ASSESSING MARINE ARTIFICIAL STRUCTURE IMPACTS ACROSS SCALES: THE VALMAS MODEL ENSEMBLE APPROACH

VALMAS is a £5.6M research programme funded by NERC and the INSITE Industry Consortium, developing evidence-based tools to sustainably manage, operate, and decommission Marine Artificial Structures (MAS). It supports a just, nature-positive energy transition that safeguards biodiversity, fisheries, and carbon sequestration. The focus is the North Sea, with an approach transferable to other regions.
The Research Theme **'Multiscale Impact Modelling and Future Scenario Assessments'** applies an ensemble of coarse-to-high resolution models. By integrating multisource data, it examines biogeochemical, connectivity, biodiversity, carbon, fisheries, and contaminant impacts across co-designed climate, sector, and policy scenarios. Shared forcing and inputs ensure each model contributes a complementary perspective.

StrathE2E: an end-to-end food web model of a full marine ecosystem

Key Features

- End-to-end nitrogen-based food web from dissolved nutrients to seabirds and mammals
- Rapid scenario exploration and sensitivity analysis
- Represents 12 fishing fleets, tracking landings, discards, and seabed abrasion

In VALMAS, StrathE2E explores system-scale effects of MAS under present-day and future climate scenarios, with new measures of ecosystem services and offshore structures linked directly to model parameters.

Key Outputs

- Biomass of all functional guilds from plankton to top predators under different scenarios
- Indices of ecosystem health and ecosystem service provision
- Trade-off analyses across fisheries yields, conservation targets, and development pressures
- Optimal management strategies for defined target outcomes
- Online app for scenario experimentation without coding

FVCOM: simulating hydrodynamics within complex shelf-sea domains

Key Features

- Unstructured mesh resolves complex coastlines and nearshore features
- Simulates tides, wind-driven circulation and stratification
- Couples to ecosystem and particle-tracking models via standard interfaces

In VALMAS, FVCOM provides the hydrodynamic foundation for the modelling framework, simulating local changes to circulation, vertical mixing, and near-bed shear stress due to MAS. Scenarios explore system sensitivity to future climate and MAS deployment.

Key Outputs

- High-resolution currents, water levels, temperature, salinity, and stratification
- Effects on productivity, habitat and biodiversity (when coupled with ERSEM)
- NetCDF outputs → maps, transects, and time series for analysis and stakeholder communication

ERSEM: simulating nutrient and carbon cycling through the lower trophic levels

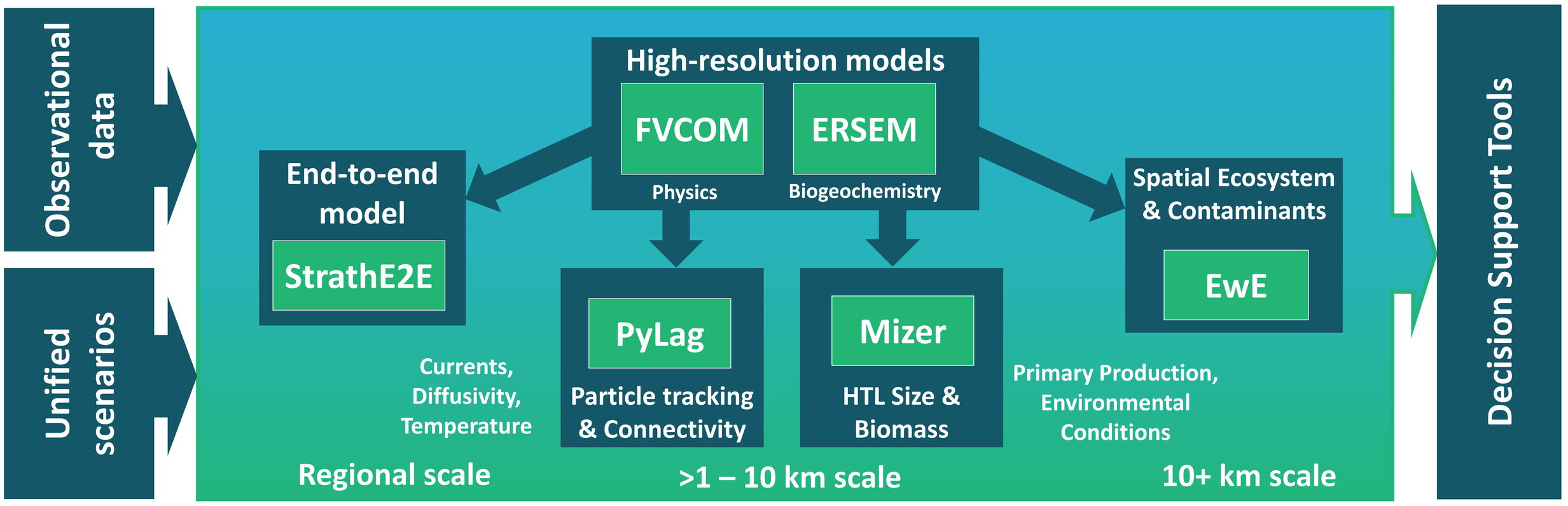
Key Features

- Dynamic stoichiometry allows organisms to adjust internal nutrient ratios to environmental conditions
- Resolves the microbial loop and benthic-pelagic coupling
- Represents epifaunal colonisation of MAS and associated biogeochemical feedbacks

In VALMAS, ERSEM simulates MAS impacts on lower trophic level ecosystems. Outputs feed Mizer, EwE, and StrathE2E to drive their ecosystem dynamics, supporting wider assessments of carbon cycling, fisheries productivity, and biodiversity under climate and deployment scenarios, informing planning, conservation, and management.

Key Outputs

- Patterns of primary production and plankton biomass
- Nutrient and carbon cycling in the water column and seabed
- Air-sea fluxes, benthic-pelagic coupling processes
- Epifaunal biomass growth on MAS, including effects on nutrient and organic matter cycling



PyLag: simulating the transport and dispersal of particles

Key Features

- 3D particle tracking with vertical migration, settlement behaviour, and mortality
- Ensemble and scenario simulation capability
- MPI parallelisation for large particle sets

In VALMAS, PyLag and FVCOM combine to model MAS as interacting ecological systems, identifying larval exchange pathways, stepping-stone connections, and connectivity hotspots – revealing when clusters of structures function as synthetic archipelagos. This evidences the ecological value of MAS and informs marine spatial planning and biodiversity management. Particle behaviour parameters are calibrated against species-specific larval data. Outputs support informed MAS network design.

Key Outputs

- Particle trajectories (latitude, longitude, depth, time) across the simulation
- Connectivity matrices, dispersal kernels, and residence-time estimates from trajectory analysis

Mizer: a size-spectrum of biomass and structure of higher trophic levels (HTL)

Key Features

- Size-based approach tractable across broad spatial and temporal scales
- Community size structure resolved via the size spectrum slope – an indicator of ecosystem state and fishing impact
- Forced by temperature and primary production, linking physical and biogeochemical conditions to HTL dynamics

In VALMAS, Mizer receives hydrodynamics, temperature, and plankton biomass from FVCOM-ERSEM to resolve HTL biomass across size classes and assess how MAS alter community structure. Outputs inform ecological assessments (community health and composition) and socio-economic evaluations (fisheries productivity and spillover effects), supporting decision-making on MAS.

Key Outputs

- Spatial maps of total HTL biomass and time series across size classes, seasonal to decadal
- Maps of size spectrum slope as an indicator of community structure and ecosystem state

Ecopath with Ecosim: multi-species food web model

Key Features

- Four components: Ecopath (mass-balance), Ecosim (time dynamics), Ecospace (spatiotemporal dynamics), and Ecotracer (contaminants)
- From single species (e.g. cod) to an age class (e.g. juvenile cod) to broader assemblages (e.g. demersal fish)
- Couples with hydrodynamic-biogeochemical model outputs

In VALMAS, EwE is applied to the greater Moray Firth, an area of high MAS density. It receives forcing from FVCOM-ERSEM and observed contaminant data to simulate accumulation of substances such as mercury released from MAS.

Key Outputs

- Species biomass, fisheries catches, and predator-prey dynamics over time and space
- Indicators of ecosystem health
- Contaminant burden estimates by functional group and trophic level
- Ecosystem change in response to MAS presence, fishing, and climate scenarios

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VALMAS: Decision Support Tools for Marine Artificial Structures

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The VALMAS (The Value of Marine Artificial Structures) suite of decision support tools (DSTs) is being developed to evaluate the environmental, social, and economic implications of marine artificial structures (MAS) across a range of future marine management scenarios. The integrated VALMAS decision-support framework combines ecosystem modelling, evidence synthesis, spatial optimisation, marine net gain approaches, and federated data systems to support sustainable and evidence-based decision-making throughout the full lifecycle of marine infrastructure — from construction and operation through to decommissioning. The tools are being co-developed with stakeholders to ensure accessibility, transparency, and practical value for policy, industry, and environmental management.

VALMAS Core Operational Decision Support Tool Suite

ASPACE

ASPACE (Assisted Planning Addressing Climate Effects) is an AI-assisted spatial prioritisation platform designed to support climate-resilient and socially acceptable marine spatial planning.

The tool enables users to:

- Identify climate-resilient spatial management opportunities
- Assess environmental, economic, and ecosystem service outcomes
- Evaluate how MAS scenarios align with stakeholder values and policy priorities

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ORIES

ORIES (Offshore. Renewable Impacts on Ecosystem Services) is an interactive evidence synthesis platform that collates environmental, social, and economic evidence related to marine artificial structures.

The tool enables users to:

- Interrogate global evidence databases
- Explore spatial evidence layers
- Compare ecosystem service outcomes of MAS
- Evaluate impacts across MAS phases and pressures
- Support evidence-based marine planning, policy development, and impact assessment.

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StrathE2E (web app)

The StrathE2E web application provides an accessible interface for exploring StrathE2E model outputs, scenario comparisons, and ecosystem-scale trade-offs to support sustainable marine management and evidence-based decision-making.

The tool enables users to:

- Explore StrathE2E ecosystem model outputs
- Compare alternative MAS development scenarios
- Assess ecosystem-scale trade-offs
- Examine climate and fisheries pressures

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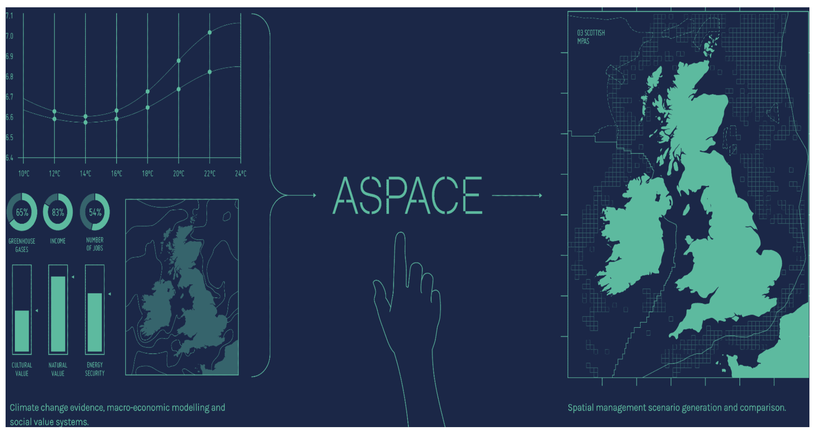

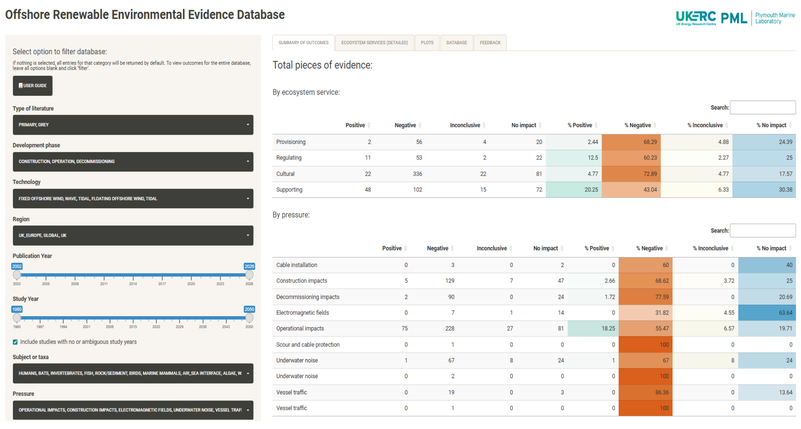

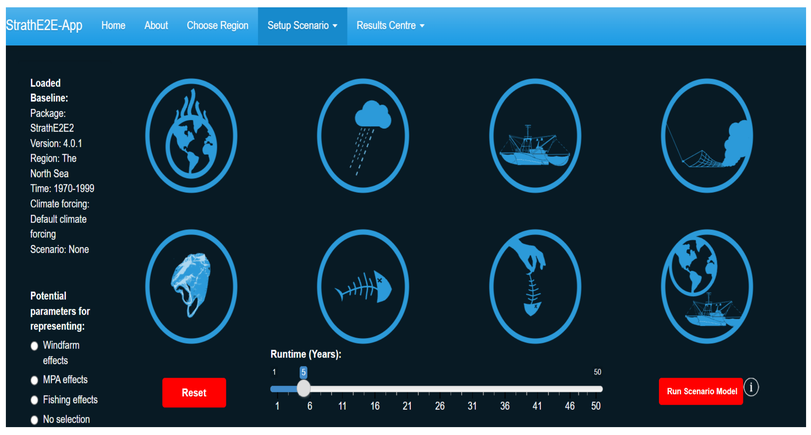

VALMAS Decision Support Tools and Frameworks in Development

Marine Net Gain Tool

A Marine Net Gain (MNG) tool will be developed within VALMAS to explore mechanisms for balancing ecological impacts from marine development through restoration, enhancement, and compensatory measures.

The framework and tool will evaluate:

- Supply and demand for marine net gain measures
- Habitat equivalence metrics
- Strategic compensation approaches
- Market-based delivery mechanisms

The tool will support transparent nature positive assessment of trade-offs and opportunities for sustainable marine development.

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VALMAS Digital Twin Framework

VALMAS is exploring how decision support tools and datasets can connect within future marine digital twin frameworks.

The digital twin concept links:

- Real-world observations
- Numerical models
- Environmental monitoring
- Decision-support tools
- Adaptive management processes

The framework supports improved data collection, scenario testing, and evidence-based marine decision-making

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Federated FAIR Data Architecture

VALMAS is developing a federated data architecture to integrate environmental, ecological, modelling and socio-economic datasets across the programme.

The federated approach enables:

- FAIR (Findable, Accessible, Interoperable, Reusable) access of *right-time* data
- Integration of models, observations, and evidence databases
- Scalable decision-support infrastructure

Rather than storing all data in one location, the federation layer connects distributed data products through common governance and metadata standards.

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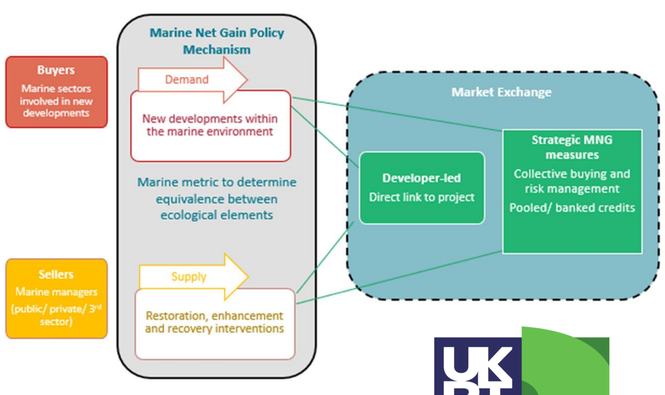

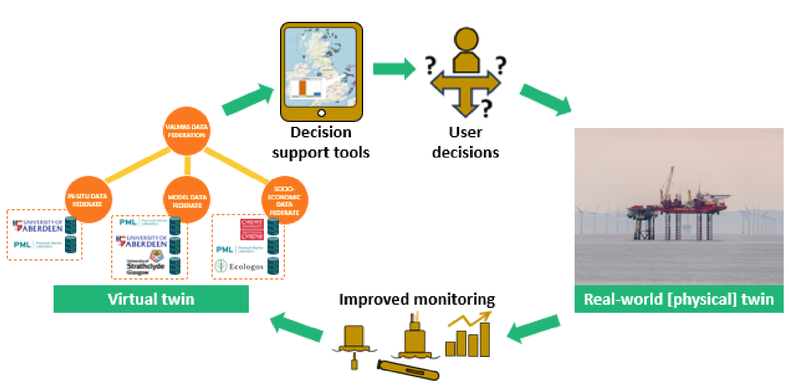

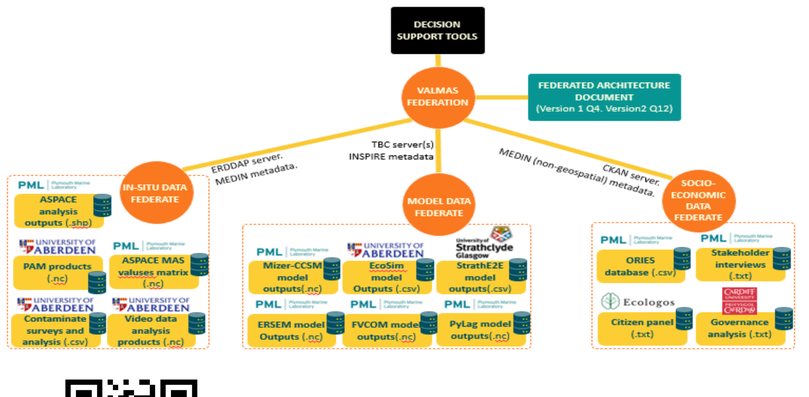

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