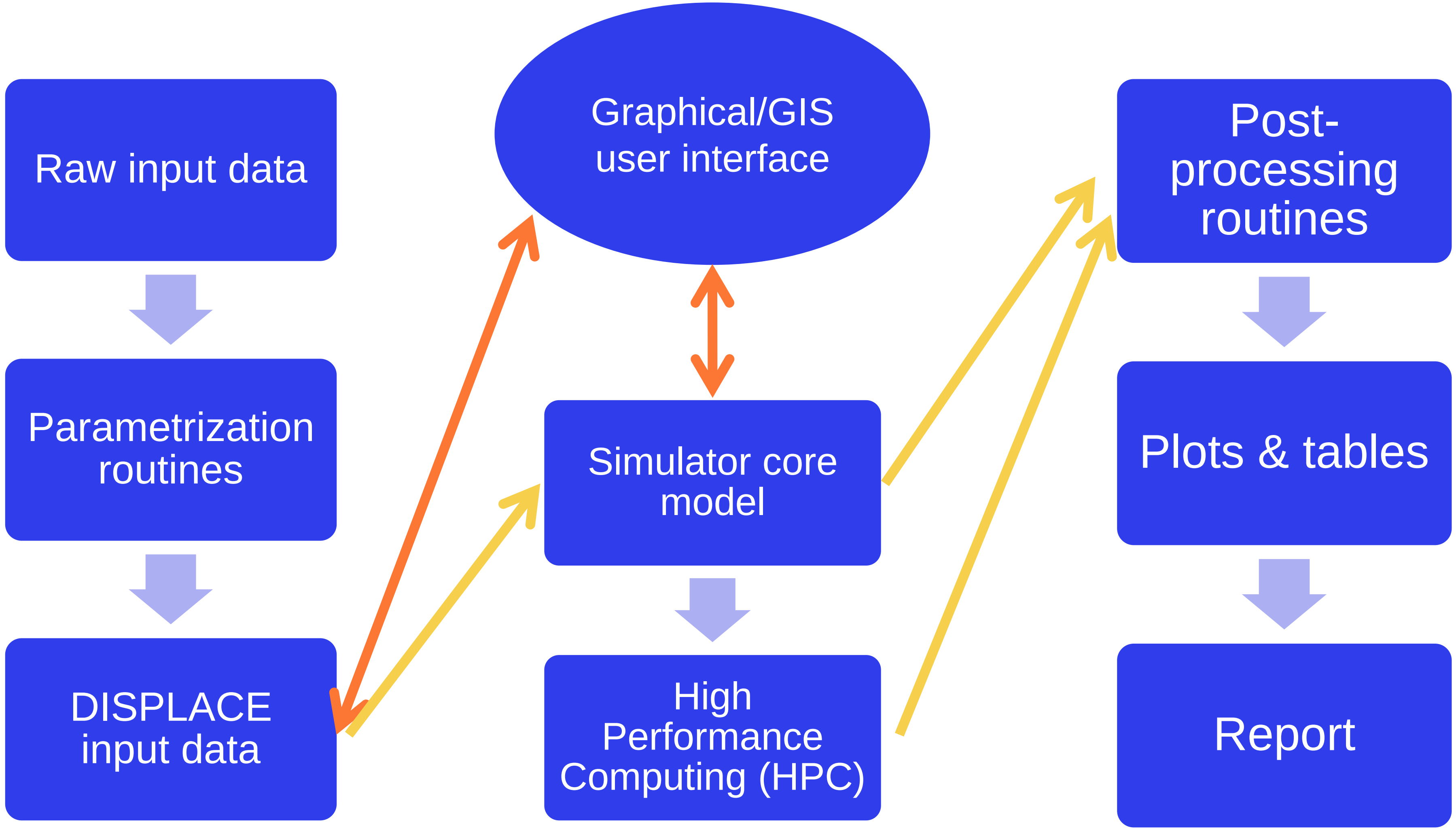
- Simulate **individual vessels** and account for:
  - diversity in those concerning e.g. vessel size, fuel use, selectivity
  - their footprint related to the fishing gear used
  - their decision making (behaviour / fishing pattern), e.g. where and when to go fishing, when shifting fishing area, when to return to port, to which port

- Dynamic coupling with fine-resolved **predictions of fish abundance** fields for different fish populations
- Dynamic coupling with **benthos dynamics**

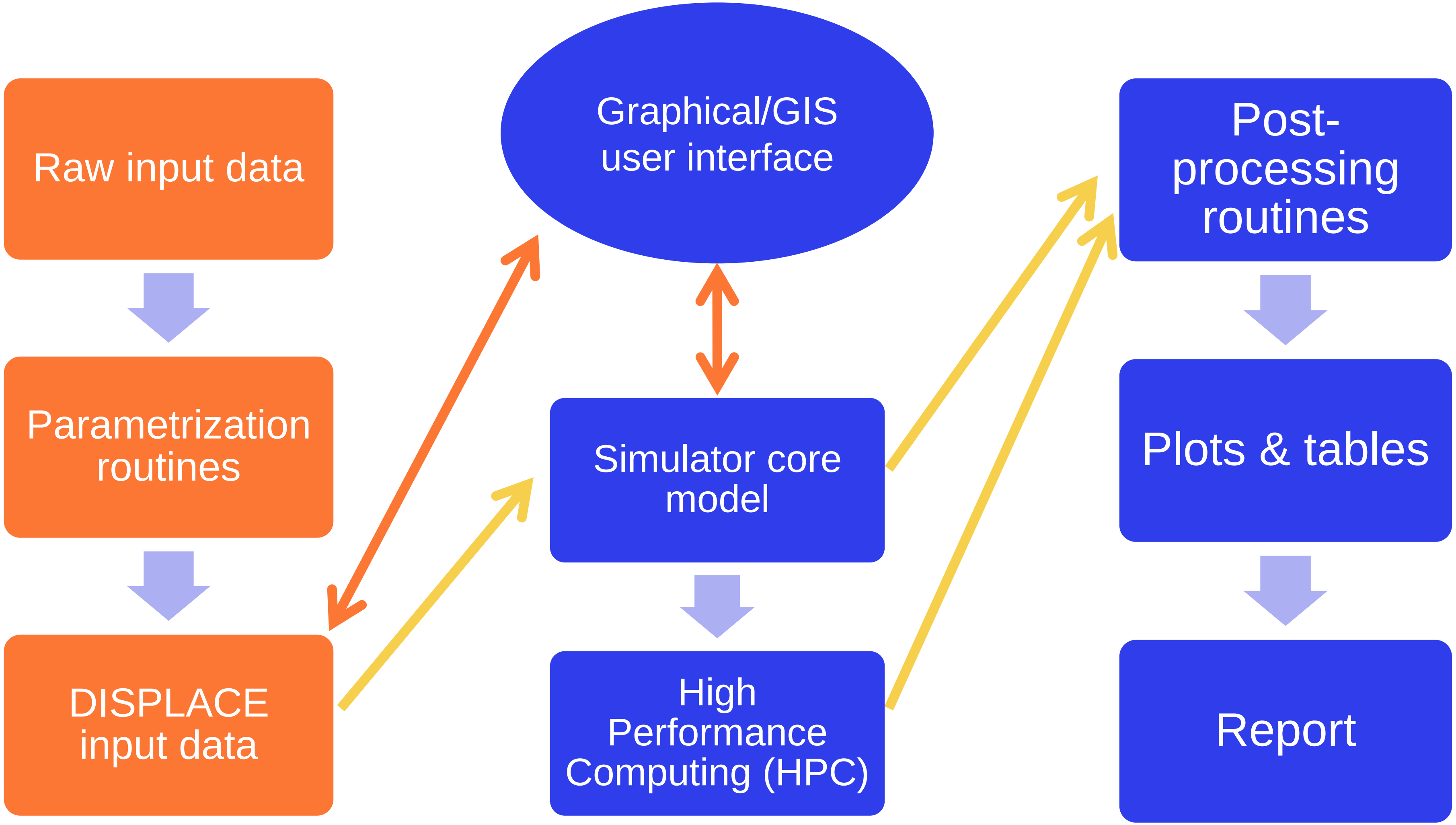
The highly detailed, local information is then included in **larger scale overall statistics:**

- Provide understandable statistics (for model parameters, fisheries, populations) while still having the possibility to look into small spatial detail and understand the intertwined dynamics
- Estimation of uncertainties of the different output parameters

DISPLACE workflow



DISPLACE Workflow



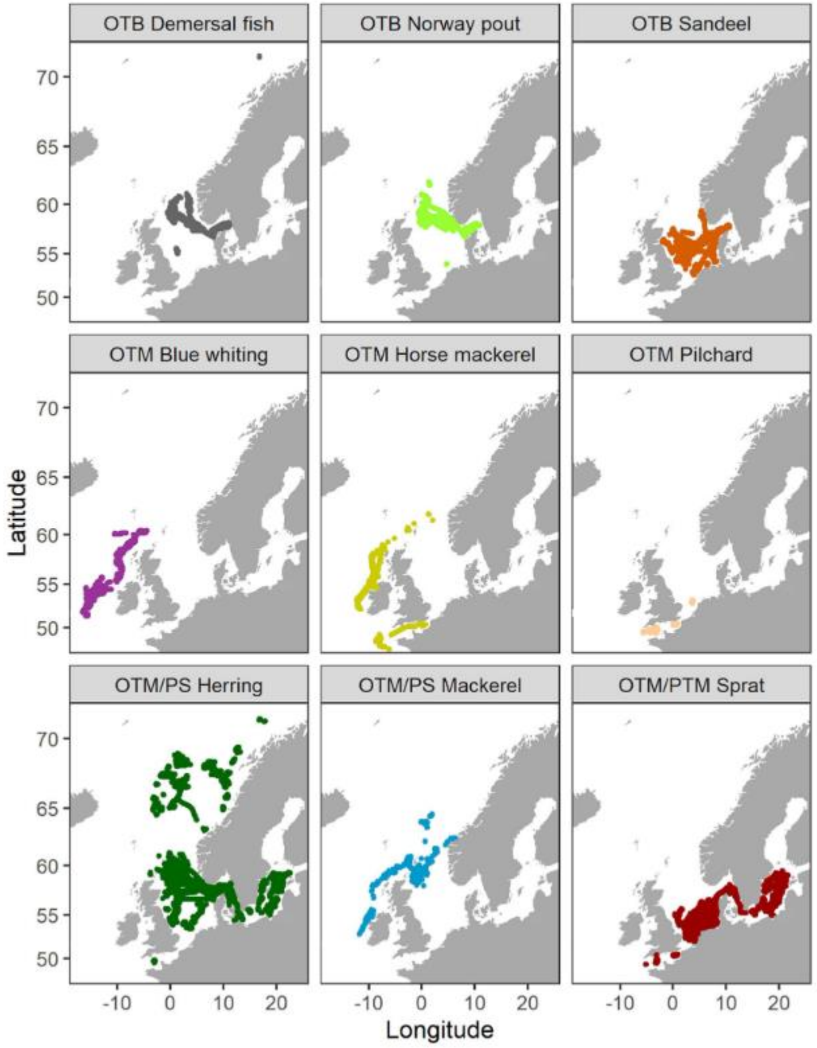
Input data and parametrization

- Geographical arena
  - Grid of cells/nodes at sea e.g. of 4 by 4 km
  - Harbour nodes

- Individual vessel characteristics
  - Specific fishing grounds
  - Harbours
  - Métier (see graph)
  - Official vessel register data

- Logbooks coupled to VMS data
  - Vessel Monitoring System (VMS) data
  - Logbooks and sales slips

- Fish prices on harbour nodes, if possible per commercial sorting / length group



Paoletti et al., 2021

Input data and parametrization

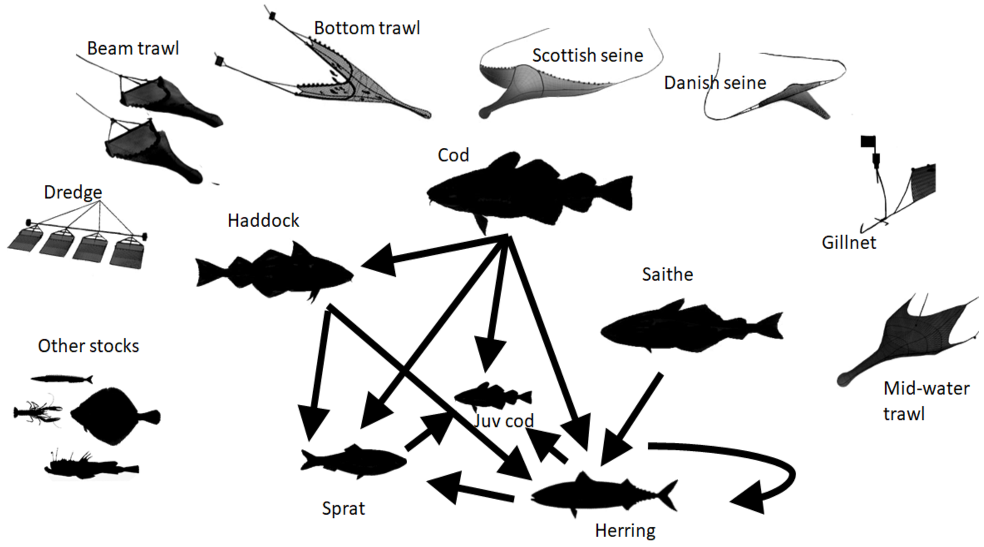
- Biological features of stocks
  - Numbers at size
  - Weight at size
  - Growth transition matrix
  - Natural mortality
  - Food-web information

- Spatial distribution of stocks

- Spatial catch rates (stock- vessel- and métier-specific)

- Métier information with size-based selectivity of gear types and selective devices

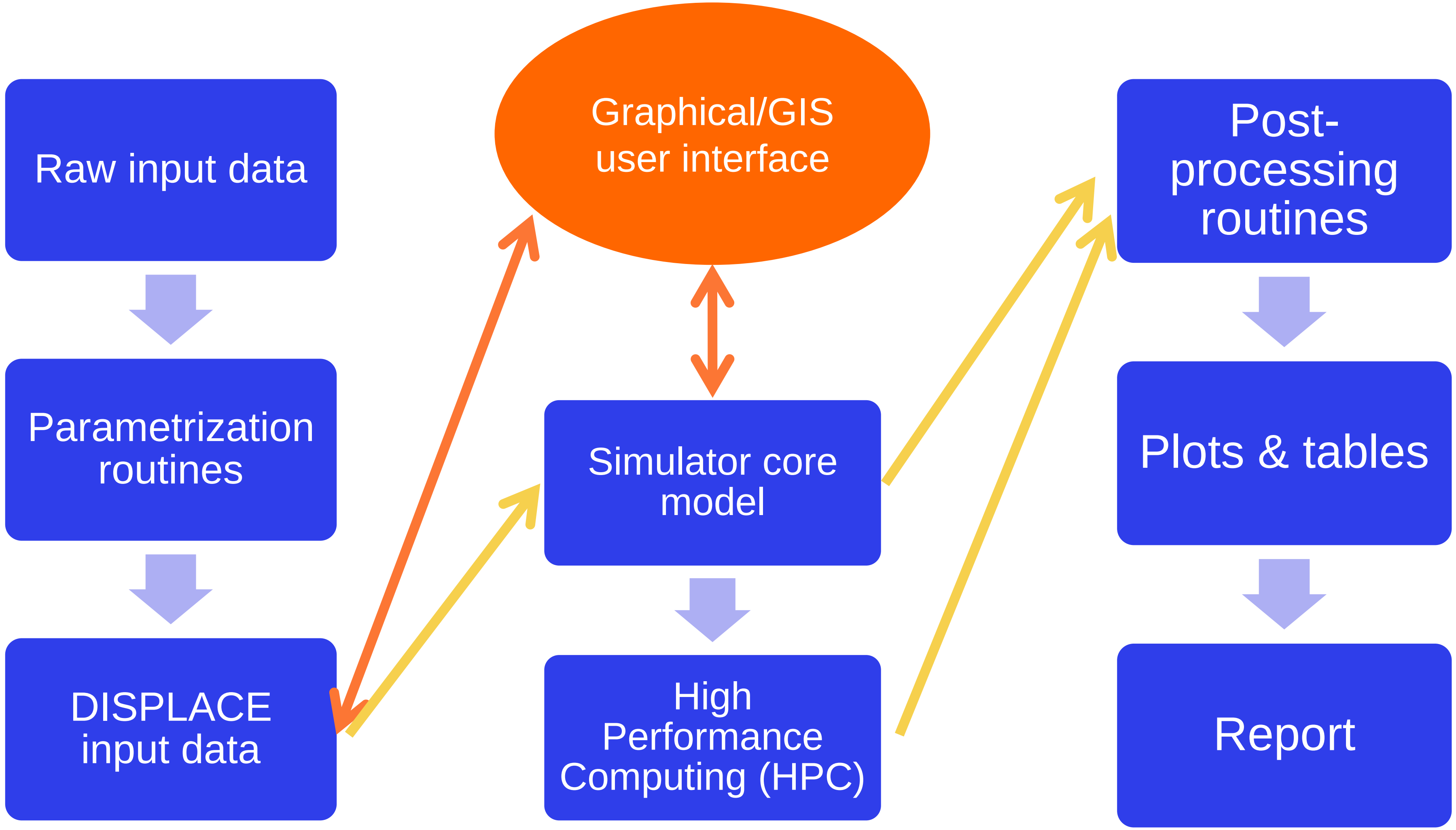
- Other non-explicit vessel depletion of stocks



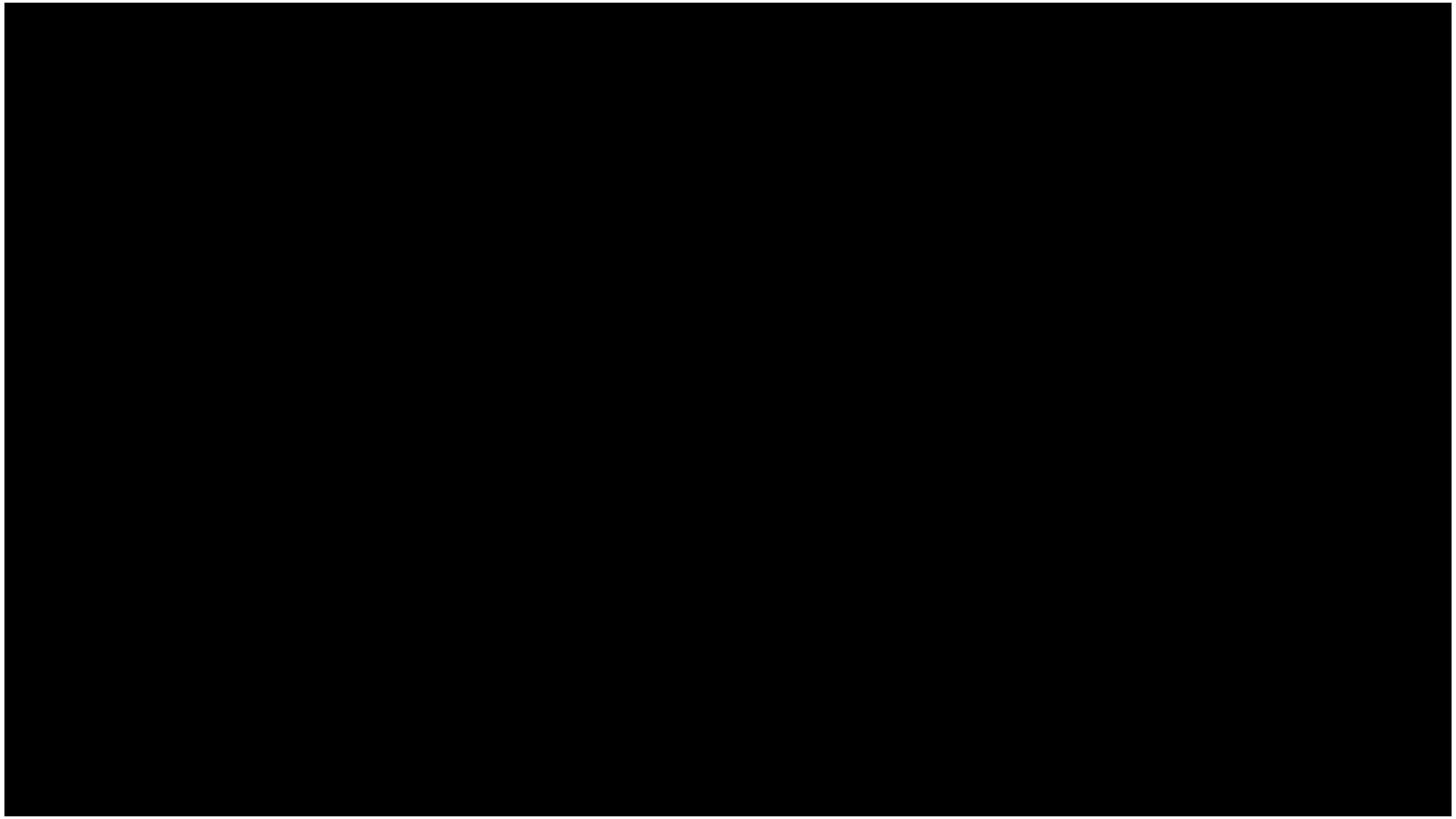
Gear types and species corresponding to the North Sea application

Currently expanded with population dynamics and different abundance scenarios for *M. muelleri* and *B. glaciale*

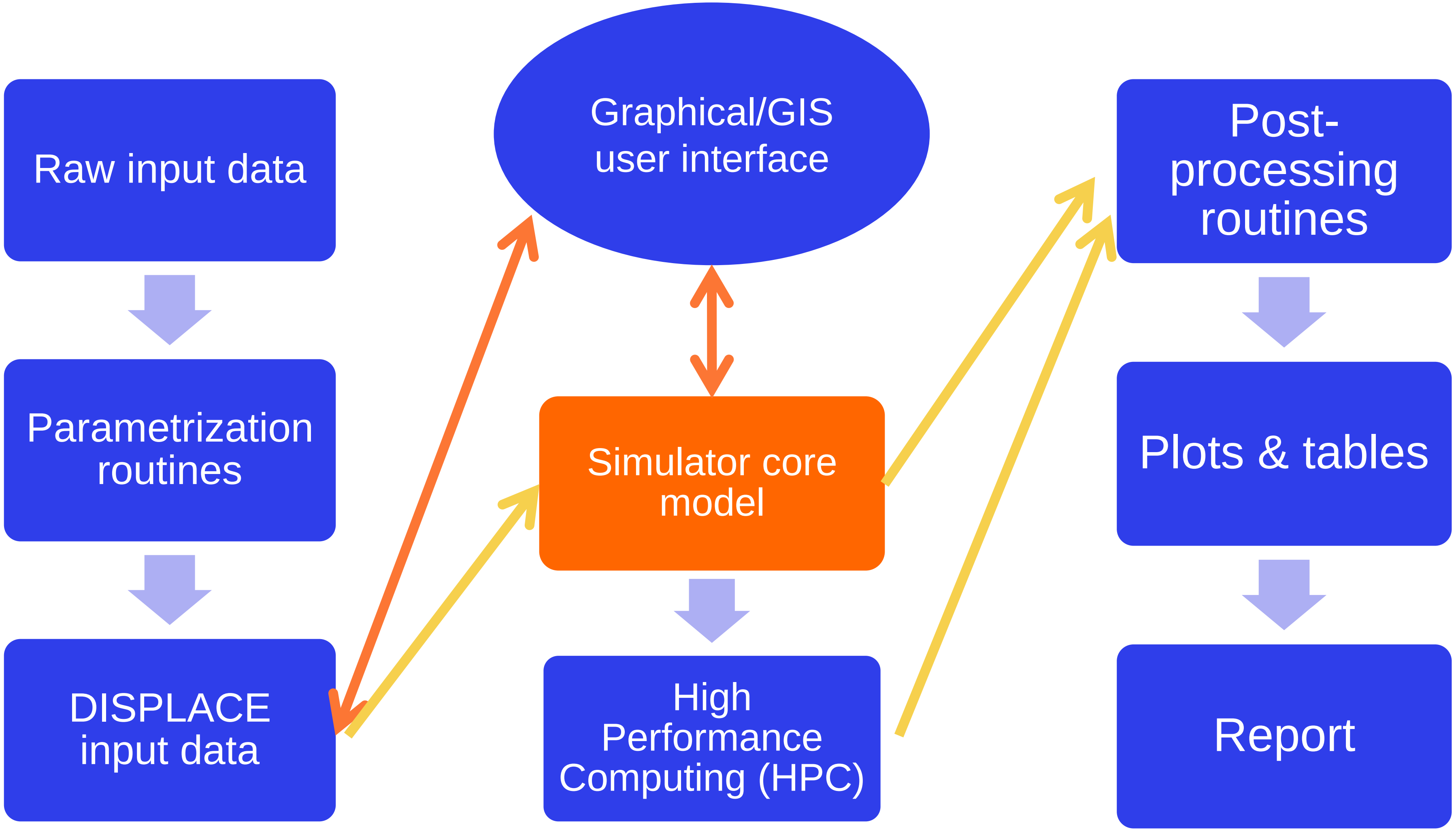
DISPLACE model structure



DISPLACE graphical user interface: Demo



DISPLACE model structure



The model

Vessel characteristics:

- Vessel size
- Fuel consumption
- Movement at sea
- Catch rates per stock
- Decision-making at each time step follows a decision tree according to the following options:
  - Fishing
  - Resting at a port
  - Moving to/from fishing grounds

At each (hourly) time step, **stocks are depleted** according to

- Vessel-specific catch rates
- Selectivity of the gear

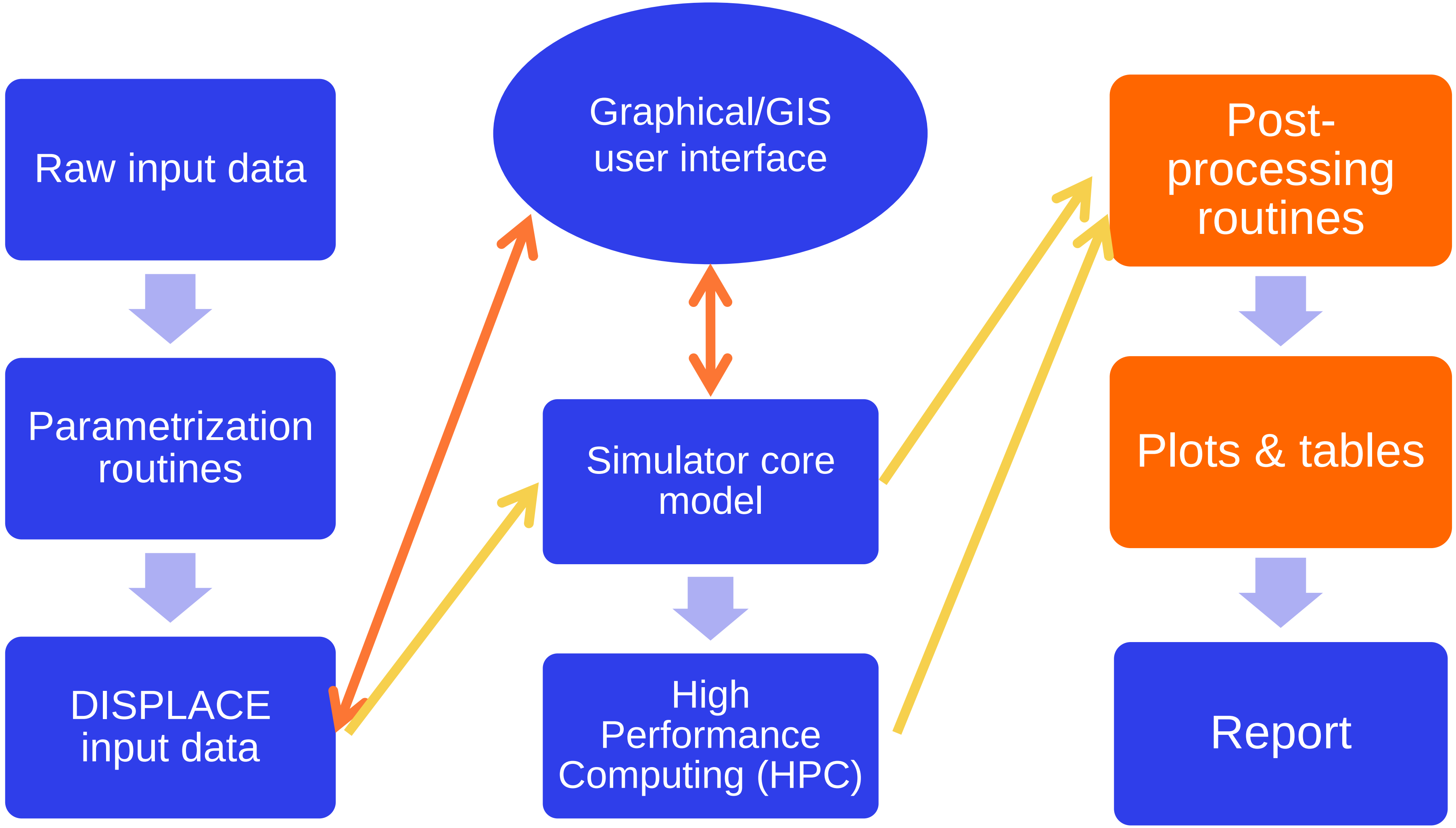
Different **management scenarios** are possible, e.g.:

- Gear selectivity improvements
- Fishing effort reductions
- Fishing closures

Stock characteristics:

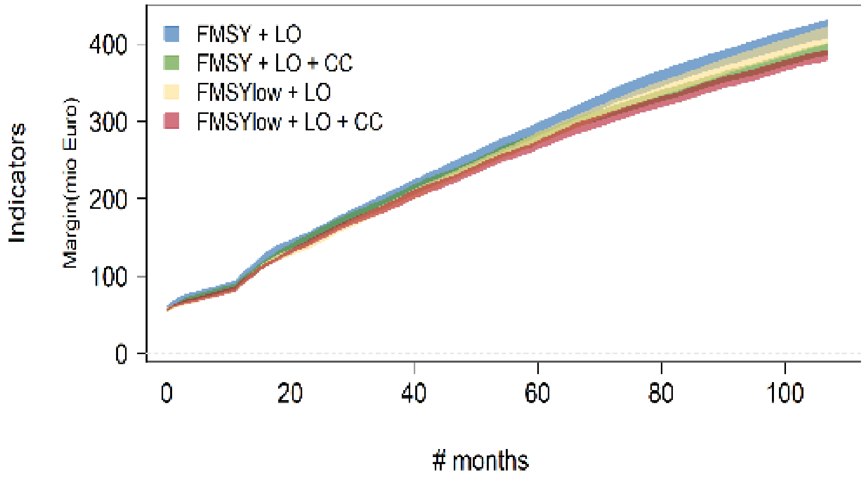
- Monthly individual growth
- Monthly mortality (length-based) and tropho-dynamics (if included)
- Yearly recruitment dependent on length-based maturity
- Spatial distribution based on survey data:
  - Constant throughout the year
  - Quarterly (re-)distribution

DISPLACE model structure



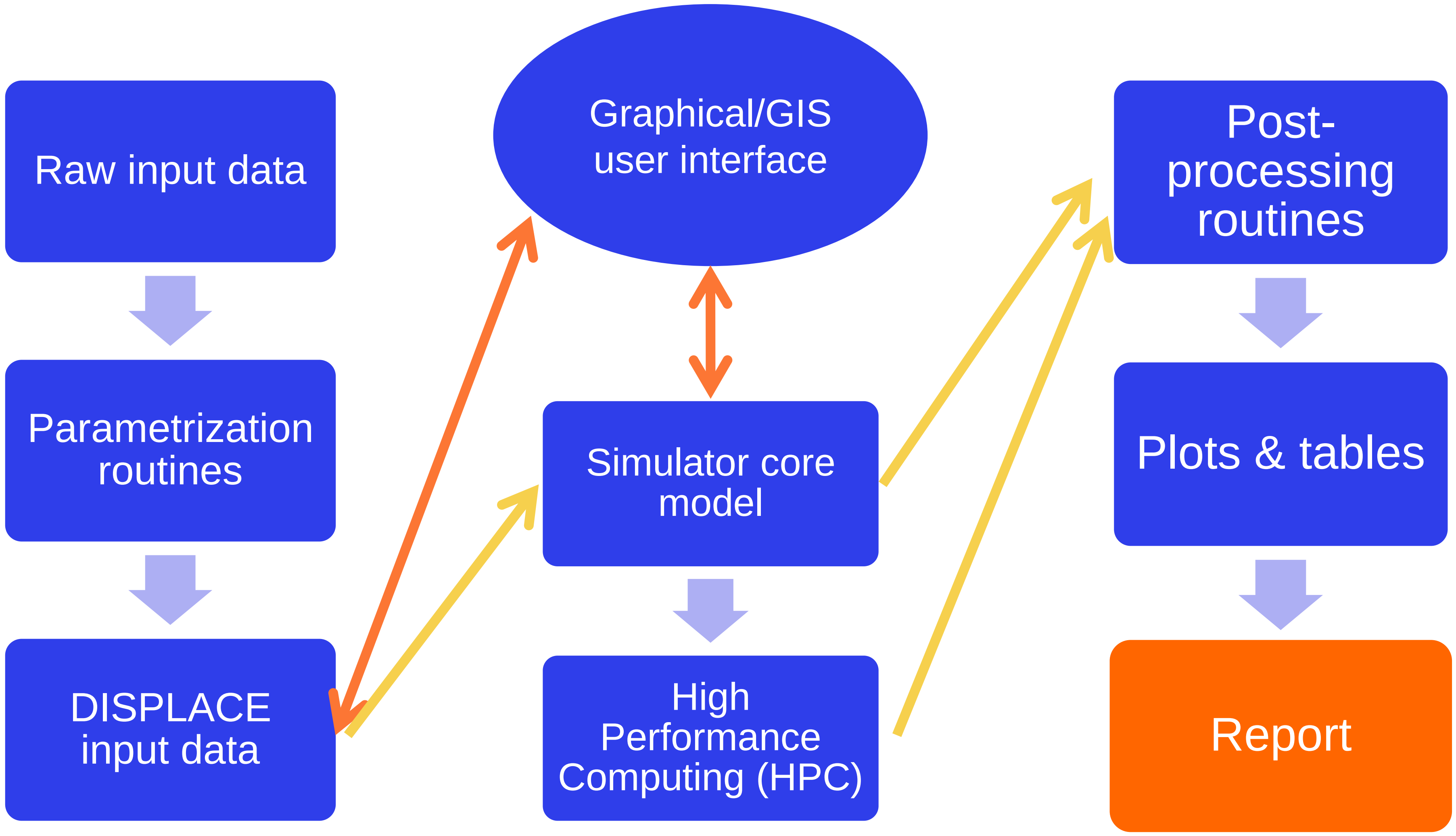
DISPLACE output

- Time series of **economic indicators** for individual vessels, fisheries and/or fleets
  - Landings, Catches and Catch rates
  - Discards and Discard rates
  - Revenues
  - Seabed swept area
  - Gross Value Added (GVA) ~ Profit
  - Fuel use and Fuel efficiency (& Emissions)
  - Labour surplus



- Time series of **biological stock indicators**
  - Fishing mortality (F)
  - Spawning Stock Biomass (SSB) and Total Stock Biomass (TSB)
  - Recruitment (R)

DISPLACE model structure



DISPLACE: different types of output formats

- Graphical user interface
  - Help to parametrize
  - Run several simulations
  - Compare and explore outcomes
  - Replay simulations
  - Store in SQL databases

- Output in simple text files
  - Use R post-processing routines to produce output figures and tables

- Use shell scripts and command line mode
  - When a large number of simulations/replicates are necessary
  - Use High Performance Computing facilities

The mesopelagic case study

- **Fishery**: parametrized for Danish large-scale pelagic fishery.
  - Select large Danish vessels (>24m) that can move to offshore, deep-sea activities
  - Further parameters related to a potential mesopelagic fishery related to costs, investments from interviews with the industry

- **Stock**: parametrized for the two mesopelagic species *Maurolicus muelleri* and *Benthosema glaciale.*

- Evaluate **scenarios** varying:
  - Population dynamic parameters
  - Costs
  - Fish prices

- Investigate different **management measures**:
  - Catch allowances
  - Gear selectivity

Parametrization

ORIGINAL RESEARCH article
Front. Mar. Sci., 24 August 2021 | https://doi.org/10.3389/fmars.2021.720897

Check for updates

Potential for Mesopelagic Fishery Compared to Economy and Fisheries Dynamics in Current Large Scale Danish Pelagic Fishery

Silvia Paoletti[1*†‡], J. Rasmus Nielsen[1†], Claus R. Sparrevohn[2], Francois Bastardie[1] and Berthe M. J. Vastenhoud[1]

[1]Section for Ecosystem Based Marine Management, National Institute of Aquatic Resources, Technical University of Denmark, Lyngby, Denmark
[2]Danish Pelagic Producers Organization, Axelborg, Denmark

Investigations as part of MEESO, e.g. to parametrize DISPLACE and other economic models

- In-depth analysis of dynamics and economics of current large-scale pelagic fishery in Denmark
- Interviews with industry to develop mesopelagic scenarios

Parametrization

Mesopelagic use case

Potential for Mesopelagic Fishery Compared to Economy and Fisheries Dynamics in Current Large Scale Danish Pelagic Fishery

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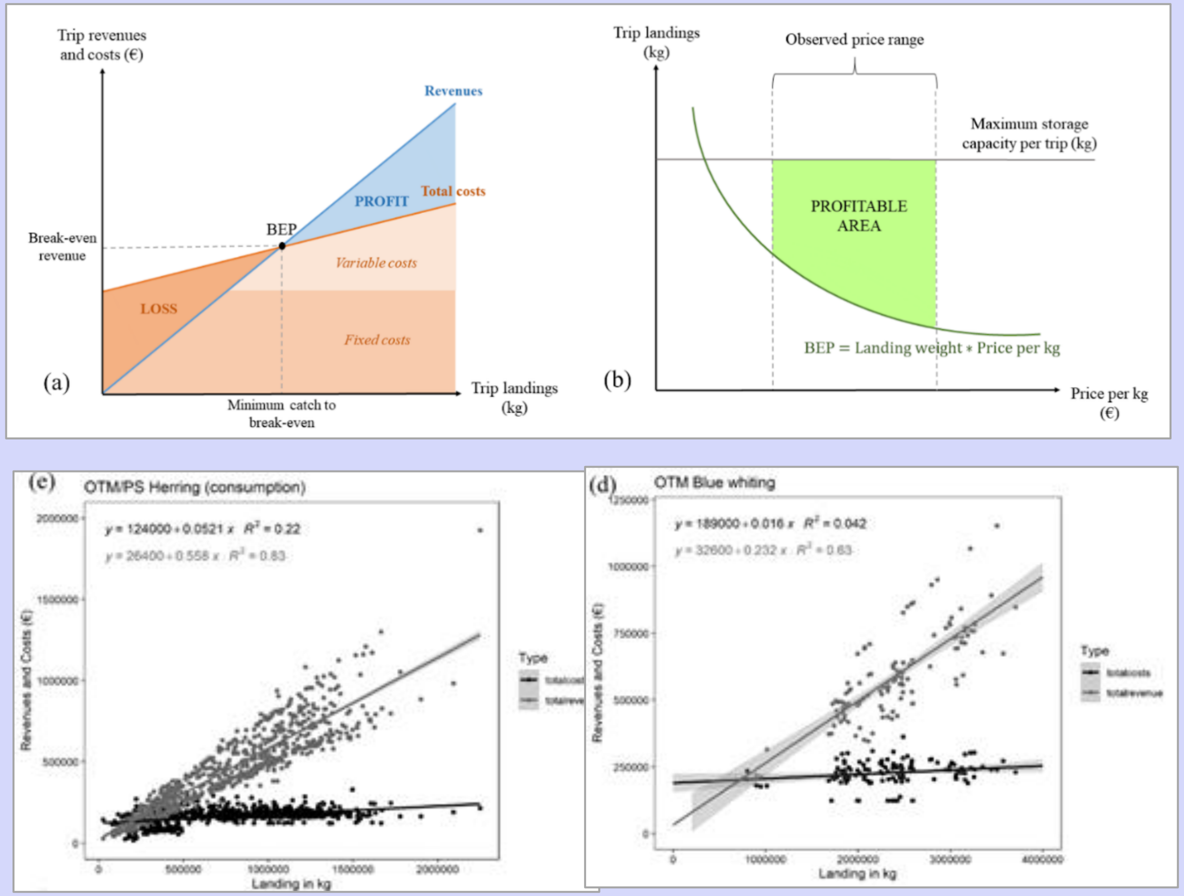
Profit per trip = Total revenues per trip - Total costs per trip

BEP (Break-Even Point): crossing of cost and revenue function

- *Fixed costs*: costs that not vary between year or effort deployed
  - Consumption of fixed capital
  - Repair and maintenance costs
- *Variable costs*: proportional to fishing effort
  - Payment of quotas
  - Energy consumption
  - Personnel costs



Parametrization

Interviews with Danish industry Representatives from MEESO Investigations:

- Expected **landing prices:**
  - ~ summer herring 0.30-0.55 €/kg
- Expected **catch amounts:**
  - ~ sandeel fishery (weight between 200-500 tonnes per haul)
- Expected **trip durations**:
  - 2-5 days
- Expected **fishing patterns and cost structure**
  - ~ blue whiting fishery (high cost)
    - Large depths
    - Small meshed deep sea trawls
    - Extensive engine power and high fuel consumption
- **Additional costs** are likely high, but uncertain:
  - Storage capacity and conservation
  - Gear adaptations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Mesopelagic scenarios

- BEP revenue functions:
  - Sprat fishery ~90’000€ (smallest)
  - Herring (consumption) fishery ~150’000€ (intermediate)
  - Blue whiting fishery ~200’000€ (highest)
- Cost functions:
  - Current blue whiting fishery
  - 50% increase in fixed and variable costs
  - 100% increase in fixed and variable costs

Parametrization

Mesopelagic use case

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BEP revenue →

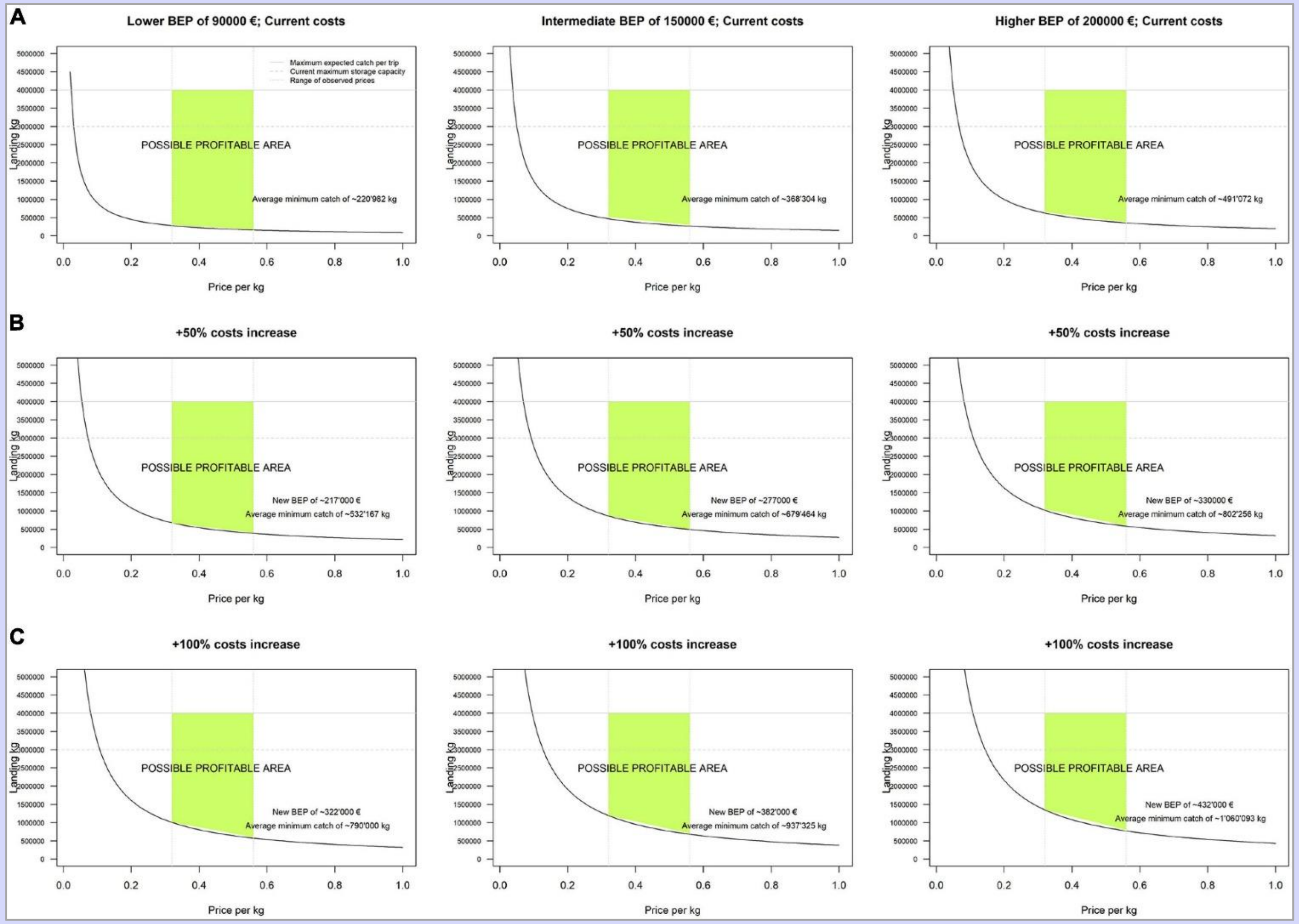
↓ Cost

Sprat | Herring (consumption) | Blue whiting

Blue whiting

50% cost increase

100 %



Limited by:

- Summer herring prices (0.30-0.55 €/kg)
- Max. expected catch per trip (Can be increased with max storage from 3000 to 4000 tonnes per trip)

Maximum profit between € 1’208’000 and €1’560’000 (up to €1’650’000) per trip

Parametrization

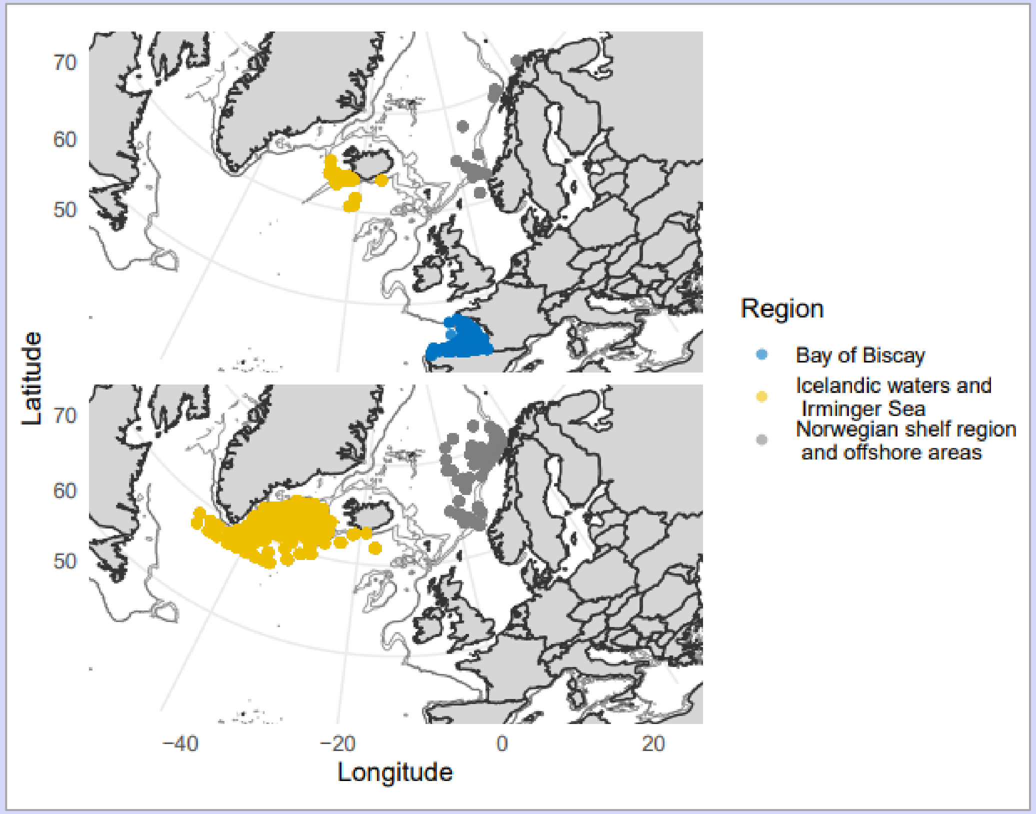
Length-frequency data available from MEESO investigations:

- Norway (Surveys 2008-2020) – *Maurolicus muelleri and Benthosema glaciale*
- Iceland (2009-2011/2020)
  - Survey – *Maurolicus muelleri and Benthosema glaciale*
  - Commercial trial fishery – *Maurolicus muelleri*
- Spain (Surveys 2013-2020) – *Maurolicus muelleri*

Analyses by sea region:

- Different gear and mesh sizes
- Different sampling frequencies

Maurolicus muelleri

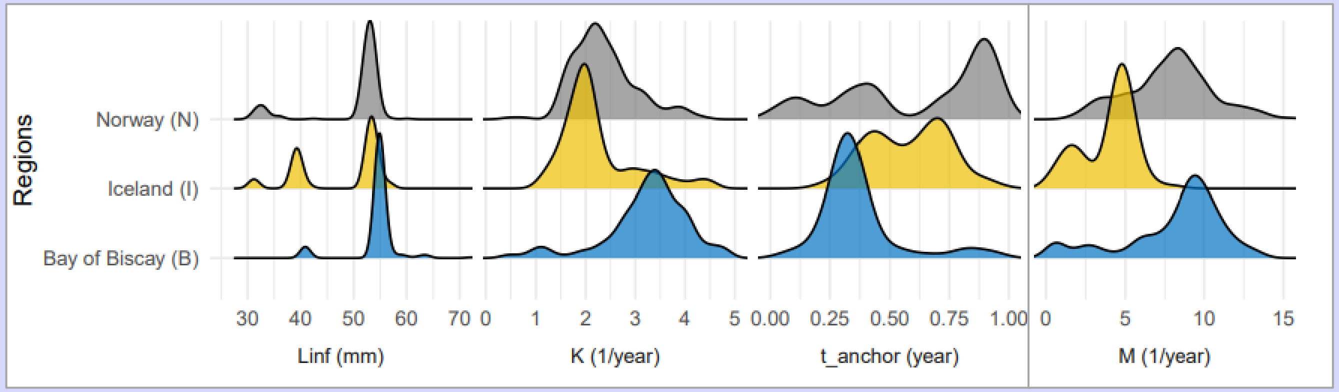


Benthosema glaciale

Vastenhoud, B.M.J., Mildenberger, T.K., Kokkalis, A., Paoletti, P., Alvarez, P., Garcia, D., Wieczorek, A., Klevjer, T., Melle, W., Jonsson, S.T., Jakobsdottir., K., Nielsen, J.R. Spatio-temporal variability in life history estimates of *Maurolicus muelleri* and *Benthosema glaciale* (In submission).

Parametrization

Regional estimates of growth and mortality parameters and their uncertainties

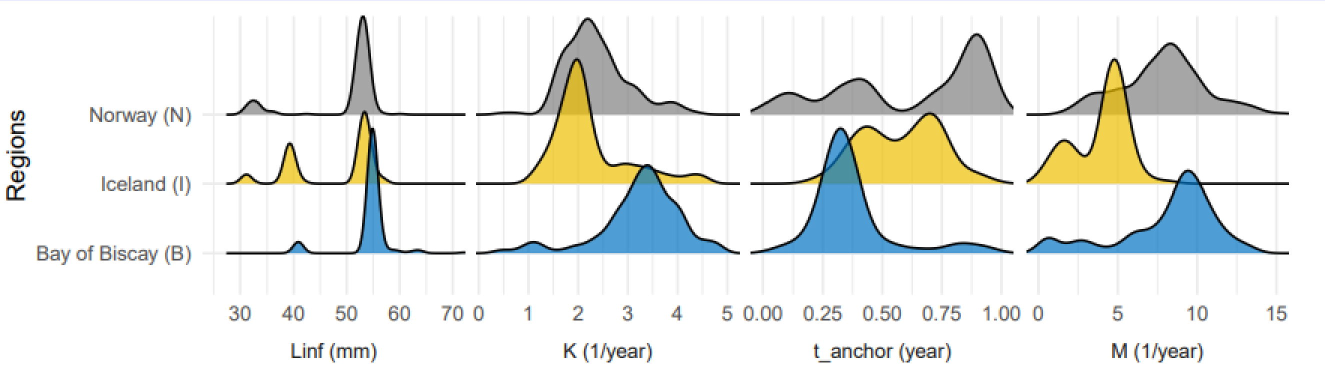


Maximum density estimates (MDE) and the uncertainty range, given by the difference between the upper and the lower limit of the 95% CI, for each estimated parameter

ID	Linf, MDE (mm)	Linf, CI (mm)	K, MDE (1/year)	K, CI (1/year)	t_anchor, MDE (year)	t_anchor, CI (year)	M, MDE (1/year)	M, CI (1/year)
Regions								
Bay of Biscay (B)	54.8	23.4	3.4	3.9	0.3	0.9	9.4	12.1
Iceland (I)	52.8	26.5	1.9	3.5	0.4	0.7	4.8	6.0
Norway (N)	53.0	26.0	2.2	2.7	0.9	1.0	8.3	10.6

DISPLACE Scenarios

- Spatial differences in **life-history parameters**



- **Fish prices** necessary to account for costs and investments under different scenarios

- Investigate different **management measures**:
  - – Catch allowances
  - – Gear selectivity

Installation of the DISPLACE model

Go to **https://displace-project.org/blog/download/**

Download an installer for the DISPLACE software for Windows or installation packages for MacOSX-64bit or Ubuntu-18.04LTS and Debian11

Illustrative datasets are available through public repositories

Further guidelines and tutorials

Go to **https://displace-project.org/blog/tutorials/** for documentation on how to set up and run scenarios

Step-by-step tutorials:

- DISPLACE step-by-step guideline – Creating a scenario file for spatial closure in DISPLACE 0-9-10
- DISPLACE step by step guideline – Set up a scenario on a spatial constraint from the baseline scenario
- DISPLACE step-by-step guideline – Set up a new graph of nodes
- DISPLACE step-by-step guideline – Use the scheduler for queuing simulations
- DISPLACE step-by-step guideline – Use the Objects Editor workflow to generate a new DISPLACE application

Video demos and tutorials:

- Demo 1 – A EU MYFISH application for the Baltic cod fisheries
- Demo 2 – A short insight into the DISPLACE model
- Demo 3 – Italian trips patterns in the Adriatic Sea
- Demo 4 – North Sea international fisheries
- Tuto 1 – Launch a DISPLACE simulation
- Tuto 2 – Set up a scenario
- Tuto 3 – Load a simulation database and replay
- Tuto 4 – Compare scenarios
- And many more.

MEESO

References

Bastardie F, Nielsen J.R., and Miethe, T. DISPLACE: a dynamic, individual-based model for spatial fishing planning and effort displacement — integrating underlying fish population models. Canadian Journal of Fisheries and Aquatic Sciences. 71(3): 366-386. https://doi.org/10.1139/cjfas-2013-0126

Paoletti S., Nielsen J.R., Sparrevohn C.R., Bastardie F. and Vastenhoud B.M.J. (2021) Potential for Mesopelagic Fishery Compared to Economy and Fisheries Dynamics in Current Large Scale Danish Pelagic Fishery. Front. Mar. Sci. 08:720897.

https://doi.org/10.3389/fmars.2021.720897/full