Model Fact Sheets

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Valuing Marine Artificial Structures

Model Fact Sheet Collection

About this collection

This collection of model fact sheets provides accessible summaries of the numerical modelling tools used within the VALMAS project. Each fact sheet describes a single model: what it does, how it works, what it produces, and its specific role in assessing the value of marine artificial structures.

Together the models form an integrated framework spanning physical oceanography, biogeochemistry, and ecosystem dynamics: from hydrodynamic circulation and particle dispersal, through lower trophic level production and fish community structure, to whole food web interactions and fisheries. The suite is designed to be read individually or as a collection, and is intended for a broad audience spanning researchers, environmental managers, regulators, and stakeholders

Models in this collection

FVCOM	3D hydrodynamic model providing ocean circulation and physical forcing
ERSEM	Biogeochemical model simulating nutrient cycling and lower trophic level ecosystem dynamics
PYLAG	Lagrangian particle-tracking model for simulating transport and dispersal
MIZER	Multi-species size-spectrum model of fish community dynamics
EwE	Food web model for whole ecosystem and fisheries scenario analysis
StrathE2E	End-to-end food web model from plankton to marine mammals

Model roles within VALMAS

FVCOM

FVCOM provides the hydrodynamic foundation for the modelling framework, simulating fine-scale circulation around marine artificial structures. In the context of marine artificial structures (MAS), FVCOM simulates local modifications to circulation, vertical mixing, and near-bed shear stress. FVCOM and ERSEM are two-way coupled, with hydrodynamic and biogeochemical processes interacting dynamically, while circulation outputs are passed to PyLag for particle dispersal. Scenario studies modify input conditions to explore key questions:

- How will altered atmospheric patterns affect stratification?
- How do different MAS configurations influence local circulation?
- How will future climate conditions modify hydrodynamic regimes?

ERSEM

ERSEM is coupled with FVCOM to simulate the ecological and biogeochemical impacts of marine artificial structures on lower trophic level ecosystem functioning. Temperature and plankton biomass by functional type produced by the FVCOM-ERSEM coupling are passed to Mizer, providing the environmental and prey conditions that drive higher trophic level dynamics.

Outputs contribute to wider project assessments of carbon cycling, fisheries productivity, and biodiversity under present and future climate and deployment scenarios, providing evidence to support marine spatial planning, conservation, and resource management. Primary production and environmental conditions from FVCOM-ERSEM also provide the biological forcing that drives ecosystem dynamics within EwE and StrathE2E

PYLAG

PyLag and FVCOM work in combination to model offshore energy structures as interacting ecological systems. This enables identification of larval exchange pathways, stepping-stone connections, and connectivity hotspots - revealing when clusters of structures begin to function as synthetic archipelagos. Understanding these system-scale ecological dynamics is critical for evidencing the ecological value of marine artificial structures and informing marine spatial planning and biodiversity management

Model roles within VALMAS

MIZER

Mizer receives hydrodynamics, temperature, and plankton biomass by functional type from FVCOM-ERSEM, translating these into spatially and temporally resolved HTL biomass across size classes. This allows assessment of how MAS alter the higher trophic level community both within and around the structures through changes in food availability, temperature, and local productivity. Outputs inform both ecological assessments (community health and composition) and socioeconomic evaluations (fisheries productivity and potential spillover effects), supporting evidence-based decision making on MAS deployment, management, and decommissioning

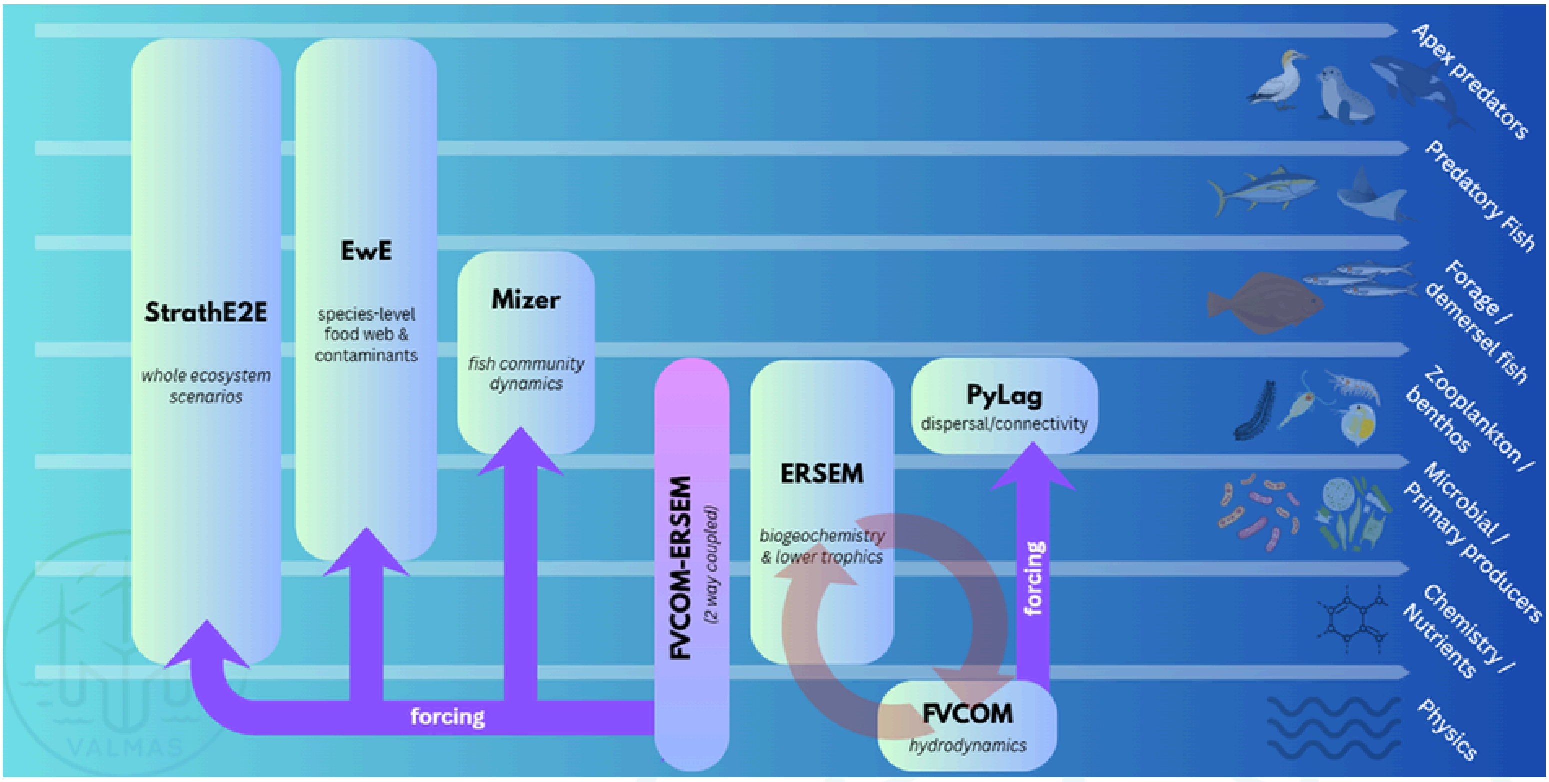
EwE

EwE will be applied to the greater Moray Firth - an area of high MAS density with both oil and gas and offshore renewable infrastructure. It will receive hydrodynamic and biogeochemical forcing from FVCOM-ERSEM and contaminant burden data from VALMAS Work Package 4 to simulate food web accumulation of substances such as mercury released from MAS, providing evidence on fisheries productivity, ecosystem health, and human health risk from contaminants in seafood

StrathE2E

StrathE2E receives hydrodynamic and biogeochemical forcing from FVCOM-ERSEM to drive whole food web dynamics. It will be used to explore the system-scale effects of MAS on the marine ecosystem under present-day and future climate scenarios. As part of VALMAS, the model will be expanded to include new measures of ecosystem services, while developing ways to link offshore structures directly to model parameters.

The VALMAS Model Ensemble



Schematic of the six models comprising the VALMAS modelling framework, showing the trophic scope of each model as used in the VALMAS project, and the data flows between them. Models are positioned against the marine food web they represent, from physical oceanography and chemistry at the base to apex predators at the top. Purple arrows indicate model forcing connections. FVCOM and ERSEM operate as standalone models and as a two-way coupled system (FVCOM-ERSEM), providing the physical and biogeochemical foundation for the ensemble.

Model Fact Sheets

FVCOM

USE THIS MODEL.....
if you need to understand how water moves around a site (tides, currents, mixing), and how structures alter local flow

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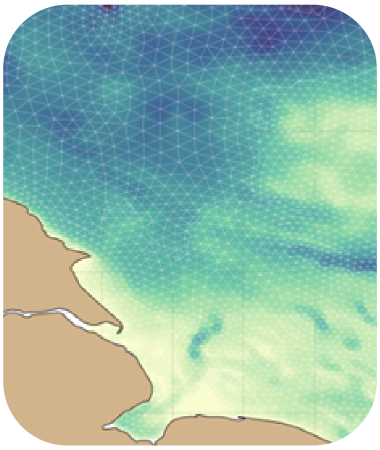
A three-dimensional unstructured-grid finite- volume coastal ocean circulation model simulating hydrodynamics across complex coastal and shelf-sea domains

Documentation: https://github.com/UK-FVCOM-Usergroup/uk-fvcom

The FVCOM codebase was originally developed by the UMass Dartmouth team. The version used in VALMAS is UK-FVCOM, maintained by the UK-FVCOM User Group and hosted at Plymouth Marine Laboratory (PML)



Example visualisation of the FVCOM unstructured grid, taken from the North Sea domain

At a glance

Model Type	3D unstructured-grid hydrodynamic model
Spatial Scale	Determined by model domain *(metres to kilometres)*
Temporal Range	Determined by model configuration *(hindcast, operational, scenario)*
Grid Type	Unstructured triangular mesh *(variable resolution)*
Coupling	ERSEM, PyLag and other ecosystem/particle tracking models
Lead VALMAS contact(s)	Dr Muchamad Al Azhar (PML) maz@pml.ac.uk; Dr Michael Bedington (NIVA), mib@akvaplan.niva.no

What is FVCOM?

The Finite-Volume Community Ocean Model (FVCOM) is a three-dimensional hydrodynamic model used to simulate water movement and changes in physical properties (e.g. temperature and salinity) in coastal and shelf-sea environments. Originally developed in the early 2000s by the University of Massachusetts Dartmouth team[1], Its defining feature is its unstructured triangular mesh, which allows spatial resolution to vary smoothly from metre-scale in narrow channels and coastal areas to kilometre-scale offshore, providing detailed representation where needed without excessive computational cost.

FVCOM represents the coastal ocean as a virtual hydrodynamic system, capturing wind-driven circulation, tides, river inputs, stratification, and air-sea exchanges, as well as the transport of tracers including contaminants and sediments. Within VALMAS, FVCOM provides the physical forcing that drives particle dispersal in PyLag and biogeochemical cycling in ERSEM.

Key features

- *Unstructured triangular mesh resolves complex coastlines and nearshore features at high resolution*
- *Fully 3D with flexible vertical layer configuration*
- *Simulates tides, wind-driven circulation, stratification, river inputs, and air-sea exchanges*
- *Readily coupled to ecosystem and particle-tracking models via standard interfaces*

Typical applications

- *Tidal dynamics and storm surge modelling in complex coastal and estuarine systems*[1]
- *Water quality and sediment transport in coastal development and management contexts*[2]
- *Coastal flood risk assessment and climate scenario modelling*[3]
- *Marine renewable energy impact assessment and site characterisation*[4]

Model Fact Sheets

FVCOM

KEY OUTPUTS.....

- High-resolution fields of ocean currents, water levels and tides, temperature and salinity, stratification intensity, and vertical mixing
- Quantification of downstream effects on productivity, habitat conditions, and biodiversity when coupled with ERSEM

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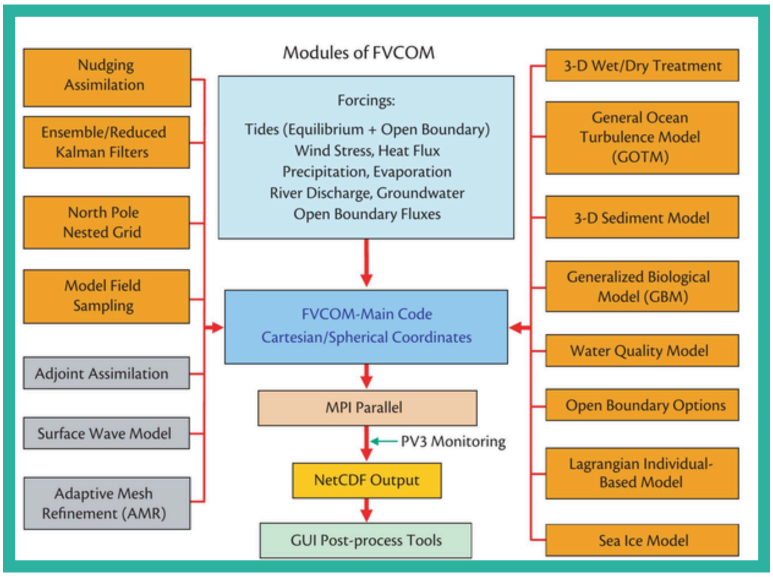
How FVCOM works



Schematic overview of FVCOM module structure, showing core forcing inputs, optional process modules, and output formats[1]

The coastal ocean is driven by a complex interplay of atmospheric, tidal, riverine, and density-driven forces that vary continuously in space and time. FVCOM operates as a virtual ocean, integrating physical forcing from multiple datasets including meteorological forcing (winds, heat fluxes, precipitation), river inputs, open-boundary conditions derived from larger-scale ocean models, and satellite products such as sea-surface temperature

Using these inputs, FVCOM simulates how tidal forcing, wind stress, river flows, and density gradients drive circulation patterns and mixing processes throughout the 3D environment. The unstructured mesh enables high-resolution representation near coastlines, estuaries, and engineered structures.

Outputs are delivered as NetCDF files and can be post-processed into maps, transects, and time series to support scientific analysis and stakeholder communication.

Why FVCOM?

FVCOM is particularly well suited for regions with complex coastline, steep bathymetry gradients, or dense coastal infrastructure. Its flexible mesh can also resolve hydrodynamic processes around MAS more accurately than traditional models using regular square grids. For MAS, the model supports assessment of how arrays or farms modify circulation patterns, stratification, and near-bed stresses. These changes directly influence ecosystem processes such as productivity, nutrient transport, and carbon cycling. FVCOM forms the physical foundation for models that simulate plankton, nutrients, oxygen, and carbon fluxes, as well as to particle tracking models assessing ecosystem connectivity. FVCOM enables testing of different development or management scenarios across pre-construction assessment, operational monitoring, and decommissioning planning in support of environmental impact assessments or marine spatial planning. By simulating how physical changes propagate through the coastal environment, FVCOM helps identify where impacts are most likely to occur and supports decisions that balance renewable-energy expansion with environmental protection.

Uncertainty and validation

In-situ observations including tide gauges, ADCP current measurements, and CTD profiles are used for calibration and skill assessment. Model uncertainty is addressed through sensitivity analysis and runs with alternative atmospheric and boundary forcing datasets to assess how input uncertainty propagates through the model. Ongoing developments include higher-resolution grids and improved turbulence parameterisations - the mathematical schemes representing sub-grid mixing processes - to better capture fine-scale dynamics around structures.

References

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3.Yang, Z., Wang, T., Leung, R., Hibbard, K., Janetos, T., Kraucunas, I., Rice, J., Preston, B. and Wilbanks, T., 2014. A modeling study of coastal inundation induced by storm surge, sea-level rise, and subsidence in the Gulf of Mexico. Natural Hazards, 71(3), pp.1771–1794.
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Model Fact Sheets

ERSEM

USE THIS MODEL.....
if you need to assess how a structure affects nutrient cycling, primary production, or carbon fluxes in the surrounding ecosystem

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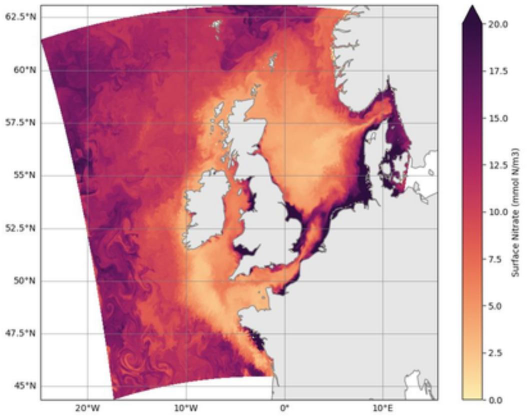
A marine biogeochemical model simulating nutrient and carbon cycling through the lower trophic levels of the ocean.

Documentation:

Model code is available at:
https://github.com/pmlmodelling/ersem

Example Usage:
https://ersem.readthedocs.io/en/latest/

ERSEM is developed and maintained by Environmental Intelligence Group at Plymouth Marine Laboratory.



Example ERSEM output (taken from ERSEM coupled with NEMO via FABM)

At a glance

Model Type	Marine biogeochemical and ecosystem model
Spatial Scale	Determined by coupled hydrodynamic model
Temporal Range	Determined by model configuration
Trophic Scope	Lower trophic levels *(nutrients, phytoplankton, zooplankton, bacteria, benthos)*_
Coupling	FVCOM, GOTM, NEMO and other hydrodynamic models via FABM; provides forcing for Mizer, EwE and StrathE2E
Lead VALMAS contact(s)	Dr Gennadi Lessin gle@pml.ac.uk

What is ERSEM?

The European Regional Seas Ecosystem Model (ERSEM) is a marine biogeochemical and ecosystem model that simulates the cycling of carbon, nitrogen, phosphorus, silicon, oxygen and iron within lower-trophic-level marine ecosystems[1]. It represents both pelagic (water column) and benthic (seabed) components and includes multiple phytoplankton and zooplankton types, the microbial loop, and the carbonate system.

Developed originally in the early 1990s as a consortium effort for the North Sea, ERSEM has evolved into a flexible framework used across diverse marine environments, from coastal regions to shelf seas and the global ocean. It supports assessments of how marine ecosystems respond to environmental pressures and human activities, including climate change, ocean acidification, nutrient inputs, demersal trawling and the expansion of marine artificial structures (MAS). ERSEM couples with physical ocean models (e.g. FVCOM) that provide currents, temperature and light fields driving biological processes.

Key features

- *Dynamic stoichiometry allowing organisms to adjust internal nutrient ratios to environmental conditions*
- *Resolves the microbial loop, benthic-pelagic coupling, and carbonate system*
- *Represents epifaunal colonisation of hard substrates and associated biogeochemical feedbacks*

Typical applications

- *Primary production and carbon budget assessment in shelf seas*[2]
- *Benthic biogeochemistry and carbon cycling*[3]
- *Ocean acidification and climate change impact assessment*[4]

Model Fact Sheets

ERSEM

KEY OUTPUTS.....

- Spatial and temporal patterns of primary production, plankton biomass, and community composition
- Nutrient cycling and carbon fluxes in the water column and seabed
- Benthic–pelagic coupling processes and epifaunal biomass growth on MAS, including effects on nutrient and organic matter cycling

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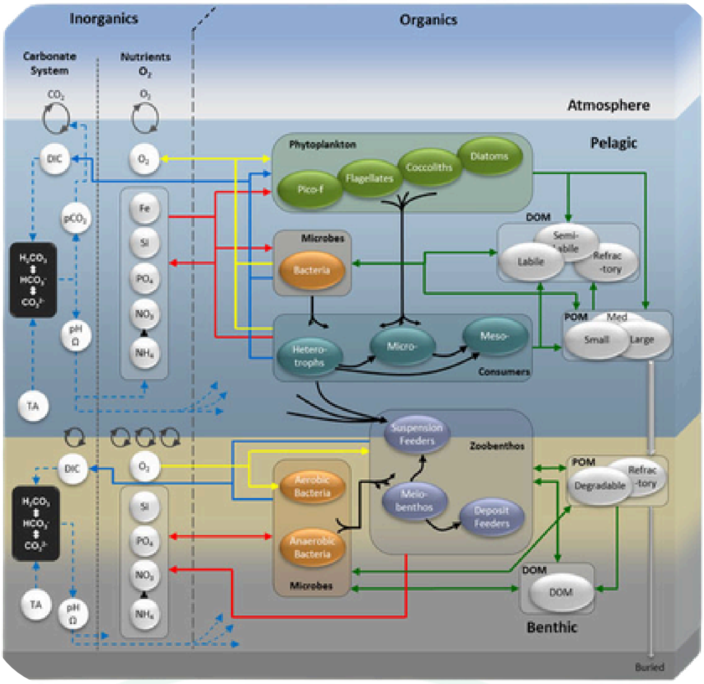
How ERSEM works

ERSEM is driven by environmental forcing including irradiance and physical transport fields supplied by its coupled hydrodynamic model (FVCOM in VALMAS). Additional inputs include satellite-derived data, river nutrient loads, atmospheric deposition, and initial and boundary conditions from larger-scale ocean models.

Ecosystem processes are represented through differential equations describing photosynthesis, respiration, grazing, nutrient uptake and release, microbial activity, and sediment–water exchange. Different scenarios can be tested by modifying input conditions, for example exploring future climate pathways, altered nutrient loads or MAS deployment patterns. Outputs are delivered as NetCDF files and can be post-processed into maps and time series for further interpretation.



Schematic of the ERSEM model structure[1]

Why ERSEM?

ERSEM is one of the most established marine biogeochemical models available, with over 200 peer-reviewed publications across global applications. Unlike simpler fixed-ratio models, ERSEM uses dynamic stoichiometry and explicitly resolves the microbial loop, benthic-pelagic coupling, and - critically for VALMAS - epifaunal biomass colonising artificial substrates and its biogeochemical feedbacks. ERSEM is run operationally by the UK Met Office to predict water quality across the North-West European shelf, demonstrating its maturity as a tool for evidence-based environmental management[5]. Coupling with FVCOM is well established via FABM, and PML's role as lead developer ensures direct model expertise within the project team.

Uncertainty and validation

Model uncertainty is addressed through sensitivity testing and parameter adjustment. Skill is assessed against satellite-derived chlorophyll, sea surface temperature, and primary production data alongside available field measurements. Boundary and initial conditions are derived from larger-scale ocean models, with calibration performed for each regional application. Within VALMAS, ERSEM is run in scenario mode rather than operational forecast mode - satellite data are used for validation rather than real-time data assimilation.

References

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5.https://www.metoffice.gov.uk/blog/2025/what-are-the-met-offices-ocean-forecasting-models

PYLAG

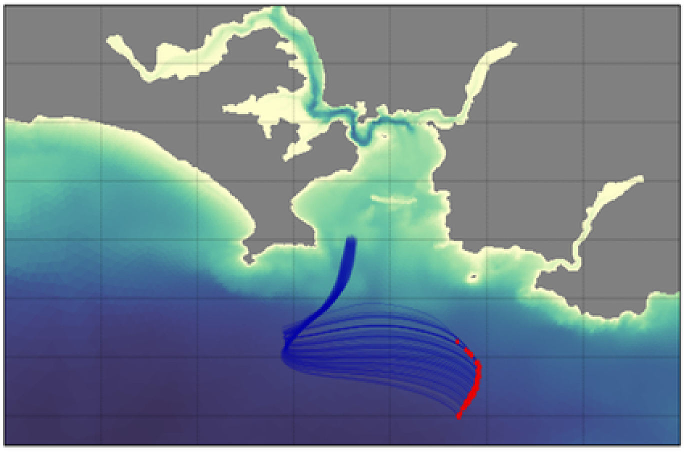
USE THIS MODEL.....
if you want to track dispersal from structures and understand how they alter ecological connectivity across a region

An open-source Lagrangian particle-tracking model for simulating the transport and dispersal of particles in aquatic environments

Documentation:
Model code is available at:
https://github.com/pmlmodelling/pylag

Example Usage:
https://pylag.readthedocs.io/en/latest/

PyLag is developed and maintained by Environmental Intelligence Group at Plymouth Marine Laboratory.



Example visualisation of a PyLag dispersal trajectory, taken from the PyLag docs

At a glance

Model Type	Lagrangian particle-tracking model
Spatial Scale	Determined by hydrodynamic input
Temporal Range	Determined by hydrodynamic input *(historical / present / future)*
Primary Use	Larval/propagule dispersal, pollutant transport
Hydrodynamic input	FVCOM, ROMS, or Arakawa A-grid *(e.g. CMEMS)*
Lead VALMAS contact(s)	Dr Molly James moja@pml.ac.uk

What is PyLag?

PyLag is an open-source, three-dimensional Lagrangian particle-tracking model used to simulate the transport, dispersal, and fate of particles in marine and aquatic environments, representing the movement of individual particles as they are advected by ocean currents and influenced by turbulence, vertical mixing, and biological or behavioural processes[1].
PyLag was originally developed to work with FVCOM and has since been extended to support additional hydrodynamic models providing time-varying flow fields, enabling application across spatial scales from fine-resolution coastal domains to regional shelf-sea systems.

Key features

- *Open-source with active community development*
- *3D particle tracking with vertical migration, settlement behaviour, and mortality*
- *Ensemble and scenario simulation capability*

Typical applications

- *Larval and propagule dispersal[2]*
- *Pollutant and debris transport[1]*
- *Outputs can be used for residence-time analysis[4], ecological connectivity and MAS assessment[3]*

Model Fact Sheets

PYLAG

KEY OUTPUTS.....

- Particle trajectory datasets recording latitude, longitude, depth, and time of each particle throughout the simulation
- Connectivity matrices, dispersal kernels, and residence-time estimates derived from trajectory analysis

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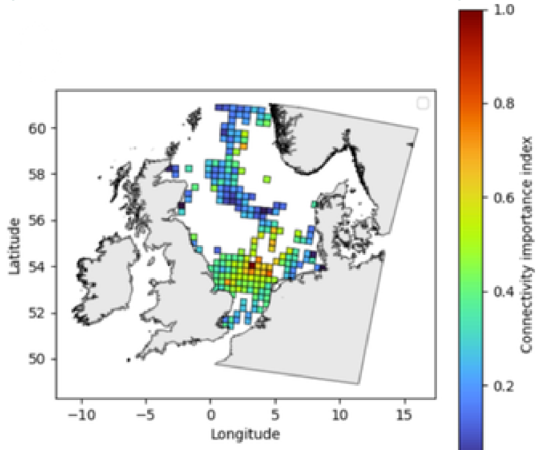
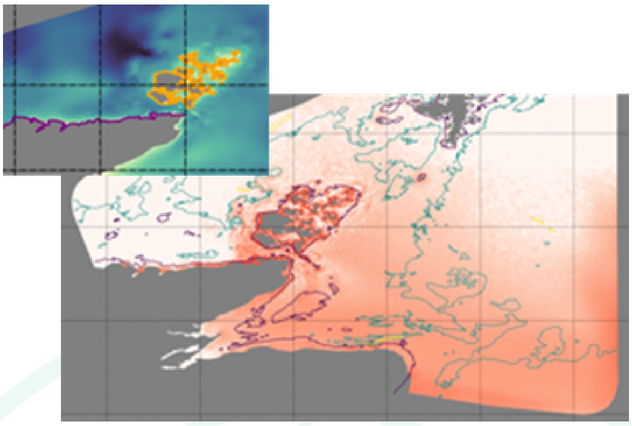
How PyLag works

PyLag simulates the movement of virtual particles released into a time-varying hydrodynamic environment. Physical forcing is supplied by coupled hydrodynamic models (FVCOM within VALMAS) providing three-dimensional fields of currents, temperature, salinity, turbulence, and vertical mixing. Where available, atmospheric and wave forcing can also be incorporated, accounting for the influence of windage and Stokes' drift on particle transport. FVCOM's unstructured mesh is particularly well suited to resolving the complex circulation and retention features generated by offshore infrastructure, and PyLag adopts this grid directly, producing dispersal predictions that reflect fine-scale local conditions. Particle positions are updated at each timestep using a fourth-order Runge-Kutta scheme for advection, with stochastic random-walk schemes applied for turbulent diffusion.

Particles are released from user-defined locations such as turbine foundations, reef structures, or spawning sites. Additional biological processes can be applied, including vertical migration, competency windows, settlement behaviour, and mortality.



Connectivity Importance Index to indicate locations where occurrence of marine structures might result in highest and lowest connectivity with other patches[3]



Annual log cumulative particle density following 30-day dispersal simulations, with daily releases from 1 January to 30 November. Inset shows release locations, coloured by source region (mainland Scotland and Orkney Isles). Main figure shows the resulting dispersal kernel density estimate (KDE) across the northern North Sea and Scottish shelf

Why PyLag?

PyLag was built to work directly with FVCOM outputs. FVCOM's unstructured mesh is particularly well suited to resolving the complex circulation and retention features generated by offshore infrastructure, and PyLag adopts this grid directly, producing dispersal predictions that reflect fine-scale local conditions.

Uncertainty and validation

Model uncertainty is addressed through ensemble simulations and sensitivity testing across release strategies, species traits, and flow conditions. Where observational data are available, model outputs can be validated against field measurements such as genetic connectivity.

References

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5.Sainz-Villegas, S., Wilson, R., James, M., Clark, J., Brown, M., Porter, J., Smale, D. and Queirós, A. (under review) 'Tracing kelp detritus export to sink sites to identify potential carbon sequestration hotspots', Ecological Applications.

Model Fact Sheets

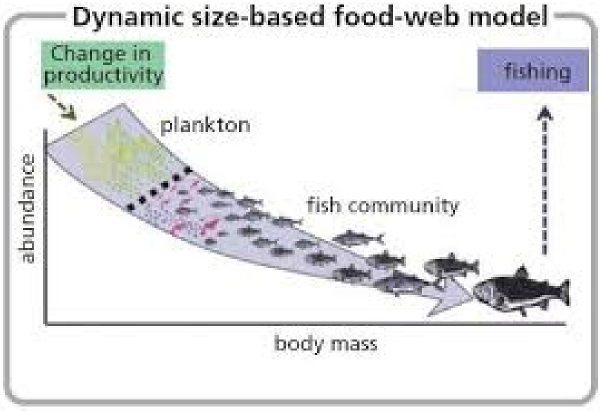
MIZER

USE THIS MODEL.....
if you want to evaluate how changes in productivity or temperature around a structure translate into effects on fish community

A community size-spectrum model simulating the biomass and community structure of higher trophic levels in response to environmental and fishing pressures

Documentation: https://github.com/pmlmodelling/fabm-mizer

The mizer R package was originally developed by Scott, Blanchard, and Andersen[1]. The implementation used in VALMAS is fabm-mizer, developed and maintained by the Environmental Intelligence Group at Plymouth Marine Laboratory (PML).



Schematic of the Mizer size-spectrum model, showing the distribution of abundance across body mass from plankton through to the fish community

At a glance

Model Type	Community size-spectrum model
Trophic scope	Higher trophic levels *(fish and other predators above zooplankton)*
Temporal Range	Monthly to decadal
Size classes	Continuous size spectrum from small juvenile fish to large predators
Input models	FVCOM-ERSEM *(hydrodynamics, temperature, plankton biomass by functional type)*
Lead VALMAS contact(s)	Dr Sevrine Sailley sesa@pml.ac.uk

What is MIZER?

The Mizer Community Size Spectrum Model (Mizer-CSSM), first published in 2014 and implemented using the mizer R package[1], simulates the biomass and size structure of higher trophic level (HTL) communities: broadly, all organisms above zooplankton. Rather than tracking individual species, it characterises the community by body size, exploiting the well-established principle that size is the primary determinant of an organism's role in a marine food web: what it eats, what eats it, and how fast it grows. Resolving HTL biomass across discrete size classes, the model captures shifts in the location and timing of biomass peaks and changes in community size structure - dynamics that are critical for evaluating the effects of environmental change, fishing pressure, and marine artificial structures on higher trophic level productivity and composition.

Key features

- *Size-based approach requiring minimal species-specific data, making it tractable across broad spatial and temporal scales*
- *Resolves community size structure via the size spectrum slope: a sensitive indicator of ecosystem state and fishing impact*
- *Forced by temperature and primary production, linking physical and biogeochemical conditions directly to HTL dynamics*
- *Implemented in R with an active development community and open-source codebase*

Typical applications

- *Fisheries management and ecosystem-based assessment[2]*
- *Climate change impacts on fish community biomass and production[3]*
- *Evaluation of ecosystem indicators and community size structure[1]*

Model Fact Sheets

MIZER

KEY OUTPUTS.....

- Spatially resolved maps of total HTL biomass and change in biomass
- Maps of size spectrum slope - an indicator of community size structure and ecosystem state
- Time series of biomass trends across size classes at seasonal to decadal scales

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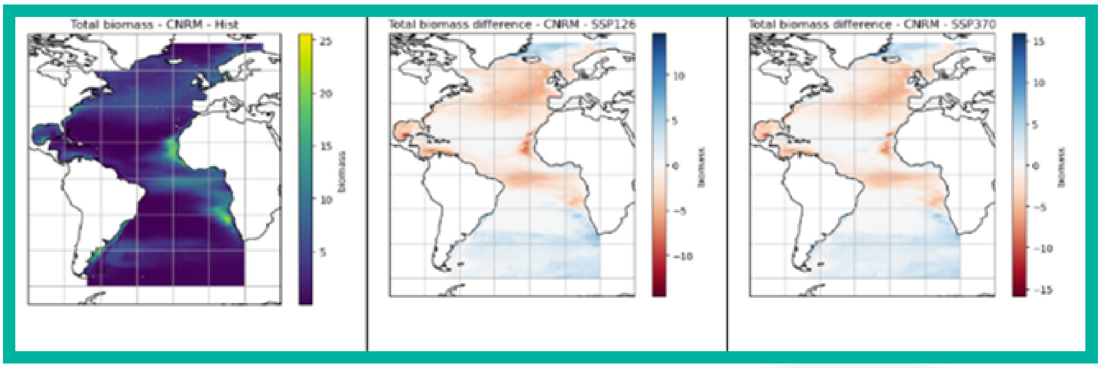
How MIZER works

Mizer is forced by FVCOM-ERSEM outputs (hydrodynamics, temperature, and plankton biomass by functional type) which drive growth and metabolism across the fish community. It explicitly resolves carbon, nitrogen, and phosphorus, conserving elemental mass between ERSEM and Mizer. Individuals grow by consuming smaller prey and are subject to predation, fishing, and background mortality, generating the size spectrum - the distribution of biomass as a function of body size. Scenario studies modifying environmental inputs and fishing pressure will be used to explore how MAS, climate change, and management interventions alter HTL dynamics on seasonal to decadal timescales.

Outputs are delivered as NetCDF files and can be post-processed into maps and time series for further interpretation.



. Example outputs from Mizer: comparison of total fish biomass in the Atlantic between historical (2000's) and mid-century (2050's) under two climate scenarios

Why MIZER?

Mizer fills a critical gap in the VALMAS model ensemble by explicitly representing higher trophic level dynamics i.e. the fish and predator communities that sit above the lower trophic levels resolved by ERSEM and below the whole food web representations of EwE and StrathE2E. Its size-based approach requires no species-specific diet data, making it computationally tractable across multiple scenarios. Implementation is tightly coupled to ERSEM via FABM, with carbon, nitrogen, and phosphorus explicitly conserved across the model boundary - creating a coherent modelling chain from physics and biogeochemistry through to higher trophic level response, directly informing the fisheries and biodiversity assessments that underpin the socioeconomic valuation of MAS.

Uncertainty and validation

Model uncertainty is addressed through sensitivity testing of key biological parameters and ensemble runs across climate and fishing scenarios. Where survey data are available, model outputs are validated against observed community size spectra and fish biomass estimates.

References

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Model Fact Sheets

EwE

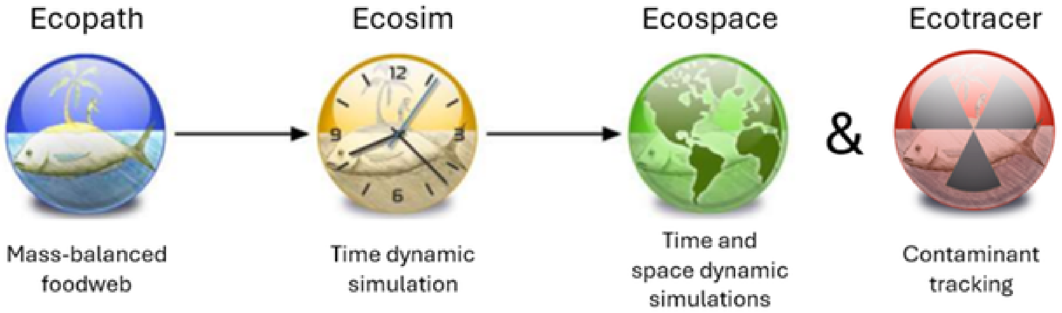
USE THIS MODEL.....
if you need to understand food web consequences of a structure, including effects on fisheries and contaminant accumulation

Ecopath with Ecosim

A food web model simulating energy flow and species interactions across marine ecosystems to assess the impacts of fishing, climate change, and environmental pressures

Documentation:
website: https://ecopath.org/ | user guide: https://pressbooks.bccampus.ca/eweguide/

The VALMAS implementation is being developed by Jacob Bentley (Natural England), Kieran Tierney (SUERC), and Rebecca von Hellfeld (University of Aberdeen).



. Schematic of the four integrated components of the EwE modelling suite

At a glance

Model Type	Food web ecosystem model
Spatial Scale	Local to regional *(Moray Firth in VALMAS)*
Temporal Range	Retrospective and forward-looking scenarios
Primary Use	Ecosystem-based fisheries management, contaminant transfer, food web scenario analysis
Trophic Scope	Full food web - primary producers to top predators
Lead VALMAS contact(s)	Jacob Bentley Jacob.Bentley@naturalengland.org.uk; Kieran Tierney Kieran.tierney@glasgow.ac.uk; Rebecca von HellfeldRebecca.vonhellfeld@abdn.ac.uk

What is EwE?

Ecopath with Ecosim (EwE) is a free, open-source food web modelling suite, originating with the Ecopath model developed in 1984[1], and expanded into the full EwE suite by the early 2000s[2,3]. Over four decades of development have added dynamic simulation (Ecosim) and spatiotemporal (Ecospace) capabilities, and the suite now has over 8,000 users in more than 150 countries. EwE simulates how energy flows through a marine food web - from primary producers to top predators - and how changes to one part of the system propagate through the whole, across scales from individual offshore structures to entire regional seas.

Key features

- *Three integrated components: Ecopath (mass-balance snapshot), Ecosim (time-dynamic), and Ecospace (spatiotemporal)*
- *Represents species as functional groups: from a single species (e.g. cod) to an age class (e.g. juvenile cod), to broader assemblages (e.g. demersal fish).*
- *Simulates contaminant accumulation through the food web*
- *Couples with hydrodynamic and biogeochemical model outputs*

Typical applications

- *Ecosystem-based fisheries management and scenario testing*[4]
- *Cumulative impact assessment of fishing, climate change, and habitat degradation*[5]
- *Food web contaminant transfer and bioaccumulation*[6,7]

Model Fact Sheets

EwE

KEY OUTPUTS.....

- Spatiotemporal biomass, catch, and predator-prey simulations
- Food web indicators - trophic level, production, transfer efficiency
- Contaminant burden by functional group and trophic level
- Ecosystem change maps across MAS, fishing, and climate scenarios

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How EwE works

EwE uses data on species physiology, abundance, diet, and exploitation to construct a mass-balanced snapshot of the food web (Ecopath), establishing who eats whom and in what quantities. Ecosim then projects this forward in time, simulating how changes in fishing pressure, environmental conditions, or species interactions alter biomass, mortality, and energy flow. Ecospace extends this to two-dimensional space, allowing habitat-specific processes and the location of MAS to be explicitly represented.

Outputs are typically presented as visualised trends, maps, data tables, and scenario comparison reports.

Why EwE?

EwE is the most widely used marine food web modelling platform globally, with decades of development and a large international user base. By explicitly resolving predator-prey interactions and energy flows between defined functional groups, it helps policymakers and resource managers understand ecosystem function and make informed decisions about sustainability, conservation, and the responsible use of natural resources, bridging the gap between science and policy in ways that whole-system biogeochemical and size-spectrum approaches are not designed to do. Within the VALMAS suite, EwE complements ERSEM and Mizer by adding species- and functional group-level ecological and socioeconomic resolution.

Uncertainty and validation

Model uncertainty is addressed through sensitivity analysis of key parameters including vulnerability multipliers governing predator-prey interactions, and Monte Carlo simulations to quantify parameter uncertainty. Models are calibrated by fitting Ecosim time-dynamic simulations to observed time series of biomass and catch data, and spatial outputs are evaluated against survey data and independent species distribution information where available.

References

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5. Heymans, J.J., Coll, M., Link, J.S., Mackinson, S., Steenbeek, J., Walters, C. and Christensen, V., 2016. Best practice in Ecopath with Ecosim food-web models for ecosystem-based management. Ecological Modelling, 331, pp.173–184.
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7. von Hellfeld, R. and Hastings, A., 2024. Contaminant transfer in marine food webs. Royal Society Open Science, 11, 230943.

Model Fact Sheets

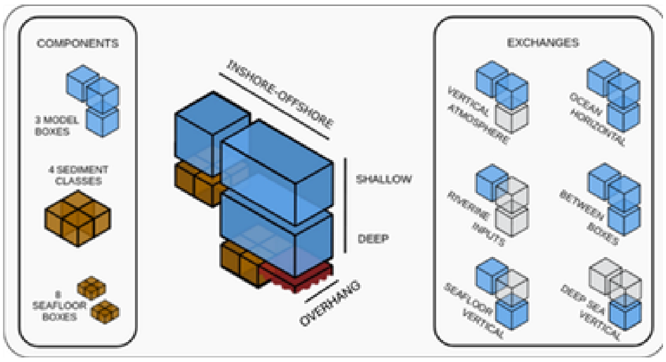
StrathE2E

USE THIS MODEL.....
if you want a whole-ecosystem view of long-term, cumulative, or strategic scenarios spanning fisheries, climate change, and offshore development

An end-to-end food web model simulating the flow of nutrients and energy through the full marine ecosystem

Documentation:
Installation instructions:
https://www.marineresourcemodelling.maths.strath.ac.uk/strathe2e/
Webapp:
https://rshiny.science.strath.ac.uk/apps/StrathE2EApp/

StrathE2E was developed at the University of Strathclyde, with the R package first published in 2021[1]



Schematic of the StrathE2E spatial structure, showing model compartments and the physical exchange processes represented between them

At a glance

Model Type	End-to-end food web model
Trophic scope	Full food web *(dissolved nutrients to birds, seals, and cetaceans)*
Temporal Range	Decadal to centennial *(climate scenario projections 2010s–2090s)*
Spatial scale	Regional shelf sea
Input models	Coupled hydrodynamic/biogeochemical models (e.g. FVCOM-ERSEM)
Lead VALMAS contact(s)	Prof Michael Heath m.heath@strath.ac.uk; Dr Jack Laverick Jack.laverick@strath.ac.uk

What is StrathE2E?

StrathE2E[1] is an end-to-end marine food web model that simulates the flow of nitrogen through the full marine ecosystem - from dissolved inorganic nutrients and plankton, through benthic communities and fish, to top predators including seabirds, seals, and cetaceans. Similar species are grouped into functional groups, with ecologically important processes explicitly represented including feeding, metabolism, reproduction, and migration, capable of producing trophic cascades. Fishing fleets are also included, allowing harvesting, discarding, and seabed abrasion to be explored alongside ecological dynamics.

Critically, StrathE2E is designed to run on a “standard” computer, allowing large numbers of "what if" scenarios to be explored rapidly, making it accessible to researchers, managers, and policymakers without specialist computing infrastructure.

Key features

- *End-to-end nitrogen-based food web spanning dissolved nutrients to seabirds, seals, and cetaceans*
- *Computationally efficient design enabling rapid scenario exploration and global sensitivity analysis on a standard laptop*
- *Represents 12 fishing fleets simultaneously, tracking landings, discards, and seabed abrasion alongside ecological dynamics.*

Typical applications

- *Whole food web consequences of fisheries management policy*[2]
- *Long-term climate change impacts on whole food webs including top predators*[3]
- *Ecosystem-scale assessment of offshore wind farm impacts on seabirds and the wider food web*[4]

Model Fact Sheets

StrathE2E

KEY OUTPUTS.....

- Biomass estimates across all functional groups under multiple scenarios
- System-wide ecosystem health and service indices
- Trade-off analyses across fisheries, conservation, and development objectives
- Optimal management strategies identified through multi-scenario targeting

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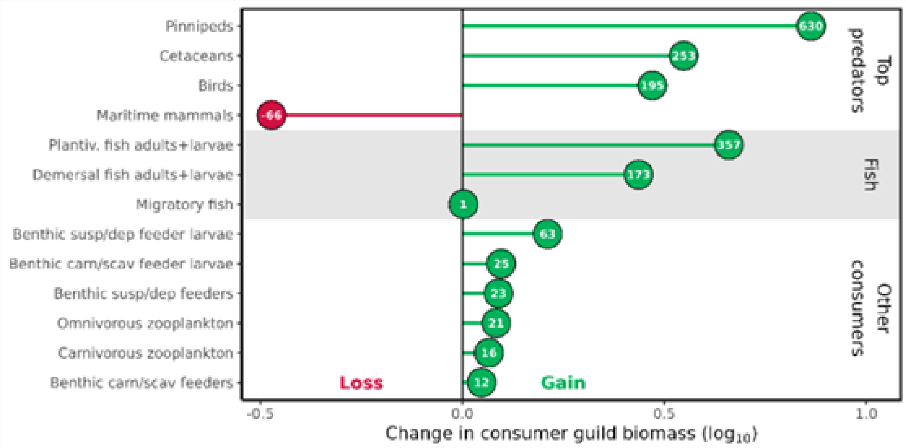
How StrathE2E works

StrathE2E is driven by hydrodynamic and biogeochemical data from coupled ocean circulation models such as FVCOM-ERSEM, alongside seabed habitat maps, field data, and fisheries data from national reports and international datasets including the Scientific, Technical and Economic Committee for Fisheries (STECF). These inputs drive a network of coupled differential equations describing the transfer of nitrogen mass between ecosystem compartments - the functional groups and resource pools representing different parts of the food web. Scenarios are tested by translating management or climate narratives into model inputs, for example, modifying fishing effort, applying climate projections, or representing the disturbance effects of MAS on feeding and migration.

Outputs are delivered as CSV files and can be post-processed into time series and scenario comparison reports. An online web app allows scenario experimentation without coding.



Projected percentage change in consumer guild biomass across functional groups under climate change, simulated using StrathE2E. Numbers indicate percentage change relative to the baseline period. Results show biomass gains across most fish and top predator groups, with the exception of maritime mammals

Why StrathE2E?

StrathE2E complements the other VALMAS models by operating at the whole ecosystem scale, representing trophic cascades from nutrients to top predators including seabirds, seals, and cetaceans. While Mizer captures size-structured fish community dynamics and EwE resolves species-level food web interactions, StrathE2E provides the big-picture ecosystem context within which those dynamics operate, supporting assessment of marine ecosystem services and long-term consequences of MAS deployment under climate change

Uncertainty and validation

Uncertainty is addressed by running simulations many times with slightly different parameter sets, generating credible intervals weighted by how well the model reproduces observed data. Target observations for validation include satellite-derived primary production, stock assessment biomass estimates, and scientific trawl survey data. Simulations are typically run to a steady state, isolating the effect of individual management choices from uncertainty in initial conditions. It is possible to use StrathE2E for transient (non-steady state) analyses for short-term and transitional questions as well.

References

1.Heath, M.R., Speirs, D.C., Thurlbeck, I. and Wilson, R.J., 2021. StrathE2E2: an R package for modelling the dynamics of marine food webs and fisheries. Methods in Ecology and Evolution, 12(2), pp.280-287.

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Acronym List

VALMAS	Value of Marine Artificial Structures (project name)
FVCOM	Finite-volume community ocean model (model name)
ERSEM	European Regional Seas Ecosystem Model (model name)
PYLAG	Python Lagrangian tracker (model name)
CSSM-MIZER	Community size-spectrum model – mizer (model name)
EwE	Ecosim with Ecopath (model name)
StrathE2E	Strathclyde End-to-End (model name)
MAS	Marine artificial structures
FVCOM-ERSEM	Coupled configuration of FVCOM and ERSEM, linking hydrodynamic and biogeochemical processes.
ADCP	Acoustic Doppler Current Profiler (equipment for measuring current speeds/directions)
CTD	Conductivity-Temperature-Depth Profiler (equipment for assessing physical properties of the water column)
FABM	Framework for Aquatic Biogeochemical Models - a standard interface for coupling biogeochemical models to hydrodynamic models.
NetCDF	Network Common Data Form - a standard file format for storing and sharing scientific array-oriented data.
GOTM	General Ocean Turbulence Model: a one-dimensional water column model providing turbulence closure schemes for vertical mixing
NEMO	Nucleus for European Modelling of the Ocean: a three-dimensional ocean circulation model used for shelf sea and global ocean applications
HTL	Higher trophic level - organisms that feed at or above the level of zooplankton, broadly encompassing fish and larger marine predators.
ROMS	Regional Ocean Modelling System: a three-dimensional ocean circulation model widely used for coastal and regional sea applications.
CMEMS	Copernicus Marine Environment Monitoring Service: a European programme providing free access to ocean data and model products for the global ocean and European seas.
PML	Plymouth Marine Laboratory (research institution)
STECF	Scientific, Technical and Economic Committee for Fisheries: an EU advisory body providing scientific advice to support the Common Fisheries Policy and marine environmental legislation.