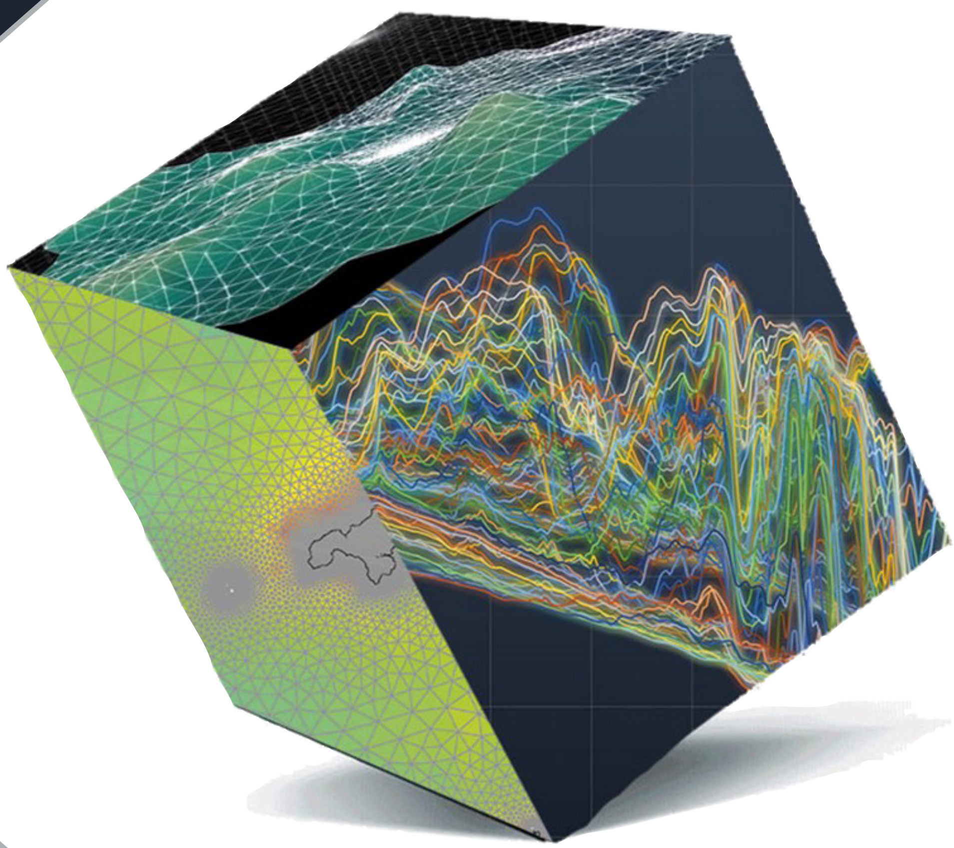
PML | Publishing

7th Conference of Advances in Marine Ecosystem Modelling Research

Plymouth, United Kingdom | July 8 – 12, 2024

Conference Proceedings and Book of Abstracts



PML | Plymouth Marine Laboratory

AMEMR 2024
8th -12th July, Plymouth UK

The AMEMR (**Advances in Marine Ecosystem Modelling Research**) **Symposium series provides an opportunity to present, discuss and learn about a wide variety of marine modelling challenges, methods, applications and outcomes.**

Held approximately every three years and now in its 7th iteration, AMEMR has grown into the forum to present and absorb the latest developments in marine (eco)system modelling and discuss new challenges and opportunities. Modelling is a fundamental tool for understanding marine ecosystems and providing projections of potential future states of the environment. Marine modelling is continuously evolving, in response to new scientific knowledge, techniques and societal needs. AMEMR promotes interdisciplinary discussion among stakeholders and modelling, observational and experimental scientists and students who want to contribute to the conceptualisation, design, development and application of improved and new marine ecosystem models of all types. We emphasize networking, discussion and encourage a strong ECR involvement.

The AMEMR Conference is organised by Plymouth Marine Laboratory

endorsed by the UN OCEAN DECADE

financially supported by SCOR, the Scientific Committee on Ocean Research

and hosted by the University of Plymouth

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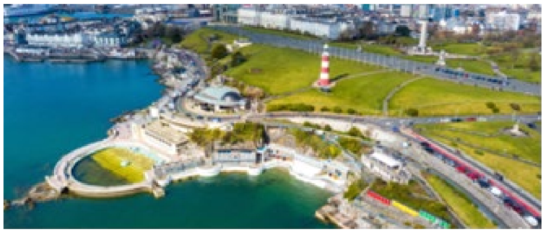
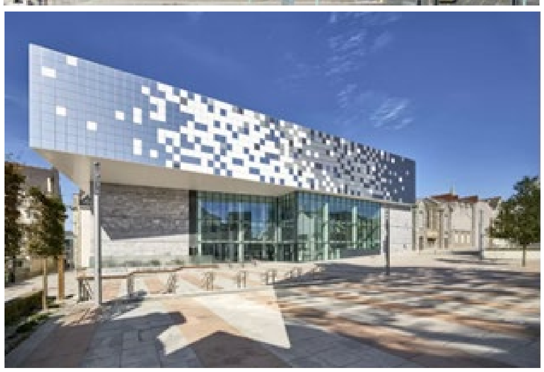
Venues and Locations



Location: In Plymouth, UK, Britain's Ocean City and site of the UK's first National Marine Park. https://www.visitplymouth.co.uk/

The conference: the University of Plymouth Roland Levinsky building (https://www.plymouth.ac.uk/facilities/roland-levinsky-building). This has a great space for posters combined with lunch and refreshments, such that the posters are accessible throughout the conference.

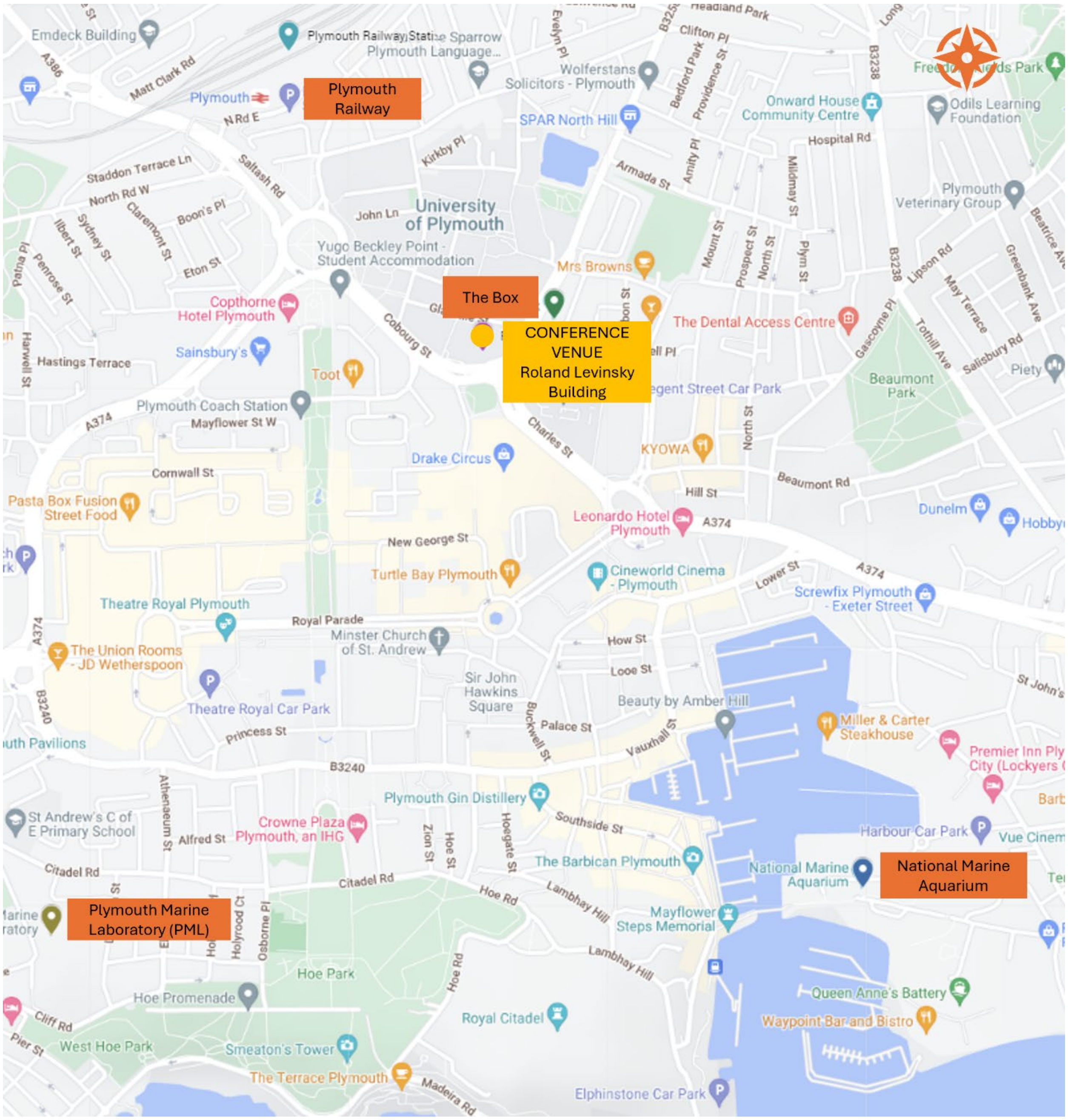


The welcome reception will be held in The Box, Plymouth's new art gallery and museum, https://www.theboxplymouth.com/ on the Monday evening.

Conference meal at the National Marine Aquarium, UK's Largest Aquarium | The National Marine Aquarium (national-aquarium.co.uk) in front of the Eddystone exhibit tank – the largest single viewing panel in the UK.

The **Modelling Workshop** on Friday 12th will be held at Plymouth Marine Laboratory, a world leader in the field of marine research, committed to the delivery of impactful, cutting-edge environmental science in support of a healthy and sustainable ocean.

Venues Map

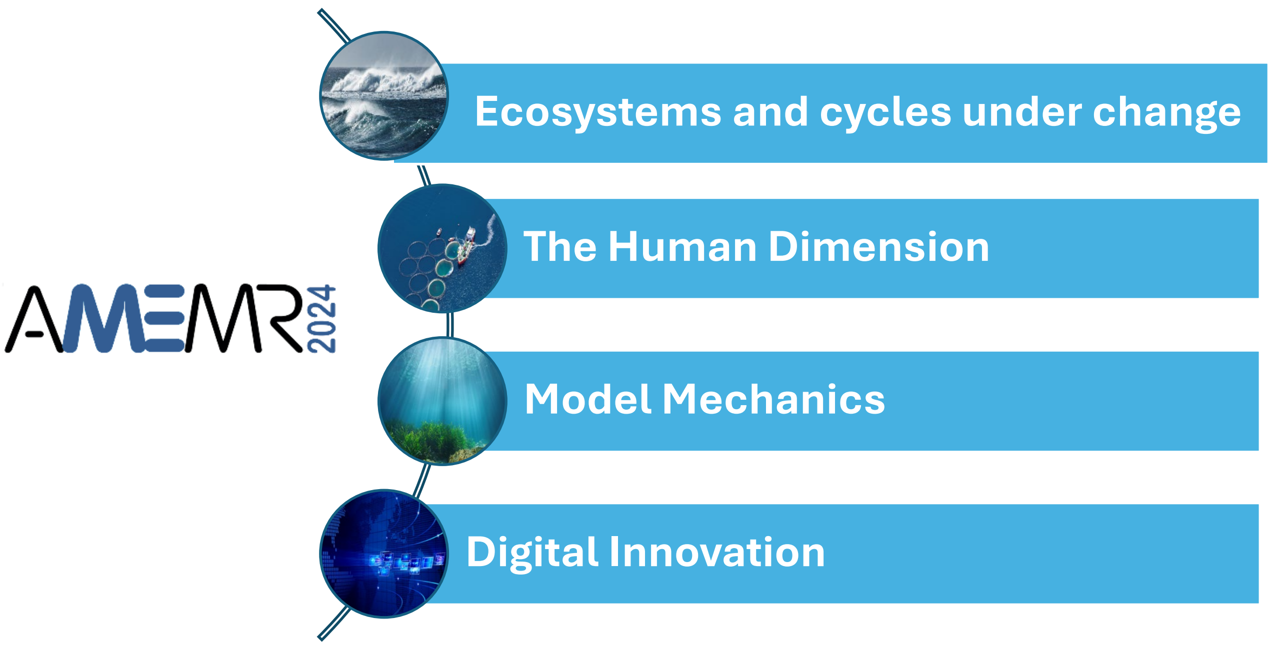


Plymouth Railway
The Box
CONFERENCE VENUE Roland Levinsky Building
National Marine Aquarium
Plymouth Marine Laboratory (PML)
University of Plymouth
Drake Circus
Theatre Royal Plymouth
Plymouth Coach Station
Hoe Park
Royal Citadel
Smeaton's Tower
The Barbican Plymouth

AMEMR 2024 Themes

AMEMR welcomes all submissions that use modelling (in the broadest sense) approaches to better understand and predict marine ecosystems and support marine sustainability. The conference is organised into four over-arching and interconnected themes: Ecosystems and cycles under change, Model mechanics, The Human Dimension, and Digital Innovation.

Cross-cutting all of our themes is a consideration of the key drivers of our work – climate, sustainable development goals, ocean decade goals and a long list of stakeholders, including Policy makers, Regulators, Indigenous peoples, Artisan users, Industry, the Public, Academia, Education and not least ourselves as marine modellers.



The following pages give a succinct overview of the themes and the key sub-themes that will be explored at AMEMR.

Theme 1: Ecosystems and cycles under change

How do our ecosystems and biogeochemical cycles respond to change, in particular to climate warming and associated processes.

- **Ecosystem response to perturbation** (e.g. resilience, plasticity, tipping points).
- **Coastal and Ocean Carbon Cycles** (e.g. mechanisms, feedback and mitigation, carbon pumps).
- **Other critical cycles in a climate and anthropogenic context** (e.g. deoxygenation, acidification, eutrophication).
- **Impacts from climate change and extreme events** (e.g. heatwaves, storms, run off).
- **Integration of Ocean, Land and Atmospheric processes** (e.g. land – ocean – atmospheric coupling).

Theme 2: The Human Dimension

This theme covers the more direct interactions, needs and impacts of humans on the marine System.

- **Socio-ecological interactions** (e.g. human and social processes in models).
- **Impacts of ocean exploitation** (e.g. windfarms, trawling, mining).
- **Ocean Resources and Ecosystem Services** (e.g. fisheries, aquaculture, pollution remediation, blue carbon).
- **Policy support and Marine Spatial Planning** (e.g. models for assessment and planning).
- **Communication** (e.g. using model derived information to communicate to stakeholders effectively).

Theme 3: Model Mechanics

This theme covers the processes and components that may (or may not) matter.

- **Accounting for biodiversity, evolution, adaptation, and behaviour** (e.g. aspects that tend not to be included in traditional models).
- **Trophic interactions** (zooplankton, mixotrophs, viruses, competition and more)
- **Parameterizing physiology** (physiological realism vs. tractable code)
- **Ecological Connectivity and spatio-temporal pattens** (physically mediated interactions, lagrangian approaches)
- **Complexity and Simplicity** (which processes matter when, learnings from model-data mismatches)
- **Are our models theoretically fit for purpose?**

Theme 4: Digital Innovation

How can we use new technologies effectively and responsibly to better understand and reduce uncertainty?

- **Digital twins, decision support tools** (aspiration vs pragmatism, examples in practice)
- **Innovative approaches, Artificial Intelligence, Machine Learning, Emulators** (capability and limitations)
- **Advances in data assimilation** (new products for stakeholders)
- **Hybrid Model and Data Approaches** (data – model fusion, autonomy)
- **Evaluation and skill** (how do we convince the audience including ourselves)

Early Career Researcher (ECR) Activities

ECR Mentoring

Mentoring sessions will be run before the conference on the following themes:

1. Caregiving as an ECR - 2nd of July
2. Mental health and work-life balance as an ECR - 3rd of July
3. Building your career as an ECR (to include both linear career paths and broader career wiggles – 4th of July.

Sunday, 7th of July - Sunday ECR icebreaker

This will be an informal gathering for ECRs arriving at the conference to have a chance to meet before the main programme begins on Monday 8th July.

At 16.00-17.30 we are planning to meet on the Plymouth Hoe, near the lighthouse. This will be for conversations on the grass overlooking Plymouth Sound, with optional icebreaking activities. If the forecast is for rain (as it often is in Plymouth) we will make alternative plans: the exact location of the meet-up will be confirmed on Friday 5th July.

We will then walk over to the Stable, on the Barbican, aiming to be there from 18.00 onwards for dinner. N.B. this is not an official AMEMR event and therefore is not funded by the conference.

Tuesday, 9th of July - ECR Coffee meet and greet

We would like to invite ECRs and mentors to coffee and croissants (if you are still hungry) from 8am on Tuesday morning. Get to know each other and expand your network over delicious pastries in the foyer in Levinsky to kick off the second day of the conference.

ECR Poster and oral presentation prizes

ECR prizes for best posters and talks will be announced before the end of the conference to recognise individuals' outstanding research efforts. Both winners will be selected by the ECRs present, so don't forget to have your say!

AMEMR Modelling Workshop

Introduction to new capabilities in marine biogeochemical and ecosystem modelling

Date: Friday, 12th July 2024
Time: 09:00 a.m - 1:00 p.m.
Venue: Plymouth Marine Laboratory

In collaboration with Horizon Europe projects NECCTON and OceanICU, on the morning of **Friday 12th July** we will be offering a **hands-on training workshop in ecosystem modelling** aimed at early career scientists as well as established researchers looking to expand their repertoire of models and tools. Participants will be able to explore ecosystem models of varying complexity (MOPS, ECOSMO, PISCES and ERSEM) and how to use them within water column (1D) and/or global (3D) simulations.

NECCTON
NEW COPERNICUS CAPABILITY FOR TROPHIC OCEAN NETWORKS

OceanICU
Understanding Ocean Carbon

AMEMR Committees

AMEMR is overseen by an international scientific steering committee who derive the themes, identify discussion topics, recommend keynote speakers and assess the abstract submissions. The SSC includes an early career group who play a full role and in addition organise the ECR focussed activities.

Scientific Steering Committee

Jerry Blackford – Plymouth Marine Laboratory, UK
Sevrine Sailley - Plymouth Marine Laboratory, UK
Luca Polimene - European Commission - Joint Research Centre, IT
Scott Condie - CSIRO, Australia
Bettina Fach – Middle East Technical University, Turkey
Kevin Flynn – University of Swansea, UK
Wendy Gentlemen - Dalhousie University, Canada
Stefano Ciavatta, Mercator Ocean International, FR
Liuqian Yu, Hong Kong University of Science and Technology, CN
Guttorm Alendal, University of Bergen, NO
Anitha Gera, NCCR, IN
Kira Krumhansl, Fisheries and Oceans, CA

Early Career Committee

Yaru Li - Plymouth Marine Laboratory, UK
Rebecca Millington - Plymouth Marine Laboratory, UK
Helen Powley - Plymouth Marine Laboratory, UK
Deniz Disa - METU IMS, TR
Javier Porobic Garate - CSIRO, AU
Samantha Grusd - UCT, SA

The task of organising the conference falls to the organising committee based at Plymouth Marine Laboratory

Organising Committee

Jerry Blackford – Plymouth Marine Laboratory, UK
Sevrine Sailley - Plymouth Marine Laboratory, UK
Helen Powley – Plymouth Marine Laboratory, UK
Rebecca Millington – Plymouth Marine Laboratory, UK
Yaru Li - Plymouth Marine Laboratory, UK
Jessica Heard - Plymouth Marine Laboratory, UK
Luz H Rodriguez-Vargas - Plymouth Marine Laboratory, UK
Leon Thompson (University of Plymouth)

Open consultation

UK marine ecosystem impacts under future climate scenarios.

In addition to the talks, posters and discussion sessions AMEMR hosted an open consultation managed by CEFAS on UK marine ecosystem, impacts under future climate scenarios.

The aim of this Defra* project is to characterize UK marine climate scenarios, collate ecosystem evidence and produce a roadmap of future needs. We at Cefas** are delivering the work in consultation with UK researchers.

We are joining the AMEMR conference to consult on the future needs and evidence required to further understand UK marine ecosystem impacts under future climate change. We are keen to gather information from both climate and ecosystem modelers regarding data, processing, tool, and capacity requirements.

During the AMEMR conference we will have a stand (in the refreshment and poster area) where you can contribute ideas and consider existing suggestions alongside discussing the project with us. We will also offer an online forum to engage during and after the session for those not able to attend and to capture further thoughts from attendees (link to be shared at the event).

We look forward to meeting you all and gathering your thoughts and ideas.

Dr Louise Rutterford (MRes, PhD)
Senior Scientist – International Marine Climate Change Centre (iMC[3])
Centre for Environment, Fisheries & Aquaculture Science (Cefas)

*Defra is the UK government Department for Environment, Food & Rural Affairs
**Cefas is Defra's Centre for Environment, Fisheries and Aquaculture Science

Cefas

AMEMR 2024 by numbers

Conference Agenda

The agenda is listed on the following pages, followed by the abstracts for each submission. During the conference there were a series of discussion sessions, some keynote led, some panel led covering some of the major challenges and opportunities for marine system modellers in the next decade.

Theme	Keynote Talks	Discussion Sessions
1	Wendy Gentleman: Uncertainty in modelled zooplankton: what matters and what to do	Panel: What can be done to make end-to-end models robust in the middle?
1	Kevin Flynn: Next generation plankton models; meeting the digital-twin challenge	Panel: Working with empiricists. How do we do a better job of convincing them that models are useful ?
2		Panel Led: Where and why has ecosystem modelling led to changed socio-economic practices and when/why has it failed?
2		Panel Led: How do we reduce and communicate uncertainty about climate-related changes to ecosystems?
3	Baris Salihoglu: Transforming the regional seas: Digital Twin Demonstrators	
3	Karen Wild-Allen: Digital twin simulations distinguish anthropogenic nutrient impacts from natural variability in a complex coastal ecosystem with salmon aquaculture	Discussion: Challenges and opportunities for AI in marine ecosystem research
4	Morten D Skogen: Bridging the gap: Integrating models and observations for better ecosystem understanding	Discussion: Novel kinds of observations that can be used to improve our models

Oral Presentations

Monday 8th of July

Theme 1 – Model Mechanics

09:00 Conference Introduction. ***Jerry Blackford***, Plymouth Marine Laboratory

Session 1 - Model Mechanics ***Chair – Gennadi Lessin, Rebecca Millington***

09:15 Modelling impact of climate change on distribution and population dynamic of marine megafauna a new dynamic modelling approach. ***Sevrine Sailley***. Plymouth Marine Laboratory.

09:30 Unveiling spatio-temporal dynamics of the Great Barrier Reef using connectivity kernels. ***Javier Porobic***. CSIRO – Environment.

09:45 Modelling the early marine migration of Atlantic salmon. ***Aislinn Borland*** University of Strathclyde.

10:00 Copepods in Arctic seas: implementing an effective dialogue between models and in situ imaging. ***Lucie Bourreau***. Université Laval.

10:15 Study of the influence of biogenic habitats on the distribution of Australian marine fauna. **Thomas Benoit**. Ifremer, DYNECO.

10:30 Break and Posters

Session 2 - Model Mechanics ***Chair – Yuri Artioli, Deniz Disa***

11:00 From physics to fish: impact of two-way coupling between a higher and lower trophic level model on carbon cycling on the Northwest European Shelf. ***Helen Powley***. Plymouth Marine Laboratory.

11:15 Trait-based modeling of marine mesozooplankton feeding strategies at global-scale. ***Lisa Di Matteo***. Sorbonne Université.

11:30 Simulating the relationship between zooplankton size and physiology in a global biogeochemical model, using the statistical method of moments. ***Camille Richon***. Sorbonne Université.

11:45 **Keynote Lecture 1** - Uncertainty in modelled zooplankton: what matters and what to do about it. ***Wendy Gentleman***. Dalhousie University.

12:05 **Discussion** - What can be done to make end-to-end models robust in the middle?
Panel: Morgane Travers-Trolet, Sevrine Sailley, Lucie Bourreau, Angus Atkinson

12:45 Lunch and Posters.

Session 3 - Model Mechanics ***Chairs: Morgane Travers-Trolet, Samantha Grusd***

13:45 Flash Presentations

14:00 An Individual-Based Model of Basking Sharks in Ireland. ***Chelsea Gray***. George Mason University.

14:15 Towards a Lagrangian Individual-Based Model for the Galician Octopus**.** ***Luz Garcia***. Centro Oceanográfico de A Coruña.

14:30 Building a novel spatialized model of regional seagrass dynamics: Coupling an ecological probabilistic Dynamic Bayesian Network with a deterministic regional ocean model. ***Carolyne Chercham***. Ifremer, DYNECO.

14:45 Bridging physiology and oceanography with thermal time to model biologically relevant time-scales in a changing climate. ***Anna Neuheimer***. Aarhus University.

15:00 Bioenergetics in the multispecies model Bioen-Osmose to reproduce past fish dynamics in the Bay of Biscay. ***Maël Gernez***. Ifremer.

15:15 Improving the reliability of food web and ecosystem models from individual life-cycle modelling. ***Pierre Bourdaud***. France Energies Marines.

15:30 *Break and Posters*

Session 4 - Model Mechanics ***Chairs: Jerry Blackford, Al Azhar***

16:00 Flash Presentations

16:15 Influence of low trophic levels resolution and dynamics on simulated fish community. ***Morgane Travers-Trolet***. IFREMER.

16:30 The power of first principles in ecological modelling. ***Ken Andersen.*** Technical University of Denmark.

16:45 **Keynote Lecture 2** - Next generation plankton models; meeting the digital-twin challenge. ***Kevin Flynn***. Plymouth Marine Laboratory.

17:05 **Discussion** - Working with empiricists. How do we do a better job of convincing them that models are useful.

Tuesday 9th of July

Theme – Model Mechanics

Session 1 - Model Mechanics ***Chairs: Liuqian Yu, Helen Powley***

09:00 Global distribution of non-cyanobacterial N2 fixers in sinking marine particles. ***Subhendu Chakraborty***. Leibniz Centre for Tropical Marine Research (ZMT).

09:15 Effects of ecosystem complexity on the air-sea CO2 flux in an ocean biogeochemistry model. ***Miriam Seifert***. Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung.

09:30 Control of carbon sequestration by the interaction between fishes and benthic fauna. ***Rebecca Millington***. Plymouth Marine Laboratory.

09:45 Integrated Nested Model Approach for Understanding the Transboundary Plastic Pollution in Norwegian Fjords. ***Prithvinath Madduri***. University of Bergen.

10:00 Spatialised ecosystem modelling to evaluate the influences of marine protected areas and provisioning ecotourism on the distributional response of top predators on the South-East coast of South Africa. ***Samantha Grusd***. University of Cape Town.

Theme – The Human Dimension

10:15 Co-producing knowledge with ocean industry stakeholders to understand the impact of activities on ocean carbon. **Fiona Culhane**. Marine Institute Ireland.

10:30 Break and Posters

Session 2 - The Human Dimension ***Chairs: Scott Condie, Lee de Mora***

11:00 Early-warning system: Climate-smart spatial management of UK fisheries, aquaculture and conservation. ***Ana Queiros***. Plymouth Marine Laboratory.

11:15 Bridging the Gap: Integrating Human Dimensions into Global Ocean Dynamic and Biogeochemistry Models. ***Katya Popova***. National Oceanography Centre.

11:30 Significant benefits from international cooperation over marine plastic pollution. ***James Clark***. Plymouth Marine Laboratory.

11:45 **Discussion:** Where and why has ecosystem modelling led to changed socio-economic practices and where and why has it failed (lessons learnt)?
Panel: Fiona Culhane, Ana Queiros, Katya Popova, James Clark

12:45 Lunch and Posters

Session 3 - The Human Dimension   Chairs: Susan Kay, Javier Porobic Garate

13:45 Flash Presentations

14:00 Modelling the influence of conservation zoning on the Great Barrier Reef ecosystem. ***Scott Condie***. CSIRO.

14:15 Use of the result of simulations with FVCOM in the zoning of a Multiple-Use Marine Protected Area (*Virtual presentation*). ***Sergio A. Rosales***. Universidad Católica del Norte.

14:30 Using social influence modelling to plot a pathway out of marine-based conflict. ***Corrine Condie***. CSIRO.

14:45 Modelling cross-jurisdictional management interventions for Australia's Great Southern Reef. ***Julia Sobol***. University of Tasmania.

15:00 Deriving pre-eutrophic conditions from an ensemble model approach for the North-West European Seas. ***Sonja van Leeuwen***. NIOZ.

15:15 Towards a trait-based modelling framework of seascape habitat features. ***Martin Marzloff***. Ifremer.

15:30 Break and Posters

Session 4 - The Human Dimension   Chairs: Sevrine Sailley, Paula Silvar

16:00 Potential impacts of offshore hydrogen production on seasonally-stratified coastal waters. ***Nils Christiansen***. Insitute of Coastal Systems, Helmholtz-Zentrum Hereon.

16:15 Cumulative effects of Offshore Windfarms on the future North Sea ecosystem. ***Ute Daewel***. Helmholtz-Zentrum Hereon.

16:30 From Shipping to the Ecosystem: A Coupled Model System Based on Observations Details the Influence of Scrubber Discharge to Support Marine Environmental Protection Measures. ***Christoph Stegert***. Bundesamt für Seeschifffahrt und Hydrographie.

16:45 Exploring fish aggregation dynamics in POSEIDON, an Agent-Based Model, by simulating the Eastern Pacific Ocean tropical tuna fishery. ***Alexandra Norelli***. University of Oxford.

17:00 Advancements in Modelling Early Life Stages: A focus on Atlantic Iberian Sardine. ***Adrian Sanjurjo***. Centro Oceanográfico de A Coruña (COAC - IEO), CSIC.

17:15 Is harvesting of mesopelagic fish stocks sustainable? ***Douglas Speirs.*** University of Strathclyde.

17:30 Posters Reception and Posters

Wednesday 10th of July

Theme - Ecosystems and cycles under change

Session 1* - Ecosystems and cycles under change *Session 1
Chairs: Wendy Gentleman, Robert Wilson

09:00 Agent-based models for modelling small pelagic population dynamics and life-histories traits. ***Elisa Donati***. National Institute of Oceanography and Applied Geophysics.

09:15 Dissolved organic carbon dynamics in a changing ocean: A COBALTv2 Earth System Model analysis. ***Lana Flanjak***. Climate and Environmental Physics, Physics Institute, University of Bern.

09:30 Evaluating impacts of climate and human pressures on primary production, with implications for management. ***Solfrid Hjøllo.*** Institute of Marine Research.

09:45 Modelling thermal niche of marine calcifying zooplankton from past to future. ***Rui Ying***. University of Bristol.

10:00 Marine heatwaves & cold spells around the UK: a cause for concern for marine ecosystems & the blue economy?. ***Zoe Jacobs***. National Oceanography Centre.

10:15 Extreme and compound ocean events are key drivers of projected low pelagic fish biomass. ***Natacha Legrix***. Oeschger Centre for Climate Change Research, University of Bern.

10:30 Break and Posters

***Session 2* - Ecosystems and cycles under change**
Chairs: Iris Kriest, Bettina Fach

11:00 Emergent ecosystem distributions from 100-model simulations with the PlankTOM12 model. ***Rebecca Wright***. University of East Anglia.

11:15 Climate change may unleash the ghost of past species' ecological niches. ***Mathieu Chevalier***. Ifremer.

11:30 **Discussion:** How do we reduce and communicate uncertainty about climate-related changes to ecosystems?
Panel: - Zoe Jacobs, Mathieu Chevalier, Yuri Artioli Kelly Ortega-Cisneros

12:30 Lunch and posters

***Session 3* - Ecosystems and cycles under change**
Chairs: Dale Partridge, Hermann Lenhart

13:30	Variability and Future Trends in Chlorophyll-a Concentration Across Coastal Upwelling Systems. ***Shailee Patel***. National Oceanography Centre.
13:45	Variability of annual primary production in the North Sea from 1983 to 2014: diatoms and non-diatoms show different trends. ***Johannes Pätsch***. Institute of Carbon Cycles, Helmholtz-Zentrum Hereon.
14:00	Observations and biogeochemical modeling reveal chlorophyll diel cycle with near-sunset maxima in the Red Sea. ***Yixin Wang***. King Abdullah University of Science and Technology (KAUST).
14:15	Impacts of Climate Change on the Ascension Island Marine Protected Area and its Ecosystem Services. ***Lee de Mora***. Plymouth Marine Laboratory.
14:30	Modelling global carbon fluxes and sequestration from fish. ***Yixin Zhao.*** Center for Ocean Life, DTU Aqua, Technical University of Denmark.
14:45	Potential continental shelf carbon sequestration by a harvested fish species. ***Paula Silvar***. Marine Institute Ireland.
15:00	Break and Posters

Session 4 - Ecosystems and cycles under change
Chairs: Luca Polimene, Helen Powley

15:30	Impact of Pacific Ocean heatwaves on phytoplankton community composition (*Virtual presentation*). ***Lionel Arteaga***. NASA GSFC.
15:45	Modelling the complete life cycle of an arctic copepod reveals complex trade-offs between concurrent life cycle strategies. (*Virtual presentation*) ***Catherine Brennan***. Bedford Institute of Oceanography, Fisheries and Oceans Canada.
16:00	Quantification of Carbon Fluxes along a Gradient from the Wadden Sea Lagoon to the North Sea and Atlantic Ocean. ***Anouk Blauw***. Deltares.
16:15	SISSOMA: A mechanistic approach in modelling the dynamics of marine aggregates. ***Athanasios Kandylas.*** DTU Aqua.
16:30	A coupled phytoplankton-flocculation model to quantify suspended particulate matter dynamics on the Belgian shelf. ***Nathan Terseleer***. Institute of Natural Sciences.

16:45 Modelling sediment-water fluxes: impacts on water column biogeochemistry in a large eutrophic estuary. ***Zheng Chen***. The Hong Kong University of Science and Technology (Guangzhou).

Thursday 11th of July

Session 1 - **Ecosystems and cycles under change**
Chairs: Katya Popova, Yaru Li

09:00	Impact of Tropical Storms on the Alkalinity of Two Contrasting Tidal Tributaries in a Coastal Plain Estuary. ***Alexa Labossiere***. Virginia Institute of Marine Science, William & Mary.
09:15	Assessing climate change impacts in the Southern Benguela: a model inter-comparison. ***Kelly Ortega Cisneros***. University of Cape Town.
09:30	IRMA: An index to predict mass fish mortality during harmful algal blooms in tropical estuaries. ***Jose Ernesto Mancera Pineda***. Universidad Nacional de Colombia.
09:45	Development of a three dimensional multispecies small pelagic fish model for the Mediterranean Sea. ***Thanos Gkanasos***. HCMR, Institute of Oceanography.
10:00	Assessing the impacts of climate change and fishing on the ecosystem's state and its resilience in the Celtic Sea. ***Mikaëla Potier***. Institut Agro, Ifremer.
10:15	Impacts of environmental pressure on the survival of early life stages of the European Smelt using an Individual-based modelling approach. ***David Drewes***. Helmholtz-Zentrum hereon.
10:30	Break and Posters

Theme - Digital innovation

Session 2 – Digital Innovation ***Chairs: Kevin Flynn, Jim Clark***

11:00	**Keynote Lecture 3**: Can digital twins help define a safe operating space for the seas? Transforming the regional seas: Digital Twin Demonstrators. ***Baris Salihoglu.*** Middle East Technical University.
11:20	**Keynote Lecture 4**: Digital twin simulations support resource management decisions in a complex coastal ecosystem with salmon aquaculture. ***Karen Wild-Allen***. CSIRO Environment.
11:40	**Discussion** - Challenges and opportunities for AI in marine ecosystem research
12:20	Lunch and Posters

Session 3 – Digital Innovation ***Chairs: Guttorm Alendal, Marius Dewar***

13:20	New reanalysis for ecosystem indicators with ensemble-based uncertainty estimates in the UK regional waters. ***Jozef Skakala***. Plymouth Marine Laboratory.
13:35	Evaluating the skill of hybrid statistical species distribution models trained with mechanistic model output. ***Dante Horemans***. Virginia Institute of Marine Science, William & Mary.
13:50	A dual machine learning and mechanistic approach to modelling future zooplankton prey for forage fish. ***Emma Tyldesley***. University of Strathclyde.
14:05	Parameterizing 3D Marine Biogeochemical Models: Surrogate-Based Optimization for Parameter Estimation and Performance Enhancement. ***Hoa Nguyen***. Helmholtz Zentrum hereon.
14:20	Delineating robust cores in marine spatial structure: Applications to Atlantic sea scallop (*Placopecten magellanicus*) connectivity. ***Karsten Economou***. Department of Engineering Mathematics and Internetworking, Dalhousie University.
14:35	Benefit of assimilating BGC-Argo observations for investigating the air-sea CO2 flux in the Southern Ocean. ***Andrea Rochner.*** Met Office.
14:50	A solution for autonomous, adaptive monitoring of coastal ocean ecosystems: Integrating ocean robots and operational forecasts. ***David Ford***. Met Office.
15:05	Break and Posters

Session 4 – Digital Innovation ***Chairs: Stefano Ciavatta, Andrea Rochner***

15:30	Representing uncertainties in global (calcifying) phytoplankton stocks***. Joost de Vries***. University of Bristol.
15:45	Review of the Copernicus Marine Service Global biogeochemical reanalysis : modelling, Ocean Color and Carbonates data assimilation and validation against BGC-Argo-based in situ datasets. ***Coralie Perruche***. Mercator Ocean.
16:00	**Keynote Lecture 5** - Bridging the gap: Integrating models and observations for better ecosystem understanding. ***Morten D Skogen***. Institute of Marine Research.
16:20	**Discussion** - Novel kinds of observations that can be used to improve our models.
16:50	Closing remarks - Jerry Blackford
17:00	End of sessions
18:15	Doors open at National Marine Aquarium
19:00	Conference Dinner – National Marine Aquarium

Posters

Theme - Ecosystems and cycles under change

1 Modelling offshore benthic blue carbon. ***John Aldridge***. CEFAS

2 Modelling ecosystems and fisheries in the Bazaruto Archipelago, Mozambique, using Ecopath with Ecosim (EwE). ***Darcie Anderson***. University of Cape Town.

3 How climate-driven changes in primary production, physiological rates and non-indigenous species will affect the Eastern English Channel-Southern North Sea (EEC-SNS) ecosystem structure and functioning by 2050.? ***Emma Araignous***. France Energies Marines.

4 Modelling ecosystem impact of offshore wind farm structures in the Northwest European shelf. ***Muchamad Al Azhar***. Plymouth Marine Laboratory.

5 Spatio-Temporal variability of Chla and phytoplankton functional types (PFTs) from satellite ocean color data in the Bay of Bengal. ***Imtiaj Ahmed Easty***. Noakhali Science and Technology University.

6 Impact of cross-shelf exchange events on eutrophication and primary production variability in the Black Sea. ***Bettina Fach***. Middle East Technical University.

7 Two-way physics-biogeochemistry coupling constrained by ocean colour data assimilation. ***David Ford***. Met Office.

8 A model-based analysis of summertime oxygen deficiency in the Elbe Estuary (Germany). ***Fabian Große***. Federal Institute of Hydrology.

9 Poor performance of regime shift detection methods in marine ecosystems. ***Hannah Haines***. AWI.

10 Modelling mid-21st century Chesapeake Bay hypoxia: The role of climate changes at the ocean, land, and atmospheric boundaries. ***Colin Hawes***. Virginia Institute of Marine Science.

11 Plankton community size structure in UK coastal waters. ***Greg Macmillan***. University of Strathclyde.

12 Seawater turbidity on the Northwest European Shelf (NWES). An investigation into the effects of light attenuation on marine biogeochemistry and ecosystem diversity in a 1D ERSEM Model. ***Rhiannon Morton***. University of Exeter.

13 Modelling marine nitrogen budgets to assess drivers and impacts of nitrogen pollution. ***Dale Partridge***. Plymouth Marine Laboratory.

15 Modelling overgrazing of temperate kelp forests due to invasive tropical herbivorous fish. ***Rachel Spencer***. University of Exeter.

16 Relative importance of factors driving hypoxia onset in the Chesapeake Bay. ***Olivia Szot***. Virginia Institute of Marine Science.

17 The fate of the terrestrial dissolved organic matter in a partially mixed estuary: The Tamar, UK. ***Ricardo Torres***. Plymouth Marine Laboratory.

18 Regions of riverine influence in the global ocean. ***Sarah Wakelin***. National Oceanography Centre United Kingdom.

19 Mechanisms governing nutrient transport from the Gulf of Aden into the Red Sea. ***Yixin Wang***. King Abdullah University of Science and Technology (KAUST).

20 Quantifying bivalve aquaculture-environment interactions using a coupled bioenergetic and biogeochemical model. ***Liuqian Yu***. The Hong Kong University of Science and Technology (Guangzhou).

21 A simple two-layered ecosystem model for the permanently stratified ocean. ***Qi Zheng***. University of Exeter.

Theme – The Human Dimension

22 Impacts of blue mussel mitigation farms in coastal ecosystems: Skive Fjord, Denmark, a model study. ***Tobias Andersen***. Technical University of Denmark.

23 Potential and uncertainties of ocean alkalinity enhancement in the Baltic Sea according to in-silico experiments. ***Anna-Adriana Anschütz.*** Leibniz Institute for Baltic Sea Research Warnemünde.

24 Modelling the spatio-temporal variability of the variegated scallop Mimachlamys varia, in order to help restoration habitat effort in the bay of Brest (French Atlantic coast). ***Philippe Cugier.*** Ifremer.

25 The direct and indirect impacts of harvesting mesopelagic fishes on carbon export. ***Deniz Disa***. METU-IMS.

26 The bio-physical impacts of offshore wind turbines in the North Sea. ***Jenny Jardine***. National Oceanography Centre.

27 The role of ecosystem modelling in promoting ocean and water literacy. ***Gennadi Lessin***. Plymouth Marine Laboratory.

28 "Coral Hospital" concept: a green management approach to coral reef conservation and restoration." ***Chiahsin Lin***. National Museum of Marine Biology and Aquarium.

29 Satellite-based data enables high-resolution monitoring of maritime traffic during a global crisis. ***Alexandra Loveridge***. Marine Biological Association.

30 Seaweed cultivation potential on EU marine regions. A modelling approach. ***Diego Macias*** European Commission.

31 Deep-sea benthic ecosystem recovery after deep-sea mining: a modelling approach. ***Sophy Oliver***. National Oceanography Centre.

32 Integrating stakeholder knowledge and observations to assess key vulnerabilities in the southern Benguela system, South Africa. ***Kelly Ortega Cisneros***. University of Cape Town.

33 A model-based, generalised eutrophication index for European Seas. ***Luca Polimene***. Joint Research Centre.

34 Impacts of bottom trawling on carbon dynamics in the North Sea: Insights from a coupled Physical-Biological-Carbon model. ***Pooja Tiwari***. Helmholtz Zentrum Hereon.

Theme - Model mechanics

35 The Nutrient-Unicellular-Multicellular (NUM) approach to zooplankton modelling. ***Ken Andersen***. Technical University of Denmark.

36 Recent and future biogeochemical trends in the Atlantic Ocean: a look into the importance of structural uncertainty. ***Yuri Artioli.*** Plymouth Marine Laboratory.

37 Predicting North Atlantic right whale distribution from currents seascapes. ***Andeol Bourgouin***. Université Laval.

38 Investigating the hydrodynamic connectivity of eelgrass *Zostera marina* population along French Atlantic coast to help management and conservation effort. ***Philippe Cugier***. Ifremer.

39 Refining Temperature-Dependent Phytoplankton Growth Functions in Global Ocean Models: Insights from the REcoM Model. ***Hannah Haines***. AWI.

40 Trait-based modelling in the eddy world. ***Trine Hansen***. University of Southern Denmark.

41 Assessing the influence of numerous river discharge on the modulation of shelf circulation in the Ganges-Brahmaputra-Meghna estuary. ***Tasin Sumaia Khan***. Bangabandhu Sheikh Mujibur Rahman Maritime University.

42 As good as it gets: Exploring the role of different data sets for global biogeochemical model calibration. ***Iris Kriest***. GEOMAR Helmholtz Centre for Ocean Research.

43 Modeling the Sinking Dynamics of Tyre-wear Microplastics in an urban fjord in western Norway. ***Prithvinath Madduri***. University of Bergen.

44 Exploring the impact of fragmentation and diel vertical migration on particle sinking (in a mechanistic model). ***Aaron Naidoo-Bagwell***. University of Bristol.

45 Addition of faecal pellets processes in a biogeochemical model. ***Margaux Perhirin.*** Sorbonne Université.

46 Interpreting the seasonal succession of Prochlorococcus phenotypes and Synechococcus near Bermuda. ***Junkun Ren***. Massachusetts Institute of Technology.

47 To be or not to be mixotroph? How niche modeling can help to inform the distribution of dinoflagellate trophic strategies in marine ecosystems. ***Gaspard Rihm.*** Institut de Systématique.

48 Coupling ocean biogeochemistry to a global Earth System model. ***Michael Mehari***. SAIC.

49 Characterization and evolution of micronektonic biomes and feedbacks on biogeochemical cycles. ***Sarah Albernhe***. Collecte Localisation Satellites.

50 Dining in danger: Resolving adaptive fish behavior increases realism of complex ecosystem models. ***Nicolas Schnedler-Meyer***. Technical University of Denmark.

51 A biogeochemical model including toxic and allelopathic interactions among marine plankton. ***Olumayowa Taiwo***. University of Reading.

52 The impacts of adapting the light climate on nutrient levels in a 3D-ecosystem model for the Wadden Sea. ***Daniel Thewes***. Universität Hamburg.

53 Zooplankton and micronekton population dynamics based on a spatial ecosystem model using Yin-Yang grid. ***Olivier Titaud***. Collecte Localisation Satellites.

54 Higher-trophic fish and macrobenthos biomass models based on ECOSMO E2E compatible to multiple lower trophic level model hosts. ***Vijayakumaran Vijith***. Helmholtz Zentrum Hereon.

Theme – Digital Innovation

55 New opportunities to develop, test and share process models in a common framework." ***Jorn Bruggeman***. Bolding & Bruggeman ApS/Plymouth Marine Laboratory.

56 Ensemble assimilation of satellite-derived carbon measurements into a global model. ***Yumeng Chen***. University of Reading.

57 Ensemble programming for oceanic modelling. ***Michal Grossowicz***. Gigablue

58 Developments in operational biogeochemical modelling at the UK Met Office. ***Susan Kay***. Met Office/Plymouth Marine Laboratory.

59 Model calibration: Treating selected parameters as random variables. ***Volkmar Sauerland***. GEOMAR Helmholtz Center for Ocean Research.

60 Improved understanding of eutrophication trends, indicators and problem areas using machine learning. ***Jozef Skakala***. Plymouth Marine Laboratory.

61 EnsAD: Assimilation of hyperspectral satellite data into the marine ecosystem model HBM-ERGOM using optical plankton classes. ***Johannes Timm***. Federal Maritime and Hydrographic Agency.

62 The two-echelon covering tour problem with varying coverage: application in carbon storage monitoring. ***Guttorm Alendal***. University of Bergen.

63 Incorporating a spatially varying attenuation coefficient improves the simulation of the summer blooms in the southern Red Sea. ***Yixin Wang***. King Abdullah University of Science and Technology (KAUST).

64 Global patterns of marine calcite production resolved using machine learning models. ***Nicola Wiseman.*** University of Bristol.

Theme 1:

Ecosystems and cycles under change

Agent-based models for modelling small pelagic population dynamics and life-histories traits.

Elisa Donati, Simone Libralato, Cosimo Solidoro

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Abstract

Sardines and anchovies play a fundamental role in trophic food webs and are crucial for fisheries. In the Adriatic Sea, they can comprise up to 70% of total annual landings. Despite sharing the same basin, they prefer different environmental gradients, spawn in different seasons, and both rely on plankton. Enhancing our ability to predict sardine and anchovy dynamics is essential for sustainable management and understanding how these populations will respond to climate change, including changes in life-history traits.

We developed an agent-based model in Julia, using the Dynamic Energy Budget Theory (DEB) to simulate the life stages of sardines and anchovies. The model includes age-dependent natural and fishery mortality, with different modules for hatching, puberty, and reproduction based on agent type (egg, juvenile, or adult). Sea water potential and food concentration data are sourced from the Mediterranean Sea Physical and Biogeochemical Reanalysis by the Copernicus Marine Service.

While the model accurately reproduces important biological patterns such as lifespan, length at age, and time to puberty, it fails to capture the expected spawning stock biomass trend from virtual population analysis, though it does match the biomass magnitude from MEDIAS echo-surveys.

The model is computationally performant and adapted to investigate expected life-history traits changes due to climate change, using environmental projections of temperature and food concentration. Julia language framework facilitated the implementation of extensive simulations within a reasonable computing time.

Our study highlights the importance of considering animal physiology and life history traits when modelling fish populations under climate change scenarios. Future research will explore spatial patterns of fish life history traits in the Adriatic Sea, providing insights into their effects on population dynamics.

Modelling the complete life cycle of an arctic copepod reveals complex trade-offs between concurrent life cycle strategies

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Abstract

Calanus hyperboreus is a large bodied and lipid rich copepod species, adapted to convert the phytoplankton spring bloom into growth and lipid reserves, which fuel higher trophic levels of the sub-Arctic pelagic ecosystem. In the rapidly warming Gulf of St. Lawrence (GSL), the biomass-dominant *C. hyperboreus* exists at the southern edge of its biogeographic domain where its future under anthropogenic climate change is highly uncertain. To synthesize existing knowledge of the species and examine the species response to environmental change, a numerical population model is developed for *C. hyperboreus*. In a first step, a conceptual model of the species life cycle in the GSL is built from a comprehensive review of literature and regional data, and key life cycle characteristics are identified as modelling targets. Then, the population model is implemented in a particle-based, 1-D configuration in the northwest GSL, with descriptions of ingestion, assimilation, respiration, egg production, stage development, mortality, and vertical migration. The model predicts the evolution of individual *C. hyperboreus* stage, structural mass, lipid, age, sex, abundance, and egg production, as well as the seasonal evolution of the population structure. Notably, dormancy timing is driven by lipid dynamics, with individual variability in the lipid threshold parameters. The model is iteratively developed and improved to simulate the set of life cycle targets identified from literature and data. The simulated population structure, phenology, and size at stage are generally consistent with observations. Under 10 years of repeat-year environmental forcing, the model simulates a quasi-stable abundance and an overwintering population composed of late stages CIV-CVI. In the conceptual model of the *C. hyperboreus* life cycle in the GSL, stage CIV is the first overwintering stage, and females may follow an iteroparous dormancy strategy. In a set of model experiments, we explore the relative success of different dormancy and reproductive phenotypes, and their role in the population response to interannual environmental variability. Potential changes in lipid allocation under warming are also considered, since the *C. hyperboreus* population could eventually become destabilized in the GSL if warming continues.

Modelling thermal niche of marine calcifying zooplankton from past to future

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Abstract

Climate change threatens marine organisms, causing migrations, biomass reduction and extinctions. However, modelling the response of marine species to these changes is still challenging on both geological and anthropogenic timescales. Here, we use a trait-based and mechanistic plankton model (EcoGENIE) to study the thermal niche of marine calcifying zooplankton (foraminifera, Rhizaria) through time. The results showed that foraminifera with algal symbionts and calcite spines shifted thermal niche with the deglacial warming from the Last Glacial Maximum (LGM, 19-21 thousand years ago, ka) to pre-industrial times, while foraminifera without symbionts (non-spinose or spinose) kept the same thermal preference and migrated poleward exploring new habitats. The response of thermal niche is supported by global fossil record and geochemical proxy data. However, when forcing the trait-based plankton model with rapid transient warming over the coming century, the model suggests that the niche change of foraminifera is limited, particularly for non-symbiont ecogroups. Foraminifera are projected to migrate poleward and drop their global carbon biomass by 2.5-12.2% by 2100 relative to 2022 (depending on warming scenario). The biomass loss due to limited adaptive response of foraminifera is likely to worsen when ocean acidification and symbiont bleaching would be taken into consideration. Our study highlights the advantages of mechanistic models in studying the behaviour of marine species under climate change and the different challenges posed by anthropogenic and geological warming on marine species and ecosystems.

Marine heatwaves & cold spells around the UK: a cause for concern for marine ecosystems & the blue economy?

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Abstract

Marine heatwaves (MHW), characterised by prolonged periods of unusually warm sea surface temperatures (SST), exert profound impacts on both ecosystems and society. In the summer of 2023, an intense MHW hit the shores of the UK, making numerous news headlines. Despite the increasing frequency and intensity of MHWs globally, little attention has been paid to their occurrence and potential impacts in British waters, particularly on the effect they may have on the regional biogeochemistry and resident marine ecosystems such as kelp and seagrass.

Here, we use a combination of remote sensing and high-resolution model output to investigate the occurrence and biogeochemical impact of MHWs and marine cold spells (MCS; unusually low SSTs) on the Northwest shelf. MHWs are defined as SSTs exceeding the 90^{th} percentile and MCSs as SSTs falling below the 10^{th} percentile for >5 days. Preliminary results indicate that across the North Atlantic, the UK doesn't stand out as a hot spot for MHWs or MCSs. However, when focusing solely on this region, interesting spatial patterns exist, particularly in the southern North Sea. Extreme chlorophyll events are also calculated using the same method as extreme SSTs (i.e. >90^{th} and <10^{th} percentiles), to assess the potential for compound events in UK waters. While a close relationship exists between the extremes in the subtropics, there is no significant correlation between these events on the Northwest shelf. Using a case study approach, including the recent MHW of 2023, the impact of MHWs and MCSs on chlorophyll, oxygen and pH are examined for the surface and subsurface waters around the UK.

Given the increasing occurrence of MHWs, it is imperative to understand the ramifications on marine ecosystems, fisheries, and blue economy of the UK. Although the UK may not be considered a global hotspot for such events, drawing insights from other nations could prove invaluable in devising effective strategies to mitigate and adapt to these marine extremes. By leveraging the experiences of countries facing similar challenges, the UK can proactively enhance its resilience and response mechanisms to safeguard its marine resources and sustain the vitality of its blue economy.

Extreme and compound ocean events are key drivers of projected low pelagic fish biomass

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Abstract

Ocean extreme events, such as marine heatwaves, can have harmful impacts on marine ecosystems. Understanding the risks posed by such extreme events is key to developing strategies to predict and mitigate their effects. However, the underlying ocean conditions driving severe impacts on marine ecosystems are complex and often unknown as risks to marine ecosystems arise not only from hazards but also from the interactions between hazards, exposure and vulnerability. Marine ecosystems may not be impacted by extreme events in single drivers but rather by the compounding effects of moderate ocean anomalies. Here, we employ an ensemble climate-impact modeling approach that combines a global marine fish model with output from a large ensemble simulation of an Earth system model, to identify the key ocean ecosystem drivers associated with the most severe impacts on the total biomass of 326 pelagic fish species. We show that low net primary productivity is the most influential driver of extremely low fish biomass over 68% of the ocean area considered by the model, especially in the subtropics and the mid-latitudes, followed by high temperature and low oxygen in the eastern equatorial Pacific and the high latitudes. Severe biomass loss is generally driven by extreme anomalies in at least one ocean ecosystem driver, except in the tropics, where a combination of moderate ocean anomalies is sufficient to drive extreme impacts. Single moderate anomalies never drive extremely low fish biomass. Compound events with either moderate or extreme ocean conditions are a necessary condition for extremely low fish biomass over 78% of the global ocean, and compound events with at least one extreme variable are a necessary condition over 61% of the global ocean. Overall, our model results highlight the crucial role of extreme and compound events in driving severe impacts on pelagic marine ecosystems.

Emergent ecosystem distributions from 100-model simulations with the PlankTOM12 model

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Abstract

The PlankTOM12 model is a global ocean biogeochemistry model based on the representation of marine microorganisms grouped into Plankton Functional Types (PFTs) as a function of their functional importance for the carbon cycle. PlankTOM12 uniquely represents explicitly bacteria, six types of phytoplankton (picophytoplankton, nitrogen fixers, coccolithophores, mixed phytoplankton, diatoms, and Phaeocystis), and five types of zooplankton (microzooplankton, mesozooplankton, pteropods, gelatinous zooplankton, and crustacean macrozooplankton). We build three distinct branches of the PlankTOM12 model, each with its own set of parameters. Branch 1 is the historical branch which has underpinned much prior research on the carbon cycle using this model and is the UEA contribution to the Global Carbon Budget 2023. Branch 2 is optimised to reproduce the mean, seasonal cycle, and interhemispheric distribution of surface chlorophyll a (Chla). Branch 3 is optimised to reproduce the mean and seasonality of the partial pressure of surface ocean carbon dioxide (pCO2). Each of these branches offers a different perspective on marine ecosystem dynamics. They differ most distinctly in the relative fraction of biomass that is distributed into small/large and medium sized PFTs.. We show how these ecosystem differences transfer through to differences in the carbon system. We then build 100 sensitivity tests by permuting model parameters. We show that small permutations in model parameters, particularly those related to grazing by top predators, can lead to important shifts in the distribution of the entire ecosystem. A clustergram analysis reveals self-organisation of the >100 tests around a limited number of emergent types of ecosystems. Finally, we discuss methods to evaluate the model results using biogeochemistry and available ecosystem data, and implications of the results for projections of changes in the carbon system.

Climate change may unleash the ghost of past species' ecological niches

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Abstract

The ability of climatic niche models to predict species extinction risks is strongly hampered if estimated niches are truncated. This can occur when niches are estimated considering only currently available climatic conditions, disregarding the fact that species could be preadapted to conditions that no longer exist but that could reappear in the future, typically when climate changes. Using a new metric, we estimated the prevalence of potential niche truncation by measuring if current niche limits are contiguous to the boundaries of currently available climatic conditions for 24,944 species at the global scale in both terrestrial and marine realms and including animals and plants. We show that 12,172 (~49%) species are showing niche contiguity, particularly those inhabiting tropical ecosystems and the marine realm. Using niche expansion scenarios, we found that 86% of species showing niche contiguity could have a niche potentially expanding beyond current climatic limits, resulting in lower - yet still alarming - rates of predicted biodiversity loss, particularly within the tropics. Caution is therefore advised when forecasting future distributions of species presenting niche contiguity, particularly toward climatic limits that are predicted to expand in the future.

Variability and Future Trends in Chlorophyll-a Concentration Across Coastal Upwelling Systems

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Abstract

Coastal upwelling (CU) is a vital process that brings cold, nutrient-rich water from the deep ocean to the surface, supporting marine life and fisheries, which are important for local coastal communities. Some studies have indicated that the SST of the eastern boundary upwelling systems are not warming as fast as the global ocean or are even cooling down in some areas (Varela et al., 2018; García-Reyes et al., 2023), indicating their potential as climate refugia. However, it remains unclear how CU systems will be affected with future climate change, with uncertainties surrounding changes in strength, spatial extent, and phenology of individual systems and even within systems.

Here, we explore the potential impacts of climate change on CU systems using a NEMO-MEDUSA high-resolution (1/12deg) future projection. This high resolution is particularly suitable for monitoring coastal areas due to its ability to capture small-scale processes and features. First, we use the present-day NEMO-MEDUSA simulation to develop novel upwelling metrics that are applicable to the global CU systems. Specifically, Chl-a and SST in conjunction with upwelled nutrients and vertical velocity are used to define the spatial coverage of CU systems and are then used to understand how these systems are changing in terms of intensity, spatial and temporal patterns. At regional scales, especially in CU systems, the ecosystem response to surface warming becomes more complex. The matric that indicates the dynamics of CU in terms of Chl-a footprints is crucial because it reflects the availability of food for the higher trophic levels in the CU regions. Hence, the objective is to formulate essential metrics for upwelling that could prove valuable for the coastal community and decision-makers.

Variability of annual primary production in the North Sea from 1983 to 2014: diatoms and non-diatoms show different trends

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Abstract

Nitrogen and phosphorus inputs via rivers entering the North Sea showed maxima in the early 1980s. This led to eutrophication phenomena near the coast with high primary production and further negative consequences for the North Sea ecosystem.

Recent simulations with the ecosystem model ECOHAM for the North Sea, nested in the model NEMO-ERSEM for the Northwest European continental shelf, show that diatom and non-diatom driven productions behave differently with respect to decreasing eutrophication. In the southern and central North Sea, non-diatom production has indeed responded to the changes in nutrient supply via the rivers. However, diatom production in this region mostly remained stable and even increased in some cases.

A different picture emerges in the northern North Sea, where the reversal of the winter NAO index from high to lower values (1995/1996) was followed by a drastic collapse in the inflow of North Atlantic water. This also led to a cut in the nutrient supply. Here, both phytoplankton groups reacted similarly: from 1996, the primary production of both species declined and then recovered again from 1999.

Our results confirm the hypothesis of Desmit et al. (2019) that in the southern North Sea primary productivity responds to reduction in nutrient inputs with shifts in community structure, and in the northern North Sea with decrease in total productivity rates.

Reference:

Desmit, X., A. Nohe, A. V. Borges, T. Prins, K. De Cauwer, R. Lagring, D. Van der Zande and K. Sabbe (2019). Changes in chlorophyll concentration and phenology in the North Sea in relation to de-eutrophication and sea surface warming. Limnology and Oceanography 9999. DOI: 10.1002/lno.11351.

Observations and biogeochemical modeling reveal chlorophyll diel cycle with near-sunset maxima in the Red Sea

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Abstract

The Red Sea is an extremely warm tropical sea that hosts diverse ecosystems; thus, it is important to understand its ecology in the context of global warming. Using a coupled physical–biogeochemical model and *in situ* data, we provide the first report on the diel cycle in the Red Sea chlorophyll concentration, revealing near-sunset chlorophyll maxima at 17h ± 1h local time over the entire basin. This chlorophyll peak time is considerably later than those reported in most other oceans, suggesting low grazing rates in this high-irradiance tropical sea. Model-based analyses reveal that chlorophyll diel cycle is predominantly controlled by irradiance, whereas longer-timescale (e.g., seasonal) chlorophyll variability is regulated by nutrient availability, suggesting a light-limited biological production at diel timescale. The identified chlorophyll diel cycle comprises a fundamental component of the Red Sea ecology and has implications for chlorophyll remote sensing and *in situ* measurements.

Impacts of Climate Change on the Ascension Island Marine Protected Area and its Ecosystem Services

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Abstract

Ascension Island is a small volcanic island in the equatorial Atlantic that harbours an abundance of marine biodiversity, including sharks, turtles, tunas, billfish, rays, and marine mammals. The island itself is also a nesting area for green turtles and seabirds.

In 2019, the Ascension Island Marine protected area (AIMPA) was created, protecting approximately 440,000 square kilometres of the Atlantic ocean from commercial fishing, making it one of the largest Marine Protected Areas (MPAs) in the world. MPAs are highly effective in reducing and reversing the impacts of fisheries and also have significant ecosystem and socioeconomic benefits. While highly-protected MPAs remain vulnerable to external threats from climate change, protected status does improve ecosystem resilience, allowing some buffer against the worst impacts of the changing climate.

We investigated a suite of metrics of marine behaviour in the AIMPA under four future climate scenarios, using data from the sixth Coupled Model Intercomparison Project, (CMIP6), a collaborative system that Earth System modellers from around the world use to share their simulations.

We found that the AIMPA will become warmer, more saline, more acidic, with lower nutrient and chlorophyll concentrations, and less primary production in the surface waters. A locally important current, the Atlantic equatorial undercurrent, is also projected to weaken. These changes are likely to reduce the MPA's ability to provide ecosystem services like healthy ecosystems, fish stocks, removing carbon dioxide from the atmosphere, or generate tourism.

This work is the first climate projection for the Ascension Island MPA, and should allow policymakers to understand in detail how the changing climate will impact their environment and ecosystem services. The recent creation of MPAs like this one has raised the percentage of the ocean that's fully protected from 2.18 percent in 2016 to 2.9 percent in 2023. There's still a long way to go to achieve the UN target of 30 percent by 2030.

Modelling global carbon fluxes and sequestration from fish

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Abstract

Oceans uptake ~30% of anthropogenic carbon emission through the physical and biological carbon pump, serving an important role in Earth's climate system regulation. Although our current understanding of the contributions from plankton to the biological carbon pump goes relatively far, the contributions from fish remain largely uncertain. We apply the FishErIes Size and functional TYpe model (FEISTY) to estimate the contributions of fish to the biological carbon pump. The FEISTY model resolves higher trophic level dynamics based on functional types and their sizes, a key trait describing marine organisms. The FEISTY model runs with outputs of a state-of-the-art Earth System Model (GFDL's ESM). We map global carbon fluxes driven by the fish, including fecal pellets, excretion, respiration, and deadfall. We also explore the fishing effects on these carbon fluxes and sequestration. We identify areas where fish carbon sequestration is highest, try to understand the trophic mechanisms driving such patterns, as well as illustrate the importance of maintaining the amount of carbon sequestrated from fish. The results of this project are expected to improve our understanding of the contributions of metazoans to the biological carbon pump and demonstrate the potential of the size-based fish model FEISTY in marine biogeochemical research.

Potential continental shelf carbon sequestration by a harvested fish species

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Abstract

The marine biological carbon pump plays a crucial role in the sequestration of atmospheric carbon and therefore is paramount to global climate regulation. Most of the existing research on biological carbon sinks has focused on understanding the role of oceanic (off-shelf) species and processes where the carbon can quickly be removed from contact with the atmosphere. We know very little about how species living on continental shelves contribute to and influence carbon sequestration due to complex dynamics in biological and physical transport processes. This knowledge gap is becoming an issue as decision-makers seek to consider the impacts of anthropogenic pressures (e.g., fishing) on the flow and storage of carbon across shelf ecosystems. Human activities impact the biological carbon pump by altering population biomasses, ecosystem dynamics, and trophic interactions. Here, we explore the potential contribution of a selected fish population in the Irish Sea to shelf sediment carbon sinks and the impacts of fishing. The Irish Sea ecosystem, situated between Ireland and the UK, is a shelf ecosystem that encompasses important populations of commercial species, such as herring. An Ecopath with Ecosim (EwE) model of the Irish Sea has been developed to reconstruct the region's food web. We combine the Irish Sea EwE ecosystem model outputs of biomass with faecal egestion, sinking, and remineralisation rates under alternate fishing scenarios to provide a novel quantitative assessment of the annual flux of carbon that may be buried in the shelf sediment if not advected. Our results provide an early insight into the relationship between commercial species, fishing, and biological carbon sink for shelf ecosystems.

Impact of Pacific Ocean heatwaves on phytoplankton community composition

Lionel Arteaga

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Abstract

Since 2013, marine heatwaves have become recurrent throughout the equatorial and northeastern Pacific Ocean and are expected to increase in intensity relative to historic norms. Among the ecological ramifications associated with these high temperature anoma- lies are increased mortality of higher trophic organisms such as marine mammals and sea- birds, which are likely triggered by changes in the composition of phytoplankton, the base of the marine trophic food web. Here, we assimilated satellite ocean color data into an ocean biogeochemical model to describe changes in the abundance of phytoplankton functional types (PFTs) during the last decade's (2010s) warm anomalies in the equatorial and northeastern Pacific Ocean. We find important changes associated with the "Blob" warm anomaly in the Gulf of Alaska, where reduced silica supply led to a switch in community composition from diatoms to dinoflagellates, resulting in an increase in surface ocean chlorophyll during the Summer–Fall of 2014. A more dramatic change was observed in the equatorial Pacific, where the extreme warm conditions of the 2016 El Niño resulted in a major decline of about 40% in surface chlorophyll, which was associated with a nearly total collapse in diatoms.

Quantification of Carbon Fluxes along a Gradient from the Wadden Sea Lagoon to the North Sea and Atlantic Ocean.

Anouk Blauw[1], Lauriane Vilmin[1], Sonia Heye[1], Lora Buckman[1], Willem Stolte[1], Iniobong Benson[1], Loreta Cornacchia[1], Vlad Macovei[2] and Yoana Voynova[2].

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Abstract

Carbon fluxes in coastal waters are strongly affected by biogeochemical processes and the inflow of organic carbon, nutrients and alkalinity from land. High concentrations of nutrients and phytoplankton in near-shore waters lead to relatively large carbon fluxes and strong variability of carbon fluxes in time and space compared to oceanic waters. As a consequence, carbon fluxes in coastal waters are expected to play a large role in global carbon budgets, but quantification of this is role is still complex. Sources of uncertainty on carbon fluxes in near-shore waters include: the strong variability in space and time that is not well represented in observation data, lack of information on land-based inputs from organic carbon, nutrients and alkalinity and complex and spatially heterogeneous interactions with the sediment.

In this study we quantify carbon fluxes in near-shore coastal waters of the North Sea with a combination of a numerical model and field observations. We use the coupled physical-biogeochemical Dutch Continental Shelf Model (DCSM) to investigate carbon fluxes and the relative importance of different processes along the gradient from land to ocean. The model covers the North Sea and surrounding shelf and ocean waters. We focus our study on the gradient from the Wadden Sea lagoon, with major riverine inputs from the Rhine and Elbe, through coastal waters and the North Sea to the Atlantic Ocean. We compare model results with a wide range of observations (in-situ, satellite and ships of opportunity) to assess uncertainties in our quantification. We discuss remaining knowledge gaps and potential solutions to fill these in terms of required system understanding, observations, model improvements and better integration between models and observations.

Dissolved organic carbon dynamics in a changing ocean: A COBALTv2 Earth System Model analysis.

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Abstract

Dissolved organic carbon (DOC) is a substantial pool of bioreactive carbon in the ocean, comparable in quantity to the atmospheric inorganic carbon reservoir. DOC plays an important role in the marine carbon cycle; its contribution to total organic carbon export corresponds to about 20%. Current modeling studies suggest a broad range of DOC surface concentration estimates, and the response of DOC concentration and export to climate change is unclear and has not been described in an Earth System Model.

To address this knowledge gap, we make use of the ocean biogeochemistry and ecosystem model COBALTv2. We analyze DOC dynamics and export under the present and future climate conditions within the high-emission scenario SSP5-8.5. The COBALTv2 model, coupled to the GFDL's ESM2M Earth System Model, enables us to trace DOC from its primary sources, including phytoplankton activity and grazer-prey dynamics, to its sinks such as bacterial remineralization. We also account for the physical processes such as advection that influences DOC distribution. Preliminary findings suggest that the current distribution of DOC in the ocean may undergo significant changes, contingent upon the biological sources and sinks that are sensitive to ocean temperature increases. The relative contributions of different phytoplankton groups to DOC production are expected to shift across various ocean regions, along with the magnitude of heterotrophic respiration, which is the predominant DOC sink. This study contributes to understanding and forecasting of potential shifts in oceanic DOC dynamics under current and future climate conditions.

SISSOMA: A mechanistic approach in modelling the dynamics of marine aggregates

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Abstract

The sinking of particulate organic matter (POM) from the surface to the deep ocean plays a crucial role in the global carbon cycle by driving the biological carbon pump. Even though the size of the sinking particles has been extensively used by many models to predict their fate, there is an increasing concern in the scientific community that this is not enough. Information about unique particle characteristics, such as its composition, porosity, shape, and density, are important aspects for efficiently predicting the carbon export into the deep ocean. We introduce SISSOMA, a mechanistic model, which uses a 2-dimensional state-space, e.g., size and excess density of an aggregate. It follows the fate of the primary particles from production to export through four main processes: aggregation, remineralization, fragmentation and sinking out of the mixed layer (see attached figure). Moreover, we investigate how the self-similarity parameter, stickiness and turbulent dissipation rate affect the shape of the flux by conducting sensitivity analyses on them. Finally, by connecting SISSOMA to the Nutrient – Unicellular – Multicellular (NUM) model will enable us to better understand how the plankton community structure affects the size – spectrum of the carbon flux and investigate its spatial and temporal variations.

A coupled phytoplankton-flocculation model to quantify suspended particulate matter dynamics on the Belgian shelf

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Abstract

Biological and mineral components of marine ecosystems are often studied and modelled separately. Yet, they interact and form an integrated dynamic system. In coastal waters, this is translated into highly variable suspended particulate matter (SPM) concentration. SPM comprises mineral particles, living organisms, detritus and extracellular organic matter. On time scales ranging from tide to year, SPM dynamics respond to interactions between physical, sedimentological and biological processes. Unravelling these dynamics needs more integrated models.
In this study, a biogeochemical 0D model simulating phytoplankton growth and production of different classes of organic matter, including transparent exopolymer particles (TEP), is coupled to a two-class population balance equation model of flocculation. TEP production follows the carbon overconsumption hypothesis, where TEP precursors are increasingly excreted at the end of the bloom under nutrient depletion. Flocculi and flocs interact following collision and breakage kinetics, primarily controlled by turbulence. The collision efficiency of mineral particles is affected by the TEP concentration, whose sticky properties enhance flocculation. Larger flocs are less constrained by water viscosity and settle faster. The coupled phytoplankton-flocculation model is applied in three intensely monitored stations on the Belgian shelf, investigating the complex SPM dynamics on time scales ranging from tide to season, and along a cross-shore transect from the high-turbid inshore to the low-turbid offshore waters. Especially in nearshore waters, observations show that SPM concentrations decrease from winter to summer while the median particle size increases with freshly produced TEP. This behaviour is simulated by the model, which indicates that biologically-induced flocculation over the bloom affects floc size and concentration to a greater extent than turbulence-induced changes over tidal time scales. In turn, the lower SPM concentration alters the light regime in the water column, though preliminary results suggest that the effect on photosynthesis and, consequently, on the bloom, remains limited. Altogether, depending on the relative importance of the mineral and organic fractions and on hydrological conditions in the distinct stations, SPM dynamics and fate quantitatively and qualitatively differ.

Modelling sediment-water fluxes: impacts on water column biogeochemistry in a large eutrophic estuary

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Abstract

Sediment-water exchange processes are crucial for water column biogeochemistry, whereas their representation in ocean biogeochemical models is often too crude to characterize the nonlinear benthic-pelagic interactions. This work aims to quantify the effects of sediment-water fluxes on the water column processes in coastal regions and assess the sensitivity of model-simulated oxygen dynamics, especially the bottom-water hypoxia, to the representation of sediment biogeochemistry. To that aim, we implement a variety of sediment-water exchange schemes of different complexity levels to a coupled physical-biogeochemical model of the Pearl River Estuary (PRE), a large eutrophic system experiencing bottom-water hypoxia in summer. Model results show that the simulated oxygen dynamics and hypoxic extent are markedly sensitive to the representation of sediment-water nutrient and oxygen fluxes. In addition to directly contributing to bottom-water hypoxia through sediment oxygen consumption, sediment-released nutrients, especially the more limiting nutrient phosphate, significantly promote hypoxia development by fueling water column organic matter production. These results highlight the critical role of sediment-water exchange in regulating water column biogeochemistry in shallow estuarine and coastal waters as well as the importance of credibly representing sediment-water interactions to model ocean ecosystems.

Impact of Tropical Storms on the Alkalinity of Two Contrasting Tidal Tributaries in a Coastal Plain Estuary

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Abstract

Carbon cycling in coastal environments is strongly influenced by short-term variability from extreme events like tropical storms, the intensity of which is predicted to increase in the future. These storms bring high winds and heavy rainfall, which can lead to enhanced mixing, storm surge, and increased river discharge, but little is known about their impact on estuarine carbon cycling, and specifically on total alkalinity (TA). This study addresses this knowledge gap by focusing on two tributaries of the Chesapeake Bay, located along the US east coast. The Potomac River Estuary is characterized by high-alkalinity river inputs (TA ~ 2000 µmol kg^{-1}), contrasting with the York River Estuary, a tributary draining a much smaller watershed with low TA river inputs (TA ~ 400 µmol kg^{-1}). A coupled 3-D hydrodynamic–biogeochemical model was run from 1985 to 2020 and captured the impact of 37 hurricanes and tropical storms that followed various paths through the region. Typically, in the initial stage of a storm, storm surge and mixing dominate and cause increases in TA throughout the tributaries, whereas in the second stage, river discharge increases, decreasing TA. Although storms cause both tributaries to exhibit lower TA upstream due to high freshwater discharge, the tributaries differ in their downstream response. Throughout the York, TA generally decreases after a storm, but the gradient of TA, increasing downstream, is maintained. In contrast, throughout the Potomac, the patterns become more spatially complex with areas of higher and lower TA. During high-discharge events, the high TA at the head of the Potomac can decrease by more than 50% and the high-TA waters are moved further downstream. The resulting dramatic shifts in TA over just a few days can cause extreme variations in the carbonate system that can detrimentally impact the local ecosystem, specifically in naturally highly alkaline rivers. Improving knowledge of how estuarine carbonate chemistry responds to extreme events is critical for local stakeholders, including shellfish aquaculturists, restoration managers, and those interested in pursuing marine carbon dioxide removal techniques.

Assessing climate change impacts in the Southern Benguela: a model inter-comparison

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Abstract

The southern Benguela upwelling system supports a productive fisheries sector that provides jobs and livelihoods for thousands of people living along the southern African coastline. This system has experienced considerable environmental variability and change in recent decades, and climate projections indicate that this is likely to continue into the future. A number of ecosystem models are available for the southern Benguela system and these have captured many aspects of the observed variability and dynamics of this ecosystem. This study aims to evaluate the possible impacts of climate change in the southern Benguela ecosystem using an Atlantis and Ecopath with Ecosim ecosystem models. These models are forced with climate projections from the Geophysical Fluid Dynamic Laboratory (GFDL) ESM2M model and the Institut Pierre Simon Laplace (IPSL) Earth system models to evaluate the effects of warming and primary productivity changes on the southern Benguela upwelling system under Shared Socioeconomic Pathways 2.6 and 8.5. Results from the ecosystem models are compared to determine agreement and differences in the biomass, catches and spatial distribution of functional groups in this system under two climate change scenarios. This comparative (ensemble) approach provides information on bounding uncertainty around climate-forced projections of the southern Benguela ecosystem. The results of this study have the potential to inform future ecosystem-based management decisions and increase understanding of climate change impacts at the system level but also to increase adaptive capacity at the local scale.

IRMA: An index to predict mass fish mortality during harmful algal blooms in tropical estuaries

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Abstract

Microalgae, an essential source of food and oxygen for marine life, can also become a serious threat to human health and the economy. Some species produce harmful events (HAB), which manifest themselves in two ways. In some cases, the species produce toxins that affect the food chain, while in others, the species produce a large biomass that, when the algae die, the decomposition of this matter can result in the depletion of oxygen, with the formation of dead zones. and mass death of aquatic organisms. In the Ciénaga Grande de Santa Marta (CGSM), the largest and most productive estuarine system in Colombia, HAB events are frequent. This led to the development of a mass fish kill indicator for integration into an early warning system. The indicator, named IRMA, was based on the HAB conceptual model mechanism described for CGSM. According to this model, the increase in PO4 stimulates the massive growth of microalgae, mainly atmospheric nitrogen-fixing cyanobacteria. After overproduction, the cyanobacteria collapse, producing hypoxia/anoxia. To calculate the IRMA, we built algorithms to score, based on values measured in the monitoring program over the past 30 years, fish mortality risk according to PO4, chlorophyll, and dissolved oxygen concentrations. We weighted the risk score values among the three variables according to their potential effect on fish mortality. Then we add the result of multiplying the risk values by their weight and express the IRMA as a percentage. Values between 0 and 10 are considered low risk of mortality; 10.1 to 20 moderate; 20.1 to 40 high, and values above 40 very high risk. The IRMA was calibrated using fish kill events recorded in CGSM and fitting a statistical model to validated the indicator with other physical and chemical variables. Considering the high predictive value of IRMA in CGSM, we believe that this index has great potential to be explored as a tool to manage eutrophication in tropical estuaries.

Development of a three dimensional multispecies small pelagic fish model for the Mediterranean Sea.

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Abstract

Anchovy and sardine constitute the two most important small pelagic fish species in the Mediterranean Sea. A three dimensional full life cycle individual based model, two-way coupled to a hydrodynamic/biogeochemical low trophic level model, enables the study of the above species in the region. It is based on an existing and tested equivalent model for the North Aegean Sea. For the parameterization and initiation of the model, data on the main habitats of the two species, including information on, among others, stock assessment, egg production and growth per age, were collected from all available literature. In the model, anchovy and sardine are divided into life stages including the egg, the larval, the juvenile, as well as three adult stages for anchovy and four for sardine. Due to data availability, the 2000-2020 period was selected for the reference simulation and as model calibration period. The result was a successful representation of the spatial distribution and size of stocks and the growth rates of each species in their habitats. Last and towards investigating the possible effects of climate change on the two species, multiyear simulations were performed using various future climatic scenarios.

Assessing the impacts of climate change and fishing on the ecosystem's state and its resilience in the Celtic Sea

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Abstract

Ecosystems are subject to multiple disturbances including fishing and climate change, both of which are known to affect community diversity and food web trophic functioning. Despite their vulnerability to cumulative pressures, these systems can display an ability to recover after a perturbation and bounce back to a reference state or maintain a certain structure and functions. Combined pressures applying in concert can alter ecosystems' resilience, thus inducing losses of functions and services.

Using an Ecopath with Ecosim (EwE) ecosystem model for the Celtic Sea we (1) assess the individual and cumulative impacts of climate and fishing and (2) explore the impact of the fishing intensity and climate on ecosystem recovery after fishing pressure is removed. Various levels of increasing fishing intensities were simulated over the whole 21st century, by forcing the EwE model with parameters of sea temperature, primary production and secondary producer's biomass from the regional POLCOMS-ERSEM climate model, under both RCP4.5 and RCP8.5 scenarios. The cumulative effects on ecosystem's state and its resilience was assessed through a set of indicators (biomass-based, community composition, trophic and length/age-based indicators), using a theoretical non-fishing and climate-constant scenario as a reference.

Our results suggest climate change-induced changes affect Boreal and pelagic species while fishing preferentially removes piscivores. Up to a specific effort level, the fishing-climate interaction leads to lower effects than expected. However, beyond this effort level the interaction induces a change in cumulative effects nature, meaning the interaction has a greater impact than expected. Intense fishing pressures impair the capacity of the ecosystem to recover, even in a no climate-change context. Climate change has minor impacts on ecosystem recovery to fishing.

Impacts of environmental pressure on the survival of early life stages of the European Smelt using an Individual-based modelling approach

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Abstract

The anadromous living European Smelt (Osmerus Eperlanus) is a commonly observed fish in the German estuaries of Elbe, Ems and Weser. The substantial amount of biomass of smelt and its ecological role as a “wasp-waist” species makes the fish a key-species of these ecosystems. However, recent findings suggest a rapid decrease of the smelt populations in all German estuaries. Causes of this population decrease were widely discussed and suggestions range from the impact of climate change due to warmer temperatures, changes in the food availability to the increased anthropogenic usage of all three estuaries. To investigate possible drivers of mortality of early life stages we present an Individual-Based model (IBM) for the European Smelt. The IBM includes the egg development, endogenous feeding (yolk-sac stage), the transition of the 0+ larvae to exogenous feeding and the subsequent growth. The necessary physical and biological forcing is provided using a coupled physical-biogeochemical (SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model) in combination with ECOSMO) ecosystem model. We set up several climate change and adaptation scenario simulations to address the possible effects of future climate change and anthropogenic use change/sustainable adaptation. A Lagrangian particle-tracking scheme is used to calculate the route of the individuals during their lifetime. Based on the particle’s trajectory, the individual’s growth and survival is estimated. Further, the model allows to determine important processes that impact the individual’s survival throughout its lifetime. We present the model validation along with a dedicated parameter sensitivity study on the individual’s survival. Further, the impact of climate change and anthropogenic use of the Elbe Estuary on the growth and survivability is presented.

Keynote

Bridging the gap: Integrating models and observations for better ecosystem understanding

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Abstract

Our understanding of complex marine ecosystem dynamics is often hindered by significant uncertainties and issues of representativeness associated with models and observations. Both observations and models provide a limited view of real-world complexities depending on what is specifically measured or simulated. When used together, they have the ability to gain a broader understanding of important ecological processes. How to properly integrate models and observations while utilizing the advantages of both approaches remains a challenge. In this presentation, we draw attention to commonly overlooked limitations of both observations and models and use examples to illustrate potential strategies to mitigate bias, properly interpret results, and help improve both models and observations. We emphasize that proper validation of all data sources (models and observations), is necessary in all marine ecosystem studies, with a careful assessment of the spatio-temporal scales that the data represent.

Modelling offshore benthic blue carbon

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Abstract

The ecosystem service of carbon sequestration and storage provided by the marine system is important in the mitigation of climate change. Blue carbon (BC) habitats and offshore sediments can act as carbon stores and sinks and their management by protection or restoration remains important. Whilst the focus has been largely on vegetated coastal systems, we propose inclusion of carbon stored in offshore seabed environments as recent publications at European and global levels have illustrated the significance of these extensive stocks.

This presentation will show results from a study using the NEMO hydrodynamic model (Graham et al., 2018) coupled via FABM (Bruggeman and Bolding, 2014) to a sediment transport model to evaluate potential accumulation locations for terrestrial and marine derived particulate organic carbon. Results will be compared with data driven maps of seabed carbon content. This will be combined with within bed simulations using the OMEXDIA (Soetaert et al., 1996) model to consider the processes responsible for carbon sequestration on the UK continental shelf and there potential vulnerability to disturbance by seabed trawling.

Modelling Ecosystems and Fisheries in the Bazaruto Archipelago, Mozambique, using Ecopath with Ecosim (EwE)

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Abstract

The Bazaruto archipelago in Mozambique consists of five islands; despite being a relatively small area, it contains a diversity of marine habitats, including coral reefs, seagrass meadows, mangrove forests, and vast sandy intertidal and subtidal habitats (Everett et al., 2008). The Parque Nacional do Arquipélago de Bazaruto (PNAB) is the oldest marine protected area (MPA) in Mozambique, which seeks to protect critically endangered dugongs (Trotzuk et al., 2022) and overall biodiversity within the Bazaruto ecosystem, whilst allowing Bazarutos to engage in artisanal fishing, which is essential for food and income security for most of the archipelago's residents (Everett et al., 2008; ANAC, 2016; D'Agata, 2016). Despite the environmental and regional importance of the archipelago, the likely impacts of climate change on the PNAB are poorly known. Further, whether the MPA will serve as an effective means of maintaining the PNAB ecosystem under future climate conditions needs investigation.

Ecopath with Ecosim is being used to develop a temporally and spatially resolved end-to-end ecosystem model of the Bazaruto ecosystem. Novel methods of data assembly are being used to parameterize and fit the model, as Bazaruto is a data-poor environment. Bazaruto-specific catch estimates are produced by applying satellite derived effort estimates of Bazaruto artisanal fishing to CPUE statistics available for the same artisanal fisheries at a national level. Once parameterized, temporally fitted, and spatialised, the model will be run under various climate change-induced warming and MPA protection scenarios to identify ecosystem tipping points, and to make projections of biodiversity, abundance, and fisheries catches in Bazaruto. The model will be interrogated for its potential as a fisheries management and conservation planning tool for PNAB, for example by using it to explore the efficacy of the PNAB as an MPA. The Bazaruto model is being developed as a prototype for the WIO 2100 ecosystem modelling project, which seeks to build a series of large scale, connected ecosystem models of strategic regions in the West Indian Ocean, with the aim of forecasting ecosystem and fisheries changes under various climate change scenarios.

How climate-driven changes in primary production, physiological rates and non-indigenous species will affect the Eastern English Channel-Southern North Sea (EEC-SNS) ecosystem structure and functioning by 2050?

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Abstract

In coastal ecosystems, climate-driven changes can induce complex consequences on ecological dynamics. In this context, the Eastern English Channel and the Southern part of the North Sea area (EEC-SNS), which supports a broad range of economic activities, is likely to undergo unexpected alterations in ecosystem structure and functioning. Management towards viable and sustainable ecosystems need to consider holistic and integrative approaches in order to fully address the consequences of cumulative impacts of such stressors. The ecosystem approach - that provides a comprehensive depiction of the structure and functioning- is a relevant tool for the examination of climate-induced changes at ecosystem level, which is crucial for understanding the direct and indirect impacts that propagate through trophic flows.

To obtain a robust representation of the EEC-SNS ecosystem, we developed an end-to-end model, fitted to observed catches and biomass from 2006 to 2018, using the Ecopath with Ecosim framework. This model was forced with ERSEM biogeochemical model outputs to capture low trophic levels dynamics at the basis of the ecosystem (i.e phytoplankton, zooplankton and bacteria). Based on projections from species distribution models and life-history trait characteristics, non-indigenous fish species (NIS) were included in the model as they are likely to extend their spatial range into the EEC-SNS under future climates. Simulations with alternative model formulations were ran till 2050 to estimate the indirect effects of climate-driven changes under IPCC scenarios RCP 4.5 and RCP 8.5, by explicitly accounting for a combination of: (1) changes in primary production, (2) changes in foraging abilities linked with specific temperature preferences and, (3) non indigenous species arrivals.

We investigated ecosystem impacts using ecological network analysis indicators (ENA) to quantify a range of emergent system properties. Simulated climate-driven impacts could lead to a reduction in biomass and production and to a shift of the food-web towards a greater dominance of detritus-based pathways. Changes in structure and functioning mostly relate to recycling and specialization of the system.

Considering the diverse anthropogenic activities in the region, this study serves as an initial step to evaluate the combined impacts of climate change and human activities. These factors may interact synergistically, potentially leading to unforeseen effects on the ecosystem

Modelling ecosystem impact of offshore wind farm structures in the Northwest European shelf

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Abstract

The increasing need for renewable energy has led to an expansion of offshore wind farms (OWFs). This man-made structures of OWFs have the potential to act as new artificial stressors which may alter dynamics of various marine receptors. It has been suggested that the OWFs structures able to create artificial reefs, increase the abundance and biodiversity of species around the structures, as well as generate redistribution of marine environment spatially. Therefore, a better understanding to quantify the ecological impacts of the OWFs on the marine ecosystem on a local and regional scales are needed. Here, we use a coupled ocean and marine biogeochemical models of FVCOM-ERSEM to estimate the impact of existing and planned OWFs structures in the North Sea on the marine biological productivity and potential alteration of its biochemical cycles. We explicitly modeled the growth of suspension feeder biota around the OWFs structures as the artificial reefs that filter organic matter from the water column and organically enrich the surrounding areas. Our model showed reduction of net primary productivity and total chlorophyll by up to 10 and 20%, respectively around the structures, but with 1-2% increase in the outer area of the structures. We also found the increase of modeled nutrients (i.e., nitrate and phosphate) up to 5% around the structures most likely due to the reduce uptake by less simulated plankton. Our results showed that the current expansion of OWFs potentially will affect the structure of marine ecosystem dynamic both locally and regionally on basin scale of the North Sea.

Spatio-Temporal Variability of Chla and Phytoplankton Functional Types (PFTs) from Satellite Ocean Color Data in the Bay of Bengal

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Abstract

The monthly and year to year variability of Phytoplankton Functional Types (PFTs) have been examined in the Bay of Bengal (BoB) from satellite ocean color data (2000-2020). Monthly Chla data, Color Dissolved Matter (CDOM), Photosynthetic Active Radiation (PAR) and Suspended Particulate Matter (SPM) of merged satellite (combination of SeaWiFS, MODIS, MERIS, VIIRS, OLCI) products provided by Glob Color, European Space Agency (ESA) was used in this study. 10 PFTs(Microplankton, Nanoplankton, Picoplankton, Diatoms, Dinoflagellates, Green Algae, Prymnesiophytes, prokaryotes, pico-eukaryotes, Prochlorococcus; 3 PSC, 7 PTC) was derived from individual monthly chla by using the equations of (Hirata et al., 2011). All data were averaged to the Bay of Bengal region. We have found that, the average chla is gradually decreasing (0.35 mg/m^3 to .25 mg/m^3 from 2000 to 2020); where CDOM showed a sinusoidal relation; PAR showed a decrease until 2014 then increase; SPM showed a rapid exponential increase from 2013. The highest chla was found in the monsoon season (August) due to the high load of river discharge, cloudy environment and favorable conditions; the lowest chla was found in summer (April) due to the increased sunlight and PAR. Diatoms (microplankton) were the most dominant group in the Bay of Bengal, which is going to be replaced by smaller planktons like Prochlorococcus (picoplankton). In terms of size, the nanoplanktons are the most dominant group. With the increase of total chla, diatoms are increasing rapidly, others show slight increase while Prochlorococcus are decreasing. CDOM has a positive effect on larger phytoplankton like diatoms. PAR has showed maximum chla in 40-45 einstein/m^2/day except Prochlorococcus which can survive in high PAR also. SPM showed nearly no effect except for diatoms and Prochlorococcus. The predominance of one group over another is strongly dependent on seasonal and physio-biological changes of the ocean. We found Prochlorococcus to be much higher as of picoplankton. In the absence of sufficient in-situ data in this region, the satellite-based analysis may not recover PFTs as it is. But it can tell us the overall situation of an area.

Impact of cross-shelf exchange events on eutrophication and primary production variability in the Black Sea

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Middle East Technical University, Erdemli, Turkey

Abstract

The unique physical and biogeochemical properties of the Black Sea make it difficult to adopt common models that are used to study different seas in the world. It is a major challenge to model in terms of biogeochemistry as it features many sophisticated processes, especially in its anoxic environment and at the oxic-anoxic interface. Considering this, an integrated modeling system has been developed that can also be used in similar basins and is contributing to the Digital Twin of the Black Sea and the Marmara Sea

To understand the impact of Black Sea specific meso-scale physical features on ecosystem dynamics, small to medium scale eddy-front systems should be understood in detail. For this purpose, the Turkish Regional Seas Ecosystem Model (TURSEM) biogeochemical model that tracks the cycles of C, N, P, Si, O, Fe, Mn, S and includes variable, quota-based stoichiometry of biological components is adapted for the Black Sea and coupled to Nucleus for a European Model of the Ocean (NEMO). The coupled modeling system is used to understand how mesoscale eddies and dynamic frontal features affect production in the Black Sea and further to conduct a resilience assessment that defines risks to the services the Black Sea ecosystem provides. First results indicate that the southeastern Black Sea is as an important area for cross-shelf transport, after the northwestern shelf. Mesoscale eddy-induced cross-shelf transport of low salinity, nutrient rich and productive waters are maximum in the presence of filaments associated with these eddies and fuel production in the open Black Sea.

Two-way physics-biogeochemistry coupling constrained by ocean colour data assimilation

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Abstract

We implemented two-way physics-biogeochemistry coupling in the global NEMO-MEDUSA model, via the use of model chlorophyll in the light attenuation calculations. This was tested with and without assimilation of chlorophyll observations from ocean colour to constrain the model, and the impact on model physics and biogeochemistry assessed. The assimilation was found to enhance the impact of biogeochemistry on model physics, especially ocean heat content, with a smaller feedback from the modified physics onto ecosystem processes. The experiments were also used to evaluate the relative uncertainty in the coupling introduced by errors in free-running model chlorophyll.

A model-based analysis of summertime oxygen deficiency in the Elbe Estuary (Germany)

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Abstract

The Elbe Estuary (Elbe-km 585 to 727) is a heavily anthropogenically modified and influenced waterbody providing access to the Port of Hamburg, one of the largest seaports in Europe and the world. A combination of factors – including eutrophication of the Elbe River causing high organic matter loads and high turbidity in the estuary – result in the formation of low oxygen conditions in the Port of Hamburg area and downstream (Elbe-km 620 to 660) every summer. However, in late June 2022, the relatively shallow upper Elbe Estuary (Elbe-km 585 to 620) experienced the lowest observed oxygen levels since the German reunification, even falling below those in the Port of Hamburg. Observations at the tidal weir in Geesthacht (Elbe-km 585) reveal that during this event, oxygen levels were unusually low in the lower Elbe River leading to the all-time oxygen low in the upper estuary. In this study, we investigate the June 2022 event using a coupled hydrodynamical-biogeochemical model system based on the QSim model representing the Elbe River and Estuary from the German-Czech border (Elbe-km 0) to the outer estuary (Elbe-km 727). Our main focus is on the effect of low discharge on water residence times and changes in the biogeochemical processes that caused a significant upstream shift of the net heterotrophic regime normally confined to the deeper parts of the Elbe Estuary. In addition, we analyze a longer model hindcast with respect to the frequency of similar, though less pronounced events as an attempt to derive a statistical relationship between river discharge and oxygen levels in the Elbe Estuary.

Poor Performance of Regime Shift Detection Methods in Marine Ecosystems

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Abstract

Regime shifts have been reported as an ubiquitous feature across the world's oceans. Many regime shift detection methods are available but their performance are rarely evaluated, and the supporting evidence for regime shifts may be thin because of the nature of marine ecological time series that are often short, autocorrelated, and uncertain. In the Norwegian Sea (NoS), a regime shift has been reported to have occurred in the mid-2000, with simultaneous changes in oceanography, plankton, and fish. Here, we evaluate the evidence for this regime shift using four commonly used regime shift detection methods (Strucchange, STARS, Envcpt and Chronological Clustering) on 32 annual time series that describe the main components of the NoS ecosystem, from hydrography and primary production, up to fish population metrics. We quantify the performance of each method by measuring its false positive rate, i.e. the proportion of times the method detects a regime shift that was not present in simulated control time series. Our results show that all methods have high to very high false positive rates. This challenges the evidence for a regime shift in the Norwegian Sea and questions earlier reviews of regime shifts across the world's oceans.

NB. This paper was recently submitted to the ICES Journal of Marine Sciences.

Modelling mid-21st century Chesapeake Bay hypoxia: The role of climate changes at the ocean, land, and atmospheric boundaries

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Abstract

Coastal hypoxia is simultaneously affected by anthropogenic nutrient loading and climate-induced oceanic, terrestrial, and atmospheric changes. Local management within the Chesapeake Bay watershed, along the US East Coast, has aimed to mitigate anthropogenically driven eutrophication, focusing on nutrient loading reductions. However, climate change also exacerbates deoxygenation's intensity and extent via decreased gas solubility, strengthened estuarine circulation, and enhanced phytoplankton growth and microbial respiration. To project the impacts of future changes in these various processes, we used a 3-D coupled hydrodynamic–biogeochemical model of the Chesapeake Bay embedded in the Regional Ocean Modeling System. The control model experiment simulated the early 1990s while mid-21st century projections were generated by applying downscaled outputs of three Earth System Models (ESMs) for a "business as usual" emissions scenario. Using the median ESM (in terms of future warming and precipitation increases), projections estimated that by mid-century, annually integrated hypoxic volume (for $O_2 < 3$ mg L^{-1}) increased by 17–29% depending on interannual variation. Future changes to hypoxia were also seasonally dependent, with the greatest increases predicted during May–June, no change or decreases in mid-summer, and small increases during September–November. Experiments with climate forcings from the more extreme ESMs provided estimates of uncertainty on future estuarine changes. Finally, experiments with modified subsets of climate forcings revealed that, including interannual variation, air temperature accounted for the majority (60 to 100%) of total increases in annually integrated hypoxic volume ($O_2 < 3$ mg L^{-1}). Next most impactful were changes to watershed inputs (–23 to 50%) and sea level (–23 to 28%) while changes to radiation, winds, non-runoff precipitation, and ocean temperature cumulatively account for small impacts (1 to 8%). Those improvements to hypoxia resulting from future watershed inputs and sea level depend on the relative magnitude of annual freshwater flow. In addition to expected major drivers like temperature, our results predict small, negative impacts on Chesapeake Bay water quality from climate change processes previously not considered. Therefore, to reach regulatory water quality goals, nutrient management actions will need to be more aggressive, or future water quality goals will need to be reassessed.

Plankton community size structure in UK coastal waters

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Abstract

Size is a master trait in plankton ecology as it controls key ecosystem processes, such as primary productivity, trophic interactions, and carbon export (Litchman & Klausmeier 2008; Litchman et al. 2013). Despite its importance, there is limited understanding of what drives plankton community size structure and its wider ecological implications in UK coastal waters.

We take particular interest in the typical seasonal cycle of size structure, and hypothesise that in winter large phytoplankton cells will have a competitive advantage over smaller cells, since the nutrient-rich waters are well suited for their surface area-to-volume ratio. In summer, when phytoplankton biomass and the resultant nutrient uptake pressure is high (Bresnan et al. 2009), we expect that small cells will dominate. Under this hypothetical, bottom-up controlled community, we expect that zooplankton community size structure will follow qualitatively similar patterns to phytoplankton, since zooplankton feeding is often restricted by prey size prey size. Alternatively, top-down effects (or a combination of both) may drive the spectra.

To test this hypothesis, we constructed biomass density estimates of plankton size spectra using data from three UK coastal observatories: Stonehaven, Loch Ewe, and Plymouth L4. To our surprise, data summaries suggest that phytoplankton mean size is small in winter and high in summer at the Scottish sites. A deeper exploration of the data suggests that differences in data collection methods may contribute to this observed pattern; cells are recorded to lower abundance concentrations at Plymouth L4 when compared to Stonehaven and Loch Ewe. Thus, large cells – which typically occur in low abundances, yet contribute significant biomass on a per cell basis – may be underrepresented in the Stonehaven and Loch Ewe sampling regime.

We construct a size-structured, slab style NPZD model forced with environmental data at each site to (a) investigate the mechanisms driving size structure, and (b) identify and fill in any potential data gaps. We use the Scottish Shelf Model to consider closely the horizontal flux of nutrients and plankton in these waters, which are influenced by currents and riverine input to varying extents across sites.

Seawater Turbidity on the North West European Shelf (NWES). An investigation into the effects of light attenuation on marine biogeochemistry and ecosystem diversity in a 1D ERSEM Model.

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Abstract

Changes to the turbidity of European seas has important implications for shelf primary production and nutrient cycling, which effects marine ecosystem health. With changes to turbidity likely to occur throughout the twenty-first century, due to increased storm events and anthropogenic activity, it is important to identify potential impacts of increased turbidity on the North West European Shelf (NWES). This research aims to determine the effects of light attenuation on marine ecosystems using a 1D ERSEM model. Optical properties at six study sites surrounding the British Isles will be examined to identify potential thresholds for ecosystem change.

Light availability in the 1D water column is controlled by the modelled particulate organic matter (POM). POM is calculated from nutrient composition, particle sinking and resuspension properties, as well as the specific shortwave absorption and backscattering (m^2/mg C) of particles. Therefore, this study looks to modify the specific shortwave absorption and backscattering properties of particles to generate a more accurate representation of light in the water column. Earth observation data will be utilized to simulate environmental conditions at each site. Secondary in-situ data and satellite data will verify the model outputs. Results from this study will provide a greater understanding of the relationship between water clarity and biogeochemistry in European coastal seas.

The ERSEM model also presents an opportunity to model potential future seawater turbidity. Seawater absorption and backscattering parameters will be altered appropriately at each site to reflect potential light availability in the future under different environmental conditions. Findings from the effects of different light availability on the nutrients and ecosystem within the 1D ERSEM analysis will be utilized in a 3D ERSEM model to map the distribution of suspended particulate matter (SPM) on the NWES. Input of SPM from European rivers to the NWES is of particular interest due to changing land use and increased storm events which effect river composition, thus altering the natural dynamics of the land-ocean continuum. Here we present the preliminary results of the 1D ERSEM turbidity analysis and we discuss the potential research outputs from the 3D ERSEM model of the NWES.

Modelling Marine Nitrogen Budgets to Assess Drivers and Impacts of Nitrogen Pollution

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Abstract

Nitrogen pollution can have a wide variety of impacts on marine ecosystems. Whilst moderate amounts of nitrate are beneficial by driving phytoplankton production, excessive amounts entering the marine environment pose a serious threat to the health and biodiversity of a region, leading to oxygen depletion, species loss, and acidification with significant consequences also for the livelihood of people and the economy of sectors who rely on a healthy and productive marine ecosystems to thrive (e.g. fishery and tourism). Quantifying the stocks and flows of nitrogen in the marine environments through nitrogen budgets allows to identify what are the major causes of such pollution, how are the components of the ecosystems affected, and whether critical thresholds have been exceeded, ultimately supporting informed management decisions,

One region where nitrogen pollution is critically high is South Asia. High population density has led to rapidly increasing levels of nitrogen pollution. Large amounts of nitrogen enter the marine environment through freshwater runoff and atmospheric deposition, directly impacting the shallow coastal regions. Additionally, the Bay of Bengal demonstrates a unique characteristic, with its oxygen minimum zone not operating as a major nitrate sink compared to equivalent zones in areas such as the Arabian Sea.

Within the context of the South Asian Nitrogen Hub, we reconstruct the marine nitrogen budget for the North Indian Ocean, by utilising fine resolution numerical coupled models on a regional scale. With input from bespoke hydrological models, the nitrogen cycle is analysed for different exclusive economic zones within the region. A range of possible policy changes to mitigate nitrogen pollution are assessed to determine their long-term impact.

The marine nitrogen pollution in the South Asian region is then compared with that in other biologically productive regions (Northwest European Shelf and South-East Asian Seas), leveraging on previous modelling studies in the context of the International Nitrogen Assessment.

Modelling Overgrazing of Temperate Kelp Forests due to Invasive Tropical Herbivorous Fish

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Abstract

Anthropogenic induced climate change is causing our oceans to increase in temperature globally, leading to profound changes in species distributions, interactions and overall ecosystem dynamics. In response to this warming, tropical species are shifting their distributions poleward into temperate regions, leading to tropicalisation of temperate ecosystems. Declines in temperate kelp forests have been observed over the past half a century, with an influx of tropical herbivores found to be one of the drivers of the transition from a kelp-dominated to a turf-dominated ecosystem.

Here, a size-based food web model is used to investigate how warming-induced changes in kelp and temperate herbivore physiological rates impacts the survival of kelp forests. Furthermore, the invasion of tropical herbivores is modelled by incorporating a separate group of herbivores with representative traits. Initial results suggest that whilst these changes to kelp ecosystems will cause declines in kelp abundance, it is unlikely that a complete population decline will occur due to changes in kelp growth rate or temperate herbivore feeding rate. A representative model of the transition from a kelp-dominated to a turf-dominated ecosystem allows us to explore possible management strategies, such as targeted fishing of tropical herbivores, that can be used to sustainably protect and restore these ecosystems.

Relative importance of factors driving hypoxia onset in the Chesapeake Bay

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Abstract

The Chesapeake Bay, located on the eastern coast of the United States, is an ecologically and economically valuable estuary that has experienced seasonal hypoxia for decades. Hypoxia is exacerbated by both global climate change and local anthropogenic stressors, and presents an environmental concern as it reduces suitable habitats, alters food webs, and degrades the overall quality of the ecosystem. In the Chesapeake Bay, hypoxia generally begins in May and persists for several months until it terminates in September or October. However, previous studies have revealed year-to-year variability in the temporal patterns of hypoxia, with some years experiencing earlier onset than others. Several environmental factors likely contribute to the onset and development of hypoxia, including air temperature, wind patterns, freshwater discharge, and nutrient delivery. While these factors are known to influence oxygen dynamics, the biological and physical processes are complex and interconnected, making it a challenge to understand the relative importance of each individual factor and the underlying mechanisms that contribute to changes in the year-to-year pattern of hypoxia onset. To address this, a three-dimensional, fully coupled hydrodynamic-biogeochemical numerical modeling system was used to simulate the Chesapeake Bay during an average hypoxic year as a control. Then, a series of sensitivity experiments were conducted in which various environmental factors were modified in a manner that is expected to hasten the onset of hypoxia (i.e., reduced wind speed, increased nutrient loading, increased temperature). The magnitude of modification to the factors was ±1 standard deviation, derived from 25 years of historical data, to ensure that the experiments were comparable to each other. The onset dates of the control simulation were compared to those of the sensitivity experiments to examine the relative importance of each environmental factor. Results suggest that the wind patterns and temperature have the greatest impact on the timing of hypoxia onset. Terrestrial input was shown to have little influence on the timing of hypoxia onset, but had the greatest influence on the magnitude of summer hypoxia.

The fate of terrestrial dissolved organic matter in a partially mixed estuary: the Tamar, UK

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Abstract

Our coastal seas support a wide range of activities and provide essential services to the local, regional and national economies. Coastal observatories, in combination with governmental monitoring programs provide essential information to support science based policies and management decisions. However, these efforts can rarely encompass the range of scales at which the coastal environment operates. To explore the role of agricultural and urban waste, PML has implemented a coupled hydrodynamic-biogeochemical model of the Tamar estuary and adjacent coastal area. The implementation of FVCOM-SPM-FABM-ERSEM-UniDOM model includes explicit formulations of terrestrial dissolved organic carbon (tDOC) transformation associated with photodegradation, flocculation and interactions with suspended sediment and bacterial degradation across the river, estuarine and ocean domains. In this presentation we will evaluate the effectiveness of each removal process in mediating the export of tDOC to the shelf UK and compare the model results with the extensive observations collected during the UK project LOCATE. We will also discuss the sensitivity of ecosystem changes in the estuarine system to the modeled tDOC influx and the role of terrestrial DOM in the export of nutrients to the coastal domain.

Regions of riverine influence in the global ocean

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Abstract

Rivers are the primary pathway for carrying both anthropogenic and natural materials from land sources via coastal and shelf seas into the open ocean, where they are dispersed and transported by oceanic circulation. Although concentrations are generally larger in coastal areas, material of land origin is found in all ocean basins, including in regions remote from land. The substances that affect marine ecosystems include pollution, litter (including plastics) and dissolved nutrients from agricultural runoff and urban wastewater (potentially causing excess primary production and eutrophication). Rivers also carry terrigenous matter to the ocean which may be transported to depths and isolated from contact with the atmosphere for long periods. For terrigenous dissolved organic carbon (tDOC) this provides a pathway for long-term sequestration of carbon from release to the atmosphere. Some of the tDOC is remineralised in shelf seas, but the spatial distribution and concentration of the remaining tDOC is currently unknown in many regions.

We use Lagrangian particle tracking driven by a 1/12 degree resolution 3D global ocean model simulation to investigate regions of influence of the earth's 100 largest rivers, representing ~62 % of the global river discharge by volume. By combining the river discharge rates and particle densities we estimate the spatial influence of groups of rivers and the depths to which riverine particles are transported in the global ocean. The 100 rivers studied carry more than 60 % of the dissolved organic carbon (DOC) exported from land by rivers. By incorporating estimates of photooxidation, flocculation and microbial remineralisation of tDOC along particle trajectories, we provide an initial assessment of the fate of tDOC in the global ocean.

Mechanisms governing nutrient transport from the Gulf of Aden into the Red Sea

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Abstract

The productivity of the Red Sea has been reported to increase during warmer El Niño-Southern Oscillation (ENSO) phases, in contrast to the global trends where warmer ENSO phases are generally associated with enhanced thermal stratification and decreased productivity.
This unusual phenomenon was associated with the intensification of nutrient-rich intrusion from the Gulf of Aden into the Red Sea during warmer ENSO phases. However, the biological mechanisms behind this phenomenon are still not fully understood, due to the lack of a three-dimensional biogeochemical model that provides information about nutrient transport, especially over long-term interannual scales. The Gulf of Aden intrusion is characterized by a winter intrusion of Gulf of Aden Surface Water (GASW) and a summer intrusion of Gulf of Aden Intermediate Water (GAIW). We utilize a coupled physical-biogeochemical (MITgcm-NBLING) model to identify the processes governing the seasonal and interannual variabilities in nutrient transport from the Gulf of Aden into the Red Sea during GASW and GAIW periods, respectively. We further assess the correlation between various climate drivers, including ENSO, with the nutrient transport during both GASW and GAIW periods. Our results indicate that GAIW carries more nutrients into the Red Sea, although characterized by a much smaller water volume transported than GASW. In terms of interannual variability, the water volume transport highly covaries with the nutrient transport during the GAIW period, but this is not the case for the GASW period. Correlation analysis with climate indices reveals a teleconnection between ENSO and the nutrient transport from the Gulf of Aden into the Red Sea and further suggests a potential role of the Indian Ocean Dipole. In the context of climate change, our investigation of the interannual variability in the Red Sea nutrient transport should provide valuable insights for understanding the local biogeochemistry in the coming decades.

Quantifying Bivalve Aquaculture-environment Interactions Using a Coupled Bioenergetic and Biogeochemical Model

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Abstract

Bivalve aquaculture has been rapidly expanding worldwide to meet the accelerating global seafood demand. To ensure a responsible and sustainable growth of bivalve aquaculture without disrupting marine ecosystems, a quantitative understanding of the dynamic bivalve aquaculture-environment interactions is required. Here we present a coupled bioenergetic and biogeochemical model to quantify such interactions. The model integrates an individual-based Dynamic Energy Budget model, which simulates the growth and reproduction of bivalves, and an ocean biogeochemical model, which simulates the planktonic food web dynamics. The model is one-dimensional, consisting of multiple horizontal well-mixed boxes, and configured for a shallow eutrophic bay in Southern China with sizeable oyster farms. We optimize the model by assimilating time series measurements of key ecosystem variables to faithfully represent major biophysical features of the bay and reproduce the observed oyster growth indicators. A series of model experiments forced with different farming strategies are then carried out to gain insights into aquaculture-environment interactions and feedback in a typical growing season of the farmed oysters in the bay. Lastly, critical steps toward implementing the coupled model in the three-dimensional framework for providing spatially explicit estimation of bivalve aquaculture-environment interactions are discussed.

A simple two-layered ecosystem model for the permanently stratified ocean.

Qi Zheng, Bob Brewin

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Abstract

In the ocean, phytoplankton, at the base of the food web, account for nearly half of the total primary production on Earth and are instrumental in regulating global carbon and nutrient cycles. Approximately 29% of our ocean is characterised by permanent stratification. Despite great effort over the past few decades to study these regions (for example through the Atlantic Meridional Transect and Hawaii Ocean Time-series (HOT) programmes), they remain relatively unexplored. Given the pivotal role of phytoplankton in ocean biogeochemical cycles, understanding their response to a changing climate in the vast permanently stratified ocean is crucial. Recent work has suggested such regions can be considered a two-layered vertically structured system. Here, we develop a two-layer ecosystem model, comprising a nutrient-limited surface layer and a light-limited subsurface layer within the euphotic zone. We present initial comparisons of our model with data at HOT, showing how well it can reproduce seasonality and interannual variability in the two layers. We plan to use the model as a tool to probe our understanding of the impacts of climate change in permanently stratified marine ecosystems.

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Theme 2:

The Human Dimension

Co-producing knowledge with ocean industry stakeholders to understand the impact of activities on ocean carbon

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Abstract

Ocean industries, such as fishing and mining, are likely to introduce changes to the biological carbon pump through their activities, though our understanding of the extent of these changes are poor. Nevertheless, the ocean as a sink for carbon is under discussion towards an approach for addressing climate change in alignment with the EU Green Deal to reduce the net emissions of greenhouse gases to Zero by 2050. Using mental modelling approaches, we worked with fishing industry stakeholders to explore their perspectives of their industry's interaction with the carbon cycle under four themes: (1) the carbon footprint of the industry; (2) changes in the carbon cycle due to removal of organisms; (3) the carbon flux due to impact on the seabed; and (4) the potential impacts of emerging and expanding industries linked to climate change. Outputs of co-produced knowledge will help to enable identification and prioritisation of societally-relevant carbon-related impacts and threats, and their impacts on associated ecosystem services.

Early-warning system: Climate-smart spatial management of UK fisheries, aquaculture and conservation.

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Abstract

Our coast and our ocean are undergoing unprecedented changes as a result of the breakdown of our global climate system. These changes represent significant challenges to the delivery of marine policy that effectively protects ecosystem health, biodiversity and the communities depending on these resources. Creating new, climate-adaptive management strategies for these ecosystems, and for economic sectors reliant on them, is thus an ongoing challenge facing diverse marine policy frameworks across the UK Nations. An ever-increasing reliance on marine space to meet our need to transition to greener energy supply and economic growth compound this challenge and must be carefully balanced against the pressing need to preserve our marine species and habitats, and their ability to adapt to climate change. Marine planning is a public process to document, consult and set priorities about how we manage and share our marine space. To harness opportunities for effective marine conservation and economic growth that emerge from spatial variation in the sensitivity of our marine ecosystems to climate change, climate-smart marine plans are thus necessary. The MSPACE project capitalized on world-class UK ocean climate modelling capability, to deliver a climate change assessment for the entire UK EEZ that, for the first time, demonstrates the spatial variation in sensitivity of our marine ecosystems to climate change. We make recommendations about how marine planning could support the management of areas identified as climate change refugia for three key sectors – marine conservation, fisheries and aquaculture. We highlight that these areas could be utilized by future climate-smart policy design, to promote the climate change adaptation of our natural marine ecosystems. Our identification of these areas also offers opportunities for sectoral policy design by highlighting where risk from climate change may be lower for our fishing and aquaculture sectors.

Bridging the Gap: Integrating Human Dimensions into Global Ocean Dynamic and Biogeochemistry Models

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Abstract

Global ocean dynamic and biogeochemistry models – which have been evolving since Mike Fasham's pioneering work in the 1990s – are integral to marine BGC research and serve as crucial components in the Earth System Models used for climate projections. With a high enough spatial resolution, these models offer significant regional realism, often eliminating the need for resource-intensive creation of dedicated regional models. Their success extends to coupling with fisheries models, yet the evolving challenges of diverse human interactions with the marine environment call for a still greater effort to expand their use to the human dimensions of coupled socio-oceanographic systems.

This presentation explores approaches to impact modelling, integrating traditional ocean dynamics and biogeochemistry models with societal aspects, and building linkages that enhance our understanding of the global ocean's role in diverse human activities. The discussion encompasses various strategies for coupling models to human aspects and aims to bridge the gap between marine science and societal needs, so that our models can provide the critical information for effective risk management in the face of evolving global challenges.

Significant benefits from international cooperation over marine plastic pollution

Nicola Beaumont[1], Tobias Börger[2], James Clark[1], Nicolas Hanley[3], Robert Johnston[4], Keila Meginnis[5], Christopher Stapenhurst[6,7], Frans de Vries[7]

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Abstract

Plastic pollution in the world's oceans threatens marine ecosystems and biodiversity, leading to a loss of well-being for people. The connected nature of the marine environment suggests that coordinated actions by countries sharing a common ocean border may provide more effective pollution control than unilateral actions by any one country. However, economic theory and empirical evidence suggest that countries often fail to cooperate, even when joint welfare would be higher under cooperation. Here we provide the first analysis of the potential economic benefits of cooperative marine plastic pollution (MPP) management in the North Atlantic. We use an ocean model to generate a transfer matrix showing how plastics move across the North Atlantic. This is combined with game theory and estimates of benefits and costs to derive the potential net benefits of international cooperation. A fully cooperative outcome across 16 countries leads to a substantial reduction in MPP, resulting in significant aggregate annual net benefits. However, MPP reduction burdens are unevenly spread across countries. Constraining the agreement to avoid such consequences results in both less MPP reduction and lower aggregate benefits. As the United Nations works on a future global plastic pollution treaty, these results demonstrate that close cooperation will be a critical determinant of its success.

At the time of submission, this work was under review for publication (de Vries et al., 2023).

References

Frans de Vries, Nicola Beaumont, Tobias Börger et al. Significant benefits from international cooperation over marine plastic pollution, 14 November 2023, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-3328986/v1]

Modelling the influence of conservation zoning on the Great Barrier Reef ecosystem

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Abstract

Australia's Great Barrier Reef (GBR) is made up of almost 4000 reefs and covers an area larger than Great Britain and Ireland combined. It is primarily managed through a zoning system that regulates where fishing is permitted. Zoning influences not only fish populations, but also the broader reef ecosystem through trophic cascades. Importantly, fish targeted by commercial and recreational fishers include predators of the crown-of-thorns starfish (CoTS, Acanthaster spp.), which can reproduce rapidly to form outbreaks capable of decimating coral populations over large areas of the GBR. This has led to concerns that fishing pressure may increase the susceptibility of some reefs to destructive CoTS outbreaks. We describe progress in modelling the effect of zoning on the GBR ecosystem using the Coral Community Network model (CoCoNet). This model represents food web interactions between fish, corals and CoTS on reefs exposed to increasing cumulative pressures from tropical cyclones, marine heatwaves and CoTS outbreaks. It also includes the influence of human activities, such as commercial and recreational fishing, as well as control of CoTS using integrated pest management approaches. Ensemble simulations suggest that commercial fleet reductions and comprehensive zoning (fishing excluded from one third of reefs) introduced in 2004 significantly benefited reef health. However, the benefits of any further zoning initiatives are likely to be modest as coral mortality increases with climate-driven heat stress.

Use of the result of simulations with FVCOM in the zoning of a Multiple-Use Marine Protected Area

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Abstract

In the north-central area of Chile, the Humboldt Archipelago Multi-Use Coastal and Marine Protected Area was created in 2023. This area, a product of the upwelling at the Lengua de Vaca and Choros Points combined with the topography and bathymetry presents a high retention that favors primary and secondary production that favors the abundance of macroalgae, invertebrates, fish, seabirds, and marine mammals. Some species in the area are classified in one of the threatened categories (Vulnerable, Endangered, or Critically Endangered) and require conservation measures. Fishing and ecotourism activities are carried out in the area, but mega ports and desalination plants have been proposed to be built, which can severely affect biodiversity in the archipelago. We used the results of the FVCOM simulations and particle tracking (PyLag) of the study of the annual and interannual variability (La Niña 2010-11, El Niño 2015-16, and Neutral Condition 2019-20) of the dynamics of the Lengua de Vaca Point – Choros Point upwelling system, in combination with the information of the chlorophyll-a satellite data, production and biological information of Areas of Management and Exploitation of Benthic Resources, to define areas of General Use, Habitat Protection, Buffer, Scientific Research, no-take areas, Navigation Zone, Recreational, Anchoring, and Mooring. The information from simulations was analyzed with empirical orthogonal function to integrate and resume the variability of the environmental variables (temperature, salinity, current components, time of residence, etc). Finally, using the method of self-organized maps we propose the zoning Humboldt Archipelago Multi-Use Coastal and Marine Protected Area.

Using social influence modelling to plot a pathway out of marine-based conflict.

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Abstract

Conflict between stakeholder groups around social and environmental issues can fragment communities and disrupt development. Attempts to mitigate these conflicts have often been counterproductive due to high levels of distrust between stakeholder groups. A lower risk approach is to evaluate strategy options within a socio-ecological systems model prior to real-world implementation. This approach enables the responses of different stakeholders and their contribution to overall conflict to be explored and assessed under a range of conflict management strategies.

We have used an agent based social influence model to simulate stakeholder attitudes to the controversial Tasmanian salmon industry. The model includes the influences of individuals, stakeholder groups, and the broadcast media. Simulation results provide (i) accurate and detailed hindcasts of major tipping points from population consensus to high conflict discourse; (ii) better understanding of the drivers and dynamics of conflict between stakeholder groups; and (iii) a platform for forecasting and quantitatively evaluating strategies and policies aimed at reducing conflict. While demonstrated in the context of salmon aquaculture, the methods and key findings are currently being deployed across a broader range of environmental issues including seaweed farming and offshore wind energy.

Modelling cross-jurisdictional management interventions for Australia's Great Southern Reef

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Abstract

In large complex ecosystems, cumulative pressures can have large impacts on habitat quality and biodiversity. These pressures, including ocean warming, extreme weather events, and overfishing, are significantly altering Australia's temperate reef ecosystems, which together form the Great Southern Reef. Renowned for its kelp forests and biodiversity hotspots, the Great Southern Reef encompasses over 8,000 km of coastline and covers approximately 71,000 km^2 of seabed surrounding the southern half of Australia. However, tropicalisation and warming rates locally surpassing 3 to 4 times the global average are leading to decline in key ecosystems across the region. Currently, management interventions operate on a state-by-state basis, creating difficulties in addressing cumulative pressures occurring over larger ecological scales. Identifying these pressures and evaluating current and novel management strategies, both on a state-level and across temperate reefs of southeast Australia, will help design a more socio-ecologically sustainable pathway. We will describe preliminary progress in developing agent-based models of the Great Southern Reef, with a view to exploring future ecological trends and evaluating alternative management strategies, potentially applied across multiple sectors at multiple scales.

Deriving pre-eutrophic conditions from an ensemble model approach for the North-West European Seas

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Abstract

Within organisations dealing with marine management (e.g. the EU, OSPAR, HELCOM) there is a need to quantify both anthropogenic marine disturbances and the effects of targeted policies to combat them. To achieve this a benchmark needs to be chosen that represents either the undisturbed state or a desired state of the marine environment. With respect to the known problem of marine eutrophication (excess growth of algae due to excess nutrient input) in Europe this would represent a state before widespread eutrophication occurred in European coastal waters. However, the pre-eutrophic state of marine waters is hard to estimate as historic observational evidence is scarce and untouched conditions are virtually non-existing nowadays. Here, we use marine ecosystem models in a weighted ensemble approach to derive pre-eutrophic conditions for Northeast Atlantic marine waters, which can serve as a benchmark for policy purposes. Eight modelling centres from around Europe participated in the ensemble, using the same inputs and boundary conditions as much as possible to ensure compatibility. The pre-eutrophic state was defined as around 1900, thus after the start of the industrial revolution but before the invention and wide spread use of artificial fertilizer. Participants simulated the years 2009-2014 with both current and historic nutrient inputs, to ensure differences were solely due to the changes in nutrient inputs between the scenarios. Mean values were reported for eutrophication indicators like winter dissolved inorganic nutrients, (nitrogen, phosphorus), the nitrogen to phosphorus ratio, growing season chlorophyll, near-bed oxygen minimum and net primary production on the level of the OSPAR eutrophication assessment areas. Results show distinctly lower nutrient concentrations and N:P ratio's in coastal areas under pre-eutrophic conditions compared to current conditions, with differences up to 40% (dissolve inorganic phosphorous, chlorophyll) or even 60% (dissolved inorganic nitrogen) in some areas. The weighted average approach reduced model disparities, and delivered pre-eutrophic concentrations in each assessment area. Our results open the possibility to establish reference values for indicators of eutrophication with a consistent methodology across marine regions. These reference values formed the basis for threshold estimates for eutrophication parameter, facilitating policy discussion on their implementation within OSPAR.

Potential impacts of offshore hydrogen production on seasonally-stratified coastal waters

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Abstract

The urgent need to replace fossil fuels is driving the development of green hydrogen production. Due to the high water and energy requirements of the production, offshore hydrogen in combination with offshore wind energy offers a promising opportunity. Offshore hydrogen production involves high water usage, desalination of sea water, and the generation of heat during production processes. At present, the waste heat and brine generated during production are intended to be recycled into the ocean, which has potential effects on ocean temperature and salinity. This study aims to understand the anthropogenic footprint of offshore hydrogen production on hydrodynamics using the German offshore hydrogen plans as an example. Numerical simulations were used to investigate the effects of high-temperature and high-salinity water from hydrogen production on summer stratification and circulation. While using available information for volume and mass fluxes at a 500 MW platform, this study examines different recirculation scenarios to determine the impact of offshore hydrogen and how to possibly minimize environmental changes. Initial results indicate that offshore hydrogen can have a similar impact on local stratification as wind and turbulence effects from the surrounding offshore wind turbines, depending on the platform's production capacity. This study aims to assess the significance of the offshore hydrogen effects in the context of existing anthropogenic pressures and propose sustainable development options for future offshore hydrogen production.

Cumulative effects of Offshore Windfarms on the future North Sea ecosystem

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Abstract

The North Sea has become a region, in which several economic sectors compete for space while at the same time marine protected areas and conservation measures are installed. Since the marine ecosystem is highly dynamic and interconnected, none of these sectors and their impacts can be considered independent from the others. Therefore, our research aims at understanding the effects of the individual stressors on the marine environment as well as the interactions and connectivity they have in the limited space of the North Sea. Here we present first analysis from scenario simulations with a 3d coupled ecosystem model ECOSMO-E2E, which covers the marine ecosystem from nutrients to macrobenthos and fish.

The objective of the study is to understand the cumulative effects on the North Sea ecosystem caused by large scale offshore windfarm clusters. We will particularly explore the interplay between large scale structural changes in the marine ecosystem caused by modifications of the atmospheric conditions and direct interventions, such as fishing closure. For this purpose, we will present a suite of simulation scenarios, in which we i) explore the effect of the individual processes on changes in primary, secondary and tertiary production of the North Sea ecosystem. ii) We will combine the processes to quantify the importance of the effects relative to each other.

The scenarios will be performed for a near future wind farm scenario that includes existing and planned large scale OWF clusters. Previous results have shown that the ongoing OWF developments can have a substantial impact on the structuring of the lower trophic part of the coastal marine ecosystems. However, the subsequent effect on higher trophic level production and the combination of effects on the latter remain unclear. With the proposed study we present baseline information on how changes related to the installations of large-scale offshore windfarm clusters effect the ecosystems productivity and how this is transferred through the food chain. By that, we want to raise awareness for the expected scales of human interventions and the connectivity of marine systems, and provide a knowledge base for supporting coastal management and monitoring.

From Shipping to the Ecosystem: A Coupled Model System Based on Observations Details the Influence of Scrubber Discharge to Support Marine Environmental Protection Measures

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Abstract

The use of scrubbers on seagoing ships has become widespread since the introduction of international regulations (MARPOL Annex VI) to reduce sulphur oxide (SOx) emissions in the maritime industry. There are environmental concerns regarding the release of scrubber discharge water as not only SOx but also other pollutants from the exhaust gas such as heavy metals, oil residues and polycyclic aromatic hydrocarbons (PAH) are discharged into the marine environment. To estimate the environmental impacts from scrubber discharges, we built a three-dimensional model system for the North Sea and Baltic Sea simulating the contaminants' physical dispersion as well as biogeochemical effects.

This model system consists of an information chain ranging from data on ship movement and a model of scrubber discharge water to a coupled hydrodynamic-biogeochemical-pollutant model. Contaminant composition as measured on board four ships, revealed nickel and vanadium among heavy metals as well as persistent and bio-accumulative PAH that may cause short- and long-term detrimental effects. These pollutants have been implemented into the biogeochemical model as a new module, and influence the ecosystem e.g. via toxic effects on plankton as well as pH and thus, gas exchange with the atmosphere. While other models have been developed before to study the passive distribution of pollutants from shipping, this is the first to include the direct impact on the matter cycle.

Results show increased levels of discharge water and respective contaminants along frequent shipping routes. Common currents in both seas and tidal flow in the North Sea lead to increased concentrations in river outlets and bays but also in coastal Marine Protected Areas such as Sylt Outer Reef. However, accumulation and different toxicity impacts of the pollutants reveal differences between passive tracer distribution and 'active' impact on other ecosystem components. Furthermore, emission scenarios determine the effect of possible discharge restrictions.

The findings provide a much-needed overview on vulnerable areas and supports the development of protective measures based on different scenarios. These scientific-based results also support the implementation of the EU MSFD (descriptor 8 "contaminants").

Exploring fish aggregation dynamics in POSEIDON, an Agent-Based Model, by simulating the Eastern Pacific Ocean tropical tuna fishery

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Abstract

Balancing the behavioral responses of fish and fishers to changes in their environment remains a critical challenge of modeling fisheries. Agent-based models (ABMs) are well suited to capture the motives of individual fishers and highlight the emergent, group-level, properties which can inform management decisions. When a sociological ABM is coupled with the complex fish dynamics of an ecological model, we can extract information about the fishery system that may not be captured from either the biological, social, or economic dimensions individually.

POSEIDON is a socio-ecological ABM which is used to simulate the Eastern Pacific Ocean tropical tuna fishery. We tested a series of aggregation algorithms to improve POSEIDON's ability to produce catch compositions seen in fishery observer data. POSEIDON implements the biologies of three tropical tuna species, the decision processes of purse seine vessels, and interactions with fish aggregation devices (FADs), using simple but adaptive agents. Fisher agents use a planning algorithm to deploy and fish upon drifting FADs which aggregate fish over time. The aggregation algorithm was treated with a series of calibration parameters and a full calibration was run and target diagnostics were compared.

Once calibrated, this model evaluated the FAD fishery across a spectrum of biological, ecological, and economic criteria. We identified the aggregation algorithm that best replicated the observed catch composition and distribution of the three species.

Advancements in Modelling Early Life Stages: A focus on Atlantic Iberian Sardine.

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Abstract

Regional projects Phys2Fish and CLONES are intended to develop End-to-end models applied to fisheries, focusing on three species of economical and ecological interest for Galicia, NW Spain: sardine , European hake and octopus. In this Abstract, we will focus on the advances and improvements in the implementation of a Lagrangian Individual Based Model (IBM) to simulate the early life stages of the Atlantic Iberian sardine. The starting point is the model published in García-García et al. (2016) that has been translated from Ichthyop to OpenDrift. The study of the early life stages of pelagic species by means of Lagrangian IBM models allows us to better understand the physical and ecological processes that occur until the larval settlement, which are known to have a major influence on species recruitment and connectivity.

The sardine Lagrangian IBM in Opendrift considers physical transport phenomena such as advection and dispersion and biological behavior, including particle stage (egg or larvae), variable egg buoyancy with development, and larvae growth depending on temperature and food (zooplankton). The three-dimensional velocity, temperature, salinity, vertical diffusion, and zooplankton fields that force offline the Lagrangian model are obtained from a hydrodynamic and N2PZD2 biogeochemical configuration of ROMS for NW Iberia. In this presentation we will present the model and explore the effect on survival and hence recruitment and connectivity of the interannual variability of the sardine spawning grounds using data collected by ichthyoplankton surveys carried out by the IEO. We will also explore different growth behaviors for larvae that feed from zooplankton and study the impact on the final results in comparison with the recruitment estimates calculated by ICES every year. Finally, the experience gained from moving from a Lagrangian software (Ichthyop) to another (OpenDrift) or testing different hydrodynamic models will also be shared to discuss the effect of the model choice.

Is harvesting of mesopelagic fish stocks sustainable?

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Abstract

Recent survey work has indicated that mesopelagic fish are considerably more abundant globally than previously thought, raising the possibility of commercial harvesting. In the northeast Atlantic the glacial lantern fish *Benthosema glaciale*, and Mueller's pearlside *Maurolicus muelleri*dominate much of the mesopelagic fish biomass and are the focus of the EU Horizon 2020 MEESO project aimed as investigating the sustainability of opening new mesopelagic fisheries. In addition to questions relating to the sustainability of fisheries under present conditions, climate change presents serious challenges to the management of fish stocks, both through direct effects of changing temperature and by indirect effects of changes in the surrounding ecosystem. For the long-term sustainable exploitation of stocks it is clearly essential to have some understanding of the likely climate-driven changes in stock abundance, productivity, and shifting geographic distributions. Harvest rates that are sustainable under the status quo may not necessarily be so in the future.

Here we present results from new spatial population models developed as part of MEESO for addressing some of these challenges for *Benthosema*and *Maurolicus*. Our approach involves a discrete-space and discrete-time length-structured population model. Individual growth depends on the local environment (temperature and food availability), while movement depends on advection and biodiffusive transport. The model is parameterised by limited demographic and survey data on these species, including recent data gathered by the MEESO project. The physical and biological drivers are taken from existing physical-biological ecosystem model outputs (NEMO-MEDUSA model), including an RCP8.5 climate change projection. Calculating the environmental drivers offline means the model is very fast to run, thereby enabling easy parameterisation and harvesting scenario explorations. Our results indicate that climate change will result both in shifting ranges for both species, changing stock biomass, and large changes in yield curves on decadal time scales.

Keynote

Digital twin simulations support resource management decisions in a complex coastal ecosystem with Salmon aquaculture

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Abstract

The response of coastal ecosystems to anthropogenic nutrient enrichment is challenging to observe due to multiple nutrient sources, rapid transformations and the limitations of nutrient sampling methods. Early detection of broadscale impacts are particularly difficult to distinguish from the natural temporal evolution and variability present in coastal waters. We use the CSIRO Environmental Modelling Suite to construct a 3D digital twin simulation of water quality in southeast Tasmania, to quantifying the impact of expanding salmon aquaculture (Wild-Allen et al., 2023). This region includes multiple estuaries, complex coastal morphology and is influenced by seasonally modulated ocean boundary currents. The biogeochemical numerical model was statistically validated against observations from satellites, moorings, landers, gliders and discrete samples over a hindcast period of 5 years to confirm that it was 'fit for purpose'. Simulations characterise the variability in regional circulation, nutrient supply, water quality and sediment dynamics. Multiple digital twin scenario simulations (with more or less salmon aquaculture) predict changes in water and sediment quality due to contrasting nutrient load. Near real time digital twin simulations have the potential to distinguish anthropogenic nutrient impacts from natural variability and show the drivers of the variability observed in monthly monitoring data. This research is informing environmental regulators making decisions on the future expansion of salmon aquaculture in the region.

Wild-Allen, K., Andrewartha, J., Baird, M., Beardsley, J., Brewer, E., Bodrossy, L., Eriksen, R., Gregor, R., Griffin, D., Herzfeld, M., Hughes, D., Jansen, P., Langlais, C., Margvelashvili, N., Martini, A., McMahon, M., Revill, A., Rizwi, F., Skerratt, J., Schwanger, C., Sherrin, K., Frydman, S., Wild, D. (2023) Storm Bay Biogeochemical Modelling and Information System: supporting sustainable aquaculture in Tasmania (FRDC 2017-215) Final Report. CSIRO Oceans & Atmosphere, Hobart, March 2023.

Impacts of blue mussel mitigation farms in coastal ecosystems: Skive Fjord, Denmark, a model study

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Abstract

Mussels play a crucial role in many coastal ecosystems and estuaries, as they mediate the benthic-pelagic coupling through activities such as filter-feeding. In recent years, mussel aquaculture production for human consumption has been increasing in Denmark. It has also been suggested that mussel aquaculture can help mitigate the effects of eutrophication by removing nutrients from the system through mussel harvesting. To assess the impact of blue mussel mitigation cultures on water quality in a eutrophic semi-enclosed fjord system, Limfjord, Denmark, an individual-level mechanistic model for blue mussel growth was scaled up to the farm-level. It was then incorporated into a coupled hydrodynamic-biogeochemical estuary model setup for the fjord system. This poster presents the model results on the effects of blue mussel mitigation cultures on water quality and the light environment, both at the farm and basin scale. We also discuss the reliability and significance of the model results by comparing them to previous studies and observations, focusing on their implications for management and policy support.

Potential and uncertainties of ocean alkalinity enhancement in the Baltic Sea according to *in-silico* experiments

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Abstract

With the aim to keep the increase in global temperature by 2100 under 2 °C, the EU has set the goal to become carbon neutral by 2050. Germany intends to achieve this target even 5 years earlier. 2023 broke yet another record as the hottest year in recorded history, making it clear that these targets will be challenging to meet. Even with the necessary drastic reductions in CO2 emissions, these goals will likely not be met without the additional use of carbon removal methods.

One marine-based approach to carbon removal is ocean alkalinity enhancement. Natural rock weathering produces alkalinity, raising the ocean's capacity to absorb atmospheric carbon dioxide while potentially buffering ocean acidification. This process can be accelerated by adding silicates or calcium carbonate and thus be used for carbon dioxide removal (CDR).

Using a coupled hydrodynamic and biogeochemical ocean model of the Baltic Sea, we simulated the release of calcite near the sediment as a proxy for ocean alkalinity enhancement. Simulations were run with and without the inclusion of a benthic weathering machine for both a release location at the shallow coast and one in a deep basin. While this made no difference for the deep basin, it resulted in a lower and an upper limit of calcite dissolution at the shallow coast site and therefore the consequent net CO2 removal. The release locations also differed substantially in efficiency and timescales of CO2 uptake. As the calcite saturation level appears to be the main limiting factor of the method, the CO2 removal potential of a release location cannot be upscaled infinitely by adding more calcite to the location.

Our results show that ocean alkalinity enhancement using calcite may have potential in the Baltic Sea. However, safe and responsible deployment of this CDR method in Germany and other Baltic states requires further research into localised dissolution rates, the alkalinity budget of the Baltic Sea and the impact of and on environmental factors of ocean alkalinity enhancement using calcite.

Modelling the spatio-temporal variability of the variegated scallop *Mimachlamys varia*, in order to help restoration habitat effort in the bay of Brest (French Atlantic coast).

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Abstract

Since several years, toxic blooms of micro-algae of the *Pseudo-nitzschia* genus occurred regularly on the French coast. The domoic acid toxin produced by these algae is then bioaccumulated in the tissues of filter-feeding organisms such as bivalves, sometimes making them dangerous for human consumption. The King scallop, *Pecten maximus*, an important fishery resource in France exhibits a slow self-detoxification, and its fishing can therefore be prohibited for several months at each episode of toxic bloom. A shifting of fishing effort is then possible on another pectinid, the variegated scallop *Mimachlamys varia*, but whose stocks are currently low. In Brest Bay (French Atlantic coast), the situation is such that fishing has been banned since 2018. An ongoing project (Mascoet project) is partly focusing on the ecological restoration of this scallop's habitat in the bay by creating artificial reefs in order to facilitate the species re-establishment and thus boost population dynamics. This restoration requires to better identify the favourable areas in the bay for growth and reproduction.

In this context, an ecophysiological model based on the DEB theory was developed that allows to better understand growth and reproduction dynamic of the species. In this study, we used the DEB model associated with a 3D ecological model of the bay of Brest to analyse the spatial and temporal variabilities of growth and reproduction potential of *M. varia*. The ECO-MARS3D ecosystem model provides realistic simulations of the environmental parameters that are essential for bivalve growth: temperature, chlorophyll and turbidity. The 3D model has a spatial resolution of 250 m and was run on several years providing daily-averaged 3D fields of environmental variables that are used to force the DEB model. This offline coupling produces maps (monthly, annual, average, etc.) of growth and other direct or indirect variables (fecundity, condition index, gonado-somatic index, date of 1st spawning, …) that allow to analyse spatial and temporal variability and identify optimal conditions for growth, reproduction and survival that can be used to optimized restoration effort.

The direct and indirect impacts of harvesting mesopelagic fishes on carbon export

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Abstract

The mesopelagic fishes are becoming an appealing potential raw material source for aquaculture fish production due to their high fat content and vast biomass in the marine realm. However, their role in marine ecosystems and the food web remains poorly understood. Before exploiting the mesopelagic fishes, it is crucial to assess their impacts on the food web dynamics and marine biogeochemical cycles. In this work, we developed a coupled one-dimensional biogeochemical model and a higher-trophic-level food web and fisheries model to explore: (i) the direct contribution of mesopelagic fishes to the gravitational carbon export through their metabolic releases and mortality, (ii) the active transport of carbon from surface waters to the ocean interior by the diel vertical migration of mesopelagic fishes, (iii) the indirect control of mesopelagic fishes on carbon export through predating on zooplankton, (iv) the direct and indirect impacts of harvesting mesopelagic fishes on carbon export due to altered biomasses in the entire food web. Our results indicated that the contribution of mesopelagic fishes to carbon export varied with depth. In the euphotic zone (i.e. 0-200 meter depths), mesopelagic fishes accounted for nearly 6% of the total carbon export. Actively transporting carbon from the euphotic zone to their daytime residence depth (i.e., 400-600 meter depths), they contributed to 40% of the total carbon export at this depth. Harvesting mesopelagic fishes reduced the mesopelagic fish driven carbon export; however, enhanced non-mesopelagic fish driven carbon export and decreased phytoplankton driven carbon export. This study emphasized the importance of adopting a holistic perspective while investigating the consequences of harvesting mesopelagic fishes, by considering the potential changes in mesopelagic fish biomass and the entire food web.

The bio-physical impacts of offshore wind turbines in the North Sea

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Abstract

The offshore wind industry remains one of the fastest growing marine industries in Europe. With more offshore wind farms (OWFs) planned around the UK, it is imperative to evaluate the potential impacts of large-scale OWFs on the marine environment. Most offshore wind developments to date have been in well-mixed, i.e. unstratified shallow waters near to the shore. New wind farms will develop in stratified waters potentially influencing water mixing and natural stratification equilibrium, which is less perturbed by wind farms installed in coastal, usually mixed waters. The Physics-to-Ecosystem Level Assessment of Impacts of Offshore Windfarms (PELAgIO) project aims to support the development of interdisciplinary policy and marine management through comprehensive observational and modelling campaigns. Using a coupled, high-resolution model (FVCOM-ERSEM) of the UK-shelf, we investigate the impact of OWFs across the North Sea. By incorporating a state-of-the-art wind turbine parameterisation, we model the marine physical and biogeochemical interactions on the shelf both with and without OWFs. Results from this study will help inform policy decisions and the future direction of the UK marine wind energy strategy.

The role of Ecosystem Modelling in Promoting Ocean and Water Literacy

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Abstract

Ocean literacy is often defined as 'the understanding of our individual and collective impact on the Ocean and its impact on our lives and wellbeing'. It encompasses understanding, meaningful communication, through to informed and responsible decision-making. All these components align exactly with the essential requirements for ecosystem modelling that serve the purpose of enhancing and testing our understanding of the world around us. Despite this similarity in purpose, modelling approaches are rarely applied in educational settings, and the many benefits of their use remain largely inaccessible to non-research communities.

The rapid increase in environmental issues led to growing demands for enhanced ocean and water (e.g. lake, river) literacy at all levels, with calls to its inclusion into school curricula worldwide. We argue that ecosystem modelling, utilising systems dynamics approaches which are readily taught to even primary school children, should be integral to this. Such tools provide unique opportunities for merging core science and mathematical skills with the exploration of aquatic ecosystem functioning coupled with scientific investigations of 'what-if?' scenarios. The modelling community can play a central role in the process through forging collaborations with educational communities, introducing them to the world of simulation modelling of the real world. In many ways the student experience, and the modellers efforts, could align with that of video games, but here directed to training and engagement in the design of simple but flexible modelling tools for science exploration and experimentation.

We present some examples of dynamic model applications for Ocean Literacy, including those developed for the Horizon Europe ProBleu project, as well as our vision for the pathway to promote modelling approach in education. Collaborative approaches are critical to the realisation of this vision and will maximise impact towards enhanced Ocean Literacy and environmental stewardship.

"Coral Hospital" concept: a green management approach to coral reef conservation and restoration

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Abstract

The "Coral Hospital" concept, inspired by human hospitals, aims to protect coral reefs by diagnosing and treating heat-stressed corals, ultimately contributing to conservation and restoration efforts. This innovative approach aligns with green management and movement by promoting sustainable practices and eco-friendly initiatives in the context of coral reefs. Coral reefs, home to over a quarter of marine species, are at risk of demise and extinction due to global climate change, and reducing greenhouse emissions and implementing mitigation strategies is crucial to ensure their future. The "Coral Hospital" concept addresses several questions related to coral health monitoring, conservation, and the use of diagnostic data for restoration plans. Additionally, the cryopreservation of coral gametes and genetic materials, along with the establishment of coral cryobanks, conserves coral diversity and contribute to long-term reef preservation. This approach also facilitates the expansion of coral nurseries by local organizations, aiding in reef conservation. In Southern Taiwan, coral convalescence aims to understand optimal seawater conditions for growth. This knowledge helps relocate corals to healthier reefs, part of global restoration efforts addressing threats like climate change. It also provides valuable samples for laboratory experiments and research on coral diseases which is essential for reef health. From a carbon footprint and financial perspective, the idea of transporting sick corals, diagnosing their physiological condition, nursing them back to health, and then re-planting them in situ may seem extravagant. However, the potential benefits of the "Coral Hospital" in understanding coral resilience and maintaining genetic diversity outweigh these concerns. In conclusion, the "Coral Hospital" concept and the cryopreservation of coral gametes and genetic materials, as well as the establishment of coral cryobanks are crucial components of green management and movement, offering innovative solutions for the conservation and restoration of coral reefs. These initiatives contribute to the resilience and long-term sustainability of coral ecosystems, aligning with the principles of sustainable practices and environmental stewardship.

Satellite-based data enables high-resolution monitoring of maritime traffic during a global crisis

Alexandra Loveridge

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Abstract

To monitor the ongoing expansion of human activity on the ocean, and to quantify the impact of disruptive activity on marine systems, there is a clear need to harness both existing and new technologies including AIS satellite tracking and nighttime lights. With over 80% of global trade carried by sea, and 600 million livelihoods depending at least partially on fisheries and aquaculture, promoting increased data fusion by using multiple datasets to identify hotspots of human activity on the ocean is key to supporting decision making. During the COVID-19 pandemic, unprecedented access to human mobility data presented a rare opportunity to quantify global human activity across marine systems. By combining the fields of Earth Observation and human mobility, we demonstrate how satellite-based data can effectively quantify high-resolution human activity on the ocean during a global crisis. We show how VIIRS Boat Detection and AIS satellite tracking data was used to (1) track the pulses and pauses in maritime traffic across 2020; and (2) identify where hotspots of maritime traffic could result in areas of high traffic and wildlife conflict. Results suggest that systems-level responses were highly context-dependent, and we pinpoint areas that experienced significant reductions and spikes in activity. These results enable researchers to strategically target areas for further investigation, in areas where human activity levels changed during the COVID-19 pandemic. This highlights satellite-based data as an important resource for mapping human impacts on the environment not only during acute events, but also across chronic stresses and when conducting analyses on climate change impacts on society. In a human-modified ocean, quantifying peoples' activities on the marine environment on a global scale will provide important insights into anthropogenic impacts, supporting the development of sustainable policy and marine spatial planning. Further integration of such data into marine ecosystem models would significantly boost ongoing efforts to prevent further biodiversity loss and protect vulnerable ecosystems, supporting progress towards a viable sustainable living on an increasingly modified planet.

Seaweed cultivation potential on EU marine regions. A modelling approach

Diego Macias, Olaf Duteil, Elisa Garcia-Gorriz, Jordi Guillen, Nuno Ferreira-Cordeiro, Svetla Miladinova, Ove Parn, Chiara Piroddi, Luca Polimene, Natalia Serpetti, Adolf Stips

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Abstract

The potential of large-scale seaweed cultivation to contribute to achieving ambitious environmental objectives at the EU level, such as food security, energy independence, carbon neutrality, and nature-based restoration, is widely recognized. However, there is a lack of information regarding the suitability of EU marine regions for the installation of floating macro-algae cultivation infrastructures. In this study, we utilized the World Offshore Macro Algae Production Potential (WOMAPP) model in conjunction with state-of-the-art coupled hydrodynamic-biogeochemical models, including the Joint Research Centre Blue2 Modelling Framework and the Copernicus Marine regional models, to assess the environmental suitability of all five EU marine regions for seaweed cultivation. Our analysis indicates that the EU Atlantic regions are the most suitable areas for seaweed cultivation in floating devices, particularly for cold-water and intermediate-water species. The potential cultivation area is extensive, exceeding 1 million km^2, which could yield (even taking a precautionary approach) a yearly production of over 35 million tonnes dry weight. Furthermore, integrated multi-trophic aquaculture (IMTA), which combines seaweed cultivation with fish farming, could significantly expand the potential cultivation areas in the Mediterranean, Black, and Baltic Seas, further increasing the future potential for this activity.

Deep-sea benthic ecosystem recovery after deep-sea mining: a modelling approach.

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Abstract

Though not a recent idea, the deep-sea environment has increasingly become a region of interest for resource extraction. One resource type, manganese nodules, are rich in desirable rare metals and are found mostly at 4500-5500m deep on the sea floor of abyssal plains. There are multiple ways mining would affect the deep-sea environment, including but not limited to direct destruction of organisms and habitats on the sea floor, and burial of surrounding organisms. In such a poorly-understood environment, it is crucial to first understand the magnitude and extent of the impact a disturbance like deep-sea mining has on the benthic ecosystem, prior to commercial deep-sea exploitation. To address this, we use a spatial, size-based seafloor community model to simulate response to a disturbance similar to deep-sea mining activity, whereby a large amount of the living biomass is instantaneously killed. We assess the impacts on all sizes of organisms, particularly their recovery times. We also show how recovery timescales are influenced by both disturbance density (i.e. how closely spaced mining activity is) and organism motility (i.e. all organisms do or don’t move the same, movement increases or decreases with size).

Integrating stakeholder knowledge and observations to assess key vulnerabilities in the southern Benguela system, South Africa

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Abstract

The analysis of risks posed by anthropogenic drivers, including climate change, is key to the sustainable management of marine ecosystems. However, ecosystem assessments are usually confounded by different uncertainty sources such as natural variability, cumulative impacts and limited knowledge of a system. Here, we used Bayesian Belief Networks (BBNs) integrating qualitative (stakeholder knowledge) and quantitative data to conduct a risk assessment of key vulnerabilities in the southern Benguela system. Key sectors, pressures and ecosystem components contributing most towards the risk of ecosystem degradation were identified using the Options for Delivering Ecosystem-Based Marine Management (ODEMM) approach through a review of available literature and stakeholder consultations. We investigate changes in risk levels from key sectors (i.e. fishing, shipping and oil and gas) on ecological components and ecosystem services provided by this system. Climate scenarios and potential management strategies are also evaluated, while accounting for the uncertainty in predictions for the southern Benguela system**.** The probability of minimising the risk level from the key sectors while achieving socio-ecological objectives is estimated.

A model-based, generalised eutrophication index for European Seas

Luca Polimene, Ove Parn, Elisa Garcia-Gorriz, Diego Macias, Adolf Stips, Olaf Duteil, Nuno Ferreira-Cordeiro, Svetla Miladinova, Chiara Piroddi, Natalia Serpetti

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Abstract

We present a new index to identify marine areas affected by eutrophication, a widespread environmental problem. Differently from traditional approaches based on biogeochemical concentrations measured in the field, we use ecosystem functions (primary production and grazing) simulated by marine biogeochemical models. We start from the assumption that, in a healthy environment, newly produced carbon is consistently transferred to higher trophic levels. According to this, areas where increased primary production is not mirrored by a linear or steeper increase in grazing are classified as affected by eutrophication. The index was tested in the Baltic Sea, using an established biogeochemical model already implemented in that basin. When compared with (modelled) traditional indicators, the new index provides a substantially different picture of the eutrophication status of this sea. The proposed approach is a means to rethink how to define, assess and manage marine eutrophication.

Impacts of Bottom Trawling on Carbon Dynamics in the North Sea: Insights from a Coupled Physical-Biological-Carbon Model

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Abstract

Understanding the factors influencing the carbon system of marine ecosystems is crucial for assessing the impacts of human activities on carbon dioxide (CO_2) exchange between the atmosphere and the sea. Bottom trawling disrupts natural carbon flows through sediment resuspension, but reliable estimates of this effect have proven difficult to compile due to the complexity of processes involved. In this study, we utilize the three dimensional coupled physical-biological model SCHISM-ECOSMO, which includes a carbonate chemistry module, to elucidate physical-biogeochemical impacts of bottom trawling on the carbon cycle of the North Sea. We evaluated the effect of bottom trawling for the period 2000-2005 using two model simulations. The first simulation includes only natural resuspension, while the second experiment also considers a parametrization for bottom trawling-induced resuspension. Daily forcing for bottom trawling resuspension rates was generated based on available data of fishing activity, including the position, size, and engine power of individual vessels, combined with estimated resuspension rates of various fishing gears in different types of sediment. Based on the simulation results, we examine trawling-induced impacts on particulate organic and dissolved inorganic carbon, alkalinity and air-sea exchange of CO_2 in the system. Our study offers valuable insights into the consequences of ongoing bottom trawling in the North Sea carbon system. The results and the modelling framework offer support in assessing the impacts of different marine management measures, such as trawling exclusion zones.

Keywords: Carbonate, Air-sea flux, North Sea, bottom trawling, remineralization.

Theme 3:

Model mechanics

Modelling impact of climate change on distribution and population dynamic of marine megafauna a new dynamic modelling approach

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Abstract

Marine megafauna often present complex life strategy with use of feeding and breeding grounds, long migrations, and life spans of decades. Modelling them needs to take these aspect in consideration and often uses statistical approaches to explore impact of future changes. We present here an approach that combines species distribution model (SDM), Dynamic Energy Budget (DEB) theory and agent based population model to a) develop a new modelling framework for marine megafauna and b) explore impact of climate change on two different species: the leatherback turtle (*Caretta caretta*) in the Mediterranean Sea and the bottlenose dolphin (*Trusiops truncatus*) in the Northeast Atlantic. We will showcase the modelling approach (see attached figure)its results, and, its potential for preservation effort as well as nature based solutions in changing oceans.

Unveiling spatio-temporal dynamics of the Great Barrier Reef using connectivity kernels

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Abstract

Assessing ecological indicators is crucial for understanding the dynamics of spatially structured ecosystems, particularly those dominated by sessile species. In such environments, the level of connectivity between habitats, such as islands and reefs, serves as a critical ecological indicator and key input into ecological models. This study focuses on the Great Barrier Reef (GBR), a highly spatially structured ecosystem consisting of almost 4000 coral reefs that face increasing cumulative pressures from tropical cyclones, heat waves, and predation by crown-of-thorns starfish (CoTS). While hydrodynamic models have been combined with particle tracking techniques to derive reef connectivity matrices for the GBR, the size and diversity of the system limited the number of spawning events that could be modelled, thereby underestimating the range of potential connections. We have addressed this issue by deriving connectivity kernels, which sacrifice the precise pairwise description of connectivity matrices to gain a more general description based on probability density functions. As well as providing new insights into the strength and spatio-temporal variability of connections between different sectors of the reef ecosystem, connectivity kernels provide unlimited (but realistic) combinations of connections to support ensemble modelling of the broader ecosystem. Capturing the full range of potential connectivity variability is becoming increasingly important as ecosystem models are used to provide future projections of reef health and evaluate the efficacy of proposed restoration and adaptation strategies.

Modelling the early marine migration of Atlantic salmon

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Abstract

Atlantic salmon (*Salmo salar*) populations have suffered declines across their range in recent decades, largely attributed to decreasing marine survival rates. The first few months spent at sea are thought to be a period of particularly low and variable survival, possibly driving this trend.

In this study, we simulate the migration of Atlantic salmon from rivers around Ireland and Scotland over their first three months at sea. Our model combines a Lagrangian particle tracking model (FVCOM i-state Configuration Model) with an active swimming (behavioural) model. The model is driven by a high-resolution ocean model (Scottish Shelf Waters Reanalysis Service), which provides a 27-year hindcast.

In the development of the active swimming model, we consider three behaviours: swimming in the direction of local ocean currents, swimming in the direction of the local increasing salinity gradient, and a directional component (representing the use of magnetic cues). Combinations of these behaviours are systematically tested, including transitions between them. We find that all three behavioural components are necessary for an effective migration model. We additionally find that the movement model is specific to a group of rivers within a closed region and cannot be applied universally; this is as expected, given the distinctness of salmon populations.

By running our model (particle tracking + all behavioural submodels) over 27 years, we investigate year-to-year changes in modelled migrations, in terms of the paths taken, the speed of migration, or the time spent in coastal waters. These metrics are found to be correlated with local surface currents and salinity. Differences in modelled migrations among rivers are explained by qualitative differences in their required migration routes.

Future work involves developing a parsimonious set of movement models to simulate early marine salmon migrations from rivers around the entire British Isles. Following this, modelled spatial distributions of salmon will also be combined with spatial measures of zooplankton energy, acting as an indicator of marine conditions for migrating salmon. This will be implemented into a decision support tool for river managers.

Copepods in Arctic seas: implementing an effective dialogue between models and in situ imaging

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Abstract

Copepods are tiny crustaceans that dominate the abundance and biomass of marine zooplankton communities in the rapidly changing Arctic seas. In these harsh environments, copepods represent both a significant source of energy for higher trophic levels such as fish and whales, and a key component of the biological carbon pump that sequesters carbon in the deep ocean. When food availability reduces as winter approaches, copepods enter a period of diapause during which they migrate to deep water and survive for several months on their large lipid reserves. Copepods have aptly optimized crucial trade-offs, such as the one between survival and feeding. Such trade-offs create an evolutionary pressure leading to the emergence of functional traits, which are morphological, physiological or phenological features measurable at the individual level and impacting fitness via growth, reproduction or survival. Since Arctic ecosystems are increasingly pressured by the accelerating impacts of climate change, known as Arctic amplification, major shifts in the copepods' phenologies are expected (e.g. timing of entry and exit of diapause), and in the composition of the communities' functional traits as well. The aim of this study is to use in situ observations to constrain the uncertainty of a copepod IBM. The model generates populations of copepod-like "agents", called compupods, defined by a set of traits (e.g., weight, lipid reserves, activity level) according to a given environment (prey availability and temperature). Using in situ images of copepods collected by two imaging devices within Baffin Bay, Canada, we will assess the model accuracy and relevance for simulating the seasonal dynamics of copepod functional groups. To do so, the existing model will be calibrated for Baffin Bay where a detailed series of observations has been collected over the past 10 years on copepods using recent imaging methods. The model calibration strategy involves the use of in situ observations of copepods' functional traits from images to estimate model parameters, and the automation of calibration using optimization algorithms. Our work will improve our understanding of the ecology of copepod communities in response to the rapidly changing environment of Arctic seas.

Study of the influence of biogenic habitats on the distribution of Australian marine fauna

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Abstract

Foundation species create complex three-dimensional structures able to shelter a variety of species. But the biogenic habitats they form are vulnerable to anthropogenic pressures. Those habitats will likely have an impact on the way coastal biodiversity responds to environmental changes. Understanding and predicting the effects of their loss and degradation is still a challenge. Biogenic habitats are found to have a positive influence on biodiversity at local scales, but studies at large scale and with multiple habitats considered are rare. The present study aims to understand the influence of biogenic habitats on the distribution of coastal species at the scale of Australia. To do so, species distribution models built with environmental variables are compared to models built with biogenic habitats variables. Another goal in this study is the identification of how the influence of biogenic habitats varies with the species and the way to describe the biogenic habitats considered. The inclusion of variables describing the habitats revealed a slight improvement of model performance compared to models using only environmental variables. If this influence is weak for most species, it can be quite strong on less frequent species and in certain taxonomic groups. The different ways to describe the biogenic habitats used have similar performances. This study is a first step in using biogenic habitats to study the future of coastal biodiversity in the face of environmental change and identifies the main challenges and ideas to develop.

From physics to fish: impact of two-way coupling between a higher and lower trophic level model on carbon cycling on the North West European Shelf

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Abstract

Fish provide a critical food supply to the human population with environmental change and anthropogenic pressures modifying global fish stocks and biomasses. It is imperative to understand the ecosystem interactions between bottom up and top down processes in controlling both plankton and fish biomasses in order to make future predictions of the marine ecosystem. Typically a one-way coupling modelling approach is used to model fish biomasses with no feedbacks occurring in the lower trophic level model due to fish predation. Here we have 2-way coupled the lower trophic level model, ERSEM, to the community size spectrum fish model, MIZER, to produce a complete model chain from photons to fisheries. We use the model to investigate the impact of two-way coupling on predictions of carbon cycling on the North West European Shelf. To successfully couple the two systems, clearance rates of fish and mortality rates of mesozooplankton were reduced suggesting the parameterisation in one-way coupled models is not adequate to capture the dynamics of real ecosystems. Our results indicate that mesozooplankton was the most sensitive group to two-way coupling with a decrease in mean annual biomass observed across the shelf in addition to changes in phenology. Overall two-way coupling decreased carbon cycling across the North West European Shelf driven by the top down pressures on meszooplankton reducing their production of organic matter and consequently weakening the microbial loop. This new model system can be used to improve prediction of the impacts of climate and anthropogenic change across the entire marine ecosystem.

Trait-based modeling of marine mesozooplankton feeding strategies at global-scale

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Abstract

Comprising a wide variety of organisms, marine zooplankton are essential in marine food webs and biogeochemical cycles. They play a key role in energy transfer from primary producers towards higher trophic levels and actively contribute to the biological carbon pump. Indeed, they convert ingested organic matter into both recyclable dissolved organic matter and nutrients, produce particulate organic matter as carcasses, molt, and large fecal pellets that rapidly sink into the water column, and also perform diel vertical migrations that redistribute matter from the surface to the mesopelagic domain.

Zooplankton are generally represented as a single size class or two size classes (micro- (20-200µm) and meso- (200µm to 2cm) zooplankton) in most ocean biogeochemical models. This means that the functional diversity of zooplankton is overall not considered. Yet, studies have shown the key role this diversity can play in ecosystem dynamics and marine biogeochemistry. This argues for the need to develop a more precise representation of zooplankton diversity through functional traits such as size, feeding strategy, reproductive strategy, thermal niches and behavior. While a better representation of zooplankton size diversity has gained attention, feeding strategy, a trait with implications for functions such as energy intake, predation risk, energetic losses and mate finding (inducing trade-offs between gains and costs), has been less studied.

In this study, we implemented several feeding strategies of mesozooplankton in the ocean biogeochemical model PISCES. Three mesozooplankton functional types (PFTs) with their associated trade-offs were considered : cruisers (active swimming feeding on suspension particles), ambushers (passive, relying on a sit-and-wait strategy) and flux-feeders (passively feeding on particle flux). Simulations have been performed using NEMO-PISCES at global scale. Our results highlight the fact that these functional groups have distinct global, regional and vertical distributions as well as different contributions to biogeochemical fluxes. Thus, our findings emphasize the necessity for a better integration of mesozooplankton trophic strategies within global biogeochemical models.

Simulating the relationship between zooplankton size and physiology in a global biogeochemical model, using the statistical method of moments

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Abstract

Zooplankton play a crucial role in maintaining ocean ecosystem and biogeochemical balance. Through grazing, recycling and respiration, they play an integral role in carbon and nutrient cycling and regulate plankton and higher trophic levels biomass. Zooplankton form a diverse group comprising several thousand species and exhibiting a remarkable range of morphological variation. In particular, their size spans several orders of magnitude, from microscopic organisms to relatively large species, which influences their metabolic activity. As a consequence, the overall metabolic rate of zooplankton in a population varies depending on the relative abundance of different-sized zooplankton groups. This variation is attributed to the different metabolic rates of different-sized zooplankton species.

In most global biogeochemical models, plankton metabolism is simulated using dependency functions with temperature and other environmental parameters (e.g. oxygen, pH), but such models often fail to capture the metabolic diversity arising from zooplankton size variation. **One way to address this problem is to explicitly represent different size classes in the models. However, this approach is not ideal because it requires increasing the number of model parameters, which can make it difficult to evaluate the model results.**

Here, we present a novel methodology to represent zooplankton metabolic diversity through the influence of varying body size within the biogeochemical model NEMO/PISCES, which only simulates 2 zooplankton size classes. Using global estimates of zooplankton size distribution as model inputs, we use the statistical method of moments to simulate zooplankton size impacts on its metabolism. This methodology allows representing zooplankton metabolic diversity and its influence on global biogeochemical cycles in a computationally efficient way.

However, the size distribution of zooplankton, employed as model inputs, is currently derived from another model. A perspective to this research is to utilize data-based global size distributions. In conclusion, this research provides essential insights into zooplankton metabolic diversity, which is a crucial step towards understanding how environmental changes may influence their functioning.

Keynote

Uncertainty in modelled zooplankton: what matters and what to do about it

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Abstract

Zooplankton serve as key trophic links and as top-down controls on biogeochemical cycling, including for the biological pump of carbon from the sea surface to the ocean's interior. Despite their significant ecological roles, our characterisation of zooplankton in ecosystem models is generally rudimentary. In particular, oversimplified grazing formulations have received much attention, recently shown to be the biggest uncertainty in marine carbon cycling climate models. It is not just about grazing, however. Most modern global models are missing zooplankton life history traits, zooplankton-mediated fragmention and production of detritus, and coupling of zooplankton mortality with predators. Such omissions put results into question, as well as leaving modellers wondering what to do in the face of data limitations.

Here I provide ideas of ways forward, inspired by the 2024 International Zooplankton Production Symposium's session on "Improving Zooplankton Representation in Models". I showcase studies that highlight important choices about the zooplankton component, and illustrate the potential impact on simulated ecosystem structure and function. I argue that we are under-utilizing model-to-model comparisons, aka sensitivity studies, that inform about what matters and what doesn't. I also discuss how to use this information to direct where we should focus additional model complexity, and what types of empirical data should be prioritized if we want to improve confidence in our model applications and predictions.

An Individual-Based Model of Basking Sharks in Ireland

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Abstract

While basking sharks are largely solitary, they gather in mixed sex aggregations, which can range from two sharks, up to 1,398 individuals. Aggregations may be related to food availability, though some observational evidence suggests feeding is not the sole reason for this behavior. As basking sharks feed on zooplankton at the surface of coastal water, these aggregations can pose a threat to boaters and the sharks themselves.

An individual-based model (IBM) of basking sharks in Inishowen, Ireland, was created in Netlogo. The IBM incorporates zooplankton data from the Continuous Plankton Recorder and localized patchiness of zooplankton on a small scale was simulated. Tests of different shark behavior (only seeking food, only seeking other sharks, a combination of both behaviors) were simulated for 1982-2018. The frequency of shark aggregations and average monthly size of aggregations in the model were compared to sightings data collected by the Irish Whale and Dolphin Group (IWDG) and Irish Basking Shark Group (IBSG).

Simulated aggregations were significantly more likely to match observations collected by the IWDG/IBSG when both seeking food, but also, in select cases, when seeking other sharks. This indicates that aggregations may be significant for both reproduction and food intake. These findings agree with previous research and indicate the need for protective measures in these areas when basking sharks are likely to congregate.

This is the first IBM of basking shark behavior and demonstrates the usefulness of such simulation methods for understanding the behavior of semi-solitary, migratory shark species such as these.

Towards a Lagrangian Individual-Based Model for the Galician Octopus

Luz Maria Garcia-Garcia, Manuel Ruiz-Villarreal, Gonzalo González-Nuevo, Paz Sampedro Pastor, Jaime Otero, Adrián Sanjurjo-Garcia

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Abstract

Regional projects Phys2Fish and CLONES are intended to develop End-to-end models applied to fisheries, focusing on three species of economical and ecological interest in Galicia, NW Spain: sardine, European hake and octopus. In this Abstract we will focus on the implementation of a Lagrangian Individual Based Model (IBM) to simulate the pelagic early life stages of the NW Iberian octopus population. The early life stages of octopus consist of: a) a benthonic egg phase, characterized by the egg strings being attached to rocky shelters where mothers take care of the brooding and b) a pelagic phase after hatching occurring mainly in early autumn. This pelagic phase lasts for around 2 to 3 months, depending on water temperature, during which octopus paralarvae feed on zooplankton and present diel vertical migration before developing their final settling behavior, when they will grow as juveniles up to adults again.

The Lagrangian IBM for octopus has been implemented in OpenDrift and considers the physical transport mechanisms of horizontal and vertical advection and dispersion, and a certain biological behavior affecting the pelagic paralarvae phase. The Lagrangian model is forced offline with the results of a three dimensional hydrodynamic and N2PZD2 biogeochemical configuration of ROMS for NW Iberia. The model considers the most probable hatching locations based on the rocky grounds around NW Iberia, includes diel vertical migration, paralarval growth based on temperature and a settling trend when the paralarvae reach a certain length. Results will be shown for several years to study the interannual variability. A measure of survival based on settling rates in favorable areas will be discussed in relation to recruitment and the connectivity between different areas will be further studied. The model results will also be used to try to bring some light into some of the biological and ecological knowledge gaps that exist for this species.

Building a novel spatialized model of regional seagrass dynamics: Coupling an ecological probabilistic Dynamic Bayesian Network with a deterministic regional ocean model

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Abstract

Seagrasses are ecosystem engineers that shape their own environment through bio-physical interactions, such as the seagrass-hydrodynamics-sediment-light feedback loop. In this loop, the presence of seagrass slows down currents and attenuates waves, which contributes to a reduction of suspended sediment in the water column and thus higher available light for photosynthesis; conversely, a degraded meadow can lead to increased shear stress, greater turbidity and reduced light. Thus, capturing feedback between ecological and hydrosedimentary processes is critical in order to better understand and predict the resilience of complex seagrass ecosystems under climate change.

We developed an innovative modelling approach to capture these complex feedback loops in the case of Zostera noltei seagrass meadows in a mesotidal semi-enclosed lagoon (Arcachon Bay, France). Our original framework overcomes the challenges of coupling a deterministic physical regional ocean model (MARS3D) (Lazure & Dumas, 2008) with a probabilistic Dynamic Bayesian Network (DBN) of seagrass dynamics (Wu et al, 2017). This implies converting quantitative estimates provided by MARS3D into state probabilities for the DBN, and vice-versa. At a horizontal resolution of 235m, we derive monthly estimates of environmental conditions (e.g. light and hydrodynamic stress) from MARS3D, which drive seagrass growth processes in the DBN. In turn, seagrass densities derived from the DBN affect regional hydrosedimentary dynamics in MARS3D.

We ran simulations on seasonal and multi-year scales using alternative model formulations, which account for different combinations of processes. Thus, we investigate the relative influence of environmental factors (light, temperature, hydrodynamics, …) and ecological processes (e.g. reproduction) on the dynamics of modelled variables throughout Arcachon Bay. We specifically assessed consequences on both regional hydrosedimentary conditions (e.g. turbidity) and seagrass spatial dynamics (e.g. distribution, density and physiological status of plants). We also compare model seasonal estimates of seagrass densities at 9 sites against available monthly observations (Cognat et al., 2018) to identify the best performing model configuration.

This coupled model allows us to explore the spatio-temporal variability of seagrass at a regional scale with the objective to simulate seagrass dynamics and its resilience over decades and even under the influence of climate change.

Bridging physiology and oceanography with thermal time to model biologically relevant time-scales in a changing climate.

Anna Neuheimer

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Abstract

In higher latitude marine ecosystems, seasonal timings of predator and prey control ecosystem dynamics and resource production. A mechanistic understanding of where and when trophic pairs meet is necessary to explain species' resilience and ecosystem production over time. Estimating seasonal timing depends on our ability to disentangle the interaction between biological and environmental (oceanographic) factors. This is particularly true for early life stages of many marine species, where seasonal timing of ectothermic, passively drifting, non-feeding stages are at the whim of the environment.

Here we show how thermal time characterisations can be used to estimate relevant time-scales for marine organisms, e.g. larval fish and invertebrates. By scaling time with temperature, thermal time bridges physiological performance with environmental forcing to give realistic time-scales for *in situ*, dynamic conditions. Formulating this as a "biological theory of relativity", we show how thermal time can help us develop needed biophysical modelling tools that are able to explain observed variation in timing, estimate timing of unobserved stages, and make seasonal timing predictions under future ocean conditions.

We present our efforts in this area including our development and application of biophysical modelling tools to explore seasonal timing of fish and invertebrate species for inland water ecosystems of the Faroe Islands and Denmark. Modelling tools are individual-based, allowing us to explore how biologically relevant stochasticity and functional diversity (e.g. traits and/or individual variability) can influence expected timing patterns, including questions of heritability and adaptation.

Bioenergetics in the multispecies model Bioen-Osmose to reproduce past fish dynamics in the Bay of Biscay

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Abstract

Fishing and global warming are the main factors that affect marine resources, leading to a reduction in biomass and a decrease in specific, genetic, and functional diversity across all trophic levels. Understanding the changes caused by these disturbances is essential to implement effective management measures. In our Bay of Biscay case study, environment and fishing pressure are suspected to have caused a reduction in fish length and body condition. Smaller fish affect fisheries activities and value, thus the underlying drivers of such changes are important to take into consideration when assessing different fisheries management strategies. We explored these drivers using the ecosystem model Bioen-Osmose applied to the Bay of Biscay ecosystem. This new module is based on the Osmose model, an individual-based and spatialized model that simulates the life cycle of several interacting fish species. It adds a bioenergetics dimension that directly integrates local temperature and oxygen into energy fluxes formulation and the resulting growth rate of fish individuals, allowing plastic physiological responses to climate change. We applied Bioen-Osmose to the Bay of Biscay through the parameterization of 18 species with different levels of available knowledge. Optimization was performed to reproduce the past 20 years of the fish community dynamics, with a focus on biomass, landings and length-at-age estimates for as many species as possible. Model outputs were explored at different hierarchical levels, from individuals to populations and trophic guilds, with a particular attention put on the fish length and body condition compared to data. Further simulations would help decipher the relative effects of drivers responsible of the observed decreasing length before testing various fisheries management scenarios under climate change.

Improving the reliability of food web and ecosystem models from individual life-cycle modelling

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Abstract

Marine food-web or ecosystem models (FW|E-M) have become an important tool to analyze indirect effects of trophic interactions, environmental perturbations, or management strategies. They rely on a simplification of real interactions between their components. Mass-balanced models, which represent most of these models, describe a pool of interacting trophic groups and their main bioenergetic functions: consumption, production, etc.

One of the criteria to evaluate the confidence on such model is the quality of its input data. It is however difficult to find well-defined input values for some groups from literature, prompting the need for alternative estimation methods. This can be done using empirical relationships or estimates from model balancing. Such estimates of natural mortalities or consumption attempt to represent individual performances, later extrapolated to populations in the FW|E-M.

Dynamic Energy Budget (DEB) theory describes the energy and mass budgets of all animals' organisms at the individual level. The models built from this theory represent the energy use for growth, maintenance, and reproduction of an individual through its life cycle. The bioenergetics described can be translated into flows such as those described in FW|E-M and be used as input with a similar upscaling.

We thus conducted a comparison between energy flows from DEB and empirical formulas for multiple taxa in an Ecopath model of the Fécamp offshore wind farm area (France). To quantify their quality, the results were compared to robust energy flows values from literature. Finally, the effects on the predicted structure and functioning of the food-web were explored.

The results display differences among taxa, with DEB predictions mostly in line with the known energy flows. Some of the results do not follow the known energy flows values, emphasizing the sensitivity to the parameterization of the assimilation process in DEB. At the food-web scale, differences appear on the predicted flows around the trophic groups of interest, highlighting the influence of input values on the development of FW|E-M.

This study presents a new way to input FW|E-M, a new methodology that could also offers opportunities to build size-related inputs or functional responses to temperature or food availability.

Influence of low trophic levels resolution and dynamics on simulated fish community

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Abstract

Regional ecosystem models are classically developed to explore the impacts of various marine management options, possibly in combination with climate change. Several of these models are built using a suite of models, and more particularly from coupling low trophic level (LTL) models with high trophic level (HTL) models. Due to the cost of ecosystem model development, the structural uncertainty around the modelled results caused by the choice of the LTL or HTL model used is rarely assessed. Here, we aim at exploring what are the effects of using different LTL models for forcing HTL dynamics. We addressed this question by using the HTL multispecies model OSMOSE applied to the Bay of Biscay ecosystem. This individual-based and spatialized model simulates the life cycle of several interacting fish species, feeding on themselves and on prey fields depending on their life stage. It is usually forced by a biogeochemical model providing temperature and planktonic and benthic prey fields for the fish. First, we defined the different LTL prey fields that could be used as forcing for OSMOSE. We used raw outputs from different biogeochemical models, but also transformed output in order to explore the role of plankton resolution (number of size bins), the relative role of benthic versus planktonic prey fields and the importance of spatio-temporal patterns for fish dynamics. Second, to be able to compare the simulations obtained when using different LTL forcings, we developed a calibration procedure that ensures that the same optimization effort was applied to all cases. Difference between LTL forcings were quantified both on the optimization fit and through fish population and community indicators. This study contributes to a better understanding of the structural uncertainty associated to ecosystem model, and can be used to assess the robustness of resulting simulations for a management perspective.

The power of "first principles" in ecological modelling

Ken Andersen

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Abstract

Global change is pushing ecosystems beyond their current limits and ecological modelling faces the challenge of projecting ecosystems into unknown future conditions. However, ecosystem models are generally tuned to historical or present conditions. In this way, the models are conditioned towards stability, which make them ill suited to represent abrupt changes or tipping points where the system undergoes a hysteresis. Here I will argue for the value of basing models as far as possible on "first principles". First principles are those universal relations that stem from geometry, mass and energy conservation, hydrodynamics (swimming, sinking, feeding, and sensing), diffusion (uptake of dissolved matter), and chemistry (reaction kinetics and stoichiometry), and, as a biological first principle, evolutionary optimization. Basing models exclusively on first principles entails a trade-off in precision because there is less room for model tuning. However, as first principles are universal, even in changing environments, model projections will be robust when models are pushed outside their calibration envelope.

Keynote

Next generation plankton models; meeting the digital-twin challenge

Kevin Flynn

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Abstract

Future plankton models will operate from digital-twin like platforms, in which the user, as a non-expert in computer coding, will exploit the simulation model through a GUI. These users will rely on, and will expect, the model to adequately portray reality consistent with a digital-twin label, while the platform itself will enable them to explore questions at the boundaries of those foreseen by the coder. To achieve this end, simulation models of individual plankton types need to describe features of the real organisms consistent with empirical knowledge. The old mantra of the model being designed only for the (limited) task at hand, often with allied gross simplifications, will increasingly be found to be wanting. Most plankton models are built on physiological and ecological concepts dating back over 50yrs; many are arguably woefully out of date, while plankton science itself has changed out of all recognition (notably with 'omics). A study conducted with empiricists (with interests in viruses through to metazoan zooplankton) demonstrates a strong deviation of their expectations from the structure and deliverables of extant plankton models. In consequence, there is a disbelief that these traditional models can adequately describe the ecology of the plankton, and critically that they can handle the emergent changes in biodiversity that are accompanying climate change etc. Alone, this is worrying because these models are key for ecosystem management, from HABs, fisheries, through to global biogeochemistry. Coupled with expectations of GUI plankton digital-twin accessibility, the subject of plankton modelling across the entire range of its deployment can be seen to provide much scope for development. This presentation will explore challenges, expectations, and opportunities for the future development of plankton models.

Effects of ecosystem complexity on the air-sea CO2 flux in an ocean biogeochemistry model

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Abstract

Marine biogeochemistry models are used to assess the carbon cycling in the ocean as well as the exchange of CO_2 between atmosphere and ocean. They also represent the ecosystem and species composition, but only with limited complexity. It is impossible to parameterize all species exhaustively, firstly because of limited knowledge about the nuances in their different responses to ecosystem drivers, and secondly because of the significant increase of computational costs with each additionally modelled organism group. Nonetheless, current marine biogeochemistry models apply a range of ecosystem complexities and vary between simplistic nutrient-phytoplankton-zooplankton-detritus models and models with numerous size-resolved plankton groups. In our study, we want to isolate the uncertainties in air-sea CO_2 flux estimates that are caused by ecosystem complexity from uncertainties caused by other factors. For this we use the ocean biogeochemistry model FESOM2.1-REcoM with four complexity levels of the ecosystem (see figure). The complexity levels differ in terms of the number of phytoplankton groups ("p" in the names given in the figure) and the numbers of zooplankton and detritus groups ("z" and "d", respectively). Furthermore, the phytoplankton group of coccolithophores comes along with carbonate-system dependent calcification with a variable ratio of calcite to carbon, while calcification is performed by a fixed share of phytoplankton with a prescribed calcite to carbon ratio in the versions without coccolithophores. We analyse differences in the CO_2 flux, surface carbonate chemistry, the surface-to-depth gradient of dissolved inorganic carbon, primary and secondary production as well as carbon export globally and in separate ocean basins. In preliminary, few decades long simulations, the global air-sea CO_2 flux varies by up to 50% between the simplest and the most complex version of our model. This points towards a low robustness of air-sea CO_2 flux and carbon cycling against changes in the ecosystem complexity in ocean biogeochemistry models. Longer simulations over a few centuries will allow us to further examine these relationships.

Control of carbon sequestration by the interaction between fishes and benthic fauna

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Abstract

The growth of seaweeds, seagrasses and mangroves to take up carbon from the atmosphere and sequester it in the seabed has been proposed as a method to mitigate climate change. However, the processes which mediate the burial of carbon in sediments are poorly resolved, especially those mediated by the macrofauna which live in, on and around the seabed. In this study, we use the biogeochemical model ERSEM, two-way coupled to a size-spectrum model of fishes, MIZER, to comprehensively model the pelagic and benthic ecosystems on the North West European shelf. We have extended the two-way coupling to include the feeding of demersal fishes on benthic fauna. This previously missing predator-prey interaction impacts both the biomasses of fishes and benthic fauna present in the system, and consecutively the fluxes of carbon into and out of the seabed. Initial runs suggest that benthic fauna biomasses are highly sensitive to predation by fishes. The new model will allow us to constrain the turnover rates of benthic fauna biomass, improve predictions for potential carbon sequestration as well as sustainable fisheries under future environmental conditions.

Integrated Nested Model Approach for Understanding the Transboundary Plastic Pollution in Norwegian Fjords

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Abstract

Transboundary plastic pollution poses a significant threat to the environment as plastics originating from one country can transcend different geopolitical boundaries. This is particularly relevant to the Norwegian coastal current (NCC), which is an important pathway for surface waters out of the North Sea. NCC contains litter from land around the southern borders of the North Sea as well as North Atlantic waters. Due to the intricate network of fjords along Norway's coast, the Norwegian fjords act as a natural sink for marine litter *(Bastesen et al., 2021)* brought by NCC.

In this study, we assess the amount of transboundary plastic coming along the coast of western Norway, employing a nested modelling approach. We utilize emissions data of buoyant plastics from major European rivers *(Meijer et al., 2021)*, as an input to our Lagrangian particle tracking model simulated using OpenDrift. The background currents are provided by the nested model which includes surface currents from three grids: A 4km model of the North Atlantic - Nordic4K *(Lein et al., 2013)*, An 800m model covering Norway's coastline - Norkyst800 *(Albertsen et al., 2011)*, and 160m hydrodynamical model - NorFjords160 *(Dalsøren et al., 2020)*. As particles transit through these nested grids, we precisely track the plastic pathways into the western Norwegian fjords around the city of Bergen. Employing this nested grid setup addresses problems with boundary conditions and mass balance. We present the estimates for the fraction of plastic moving into the fjord with a focus on the relative influence of wind and ocean currents on the transboundary movement of plastic. This study sheds light on processes responsible for near and far field transport, providing valuable insights for agencies working on trans-national pollution laws and implementing ocean clean-up strategies.

Spatialised ecosystem modelling to evaluate the influences of marine protected areas and provisioning ecotourism on the distributional response of top predators on the South-East coast of South Africa

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Abstract

Ecosystem-regulating top predators are considerably prominent along the South-East coast of South Africa. The unique oceanographic characteristics and prey abundance in this region make it a biodiversity hotspot, which consequently provides ideal conditions for commercial fishing, spatial management, and shark cage diving ecotourism that involves routine provisioning (attracting sharks to tourists); all of which have unknown spatio-temporal implications on top predator-prey dynamics in the system. This study developed spatial ecosystem models using *Ecospace* to investigate the distributional response of top predators on the South-East coast to the introduction of new marine protected areas (MPAs) in 2019 and seasonal provisioning for shark cage diving in 2020 in the region. A baseline *Ecospace* model was constructed, calibrated and validated to reflect real-world observations and act as a reference for the two exploratory models, which introduced the new MPAs and shark cage diving operation into the model, respectively. Spatial indicators were calculated at various model timesteps to analyse the spatio-temporal shift in top predator concentration and quantify their distributional response five, 10 and 15 years following the implementation of new MPAs and provisioning operation. Results revealed a consistent distributional shift in top predator concentration in response to the new MPAs and provisioning operation. Top sharks that utilise inshore nursery areas (smooth hammerhead, dusky, raggedtooth) and less-transient top predators (humpback dolphin, sevengill shark) evidently received positive indirect effects of the coastal MPAs (e.g., sufficient prey availability), compared to the more transient top predators. Subsequently, this made these coastal predators more readily available for consumption by great white sharks around the cage diving site once seasonal provisioning was concurrently introduced to the model. However, no indication of adverse cascading effects at the ecosystem level were evident, suggesting that the new shark cage diving in this region is currently operating at a small enough scale that it will not have adverse effects on current spatial management procedures, or on the whole-system dynamics. This was the first study to model the ecotourism activity of shark cage diving spatially and presents a novel approach to modelling the possible trophic effects of introducing anthropogenic activities into the marine environment.

Towards a trait-based modelling framework of seascape habitat features

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Abstract

Non-trophic interactions are increasingly recognised as essential for ecosystem models to realistically capture ecological dynamics, particularly for coastal ecosystems and benthic communities where complex feedbacks between seafloor habitats and mobile fauna are ubiquitous. Yet, while current ecosystem modelling approaches, including size-based frameworks, can capture pelagic ecosystem dynamics and their responses to global changes, they are often limited to account for seafloor habitat-mediated feedback. To adequately capture the response of benthic ecosystems to global changes, new ecosystem modelling frameworks that account for all trophic and non-trophic ecological processes are needed. Because habitat-mediated processes remain challenging to observe directly, we aim to develop an original modelling approach that relies on species traits (such as those associated with habitat engineering) to generically capture how habitat-mediated processes contribute to benthic ecosystem dynamics. Based on a workshop to elicit expert knowledge about major seascape features across scales, in combination with a systematic review of scientific literature, we have developed an original framework to characterise how major interactions and feedback between functional groups and benthic habitat contribute to benthic ecosystem dynamics. Our expert workshop identified how benthic species can contribute to seafloor habitat characteristics according to 3 major dimensions: (1) energy flow (e.g. primary production); (2) spatial structuring (e.g. substrate modification or tridimensional complexity); and (3) temporal stability (e.g. buffering of environmental variability to maintain microclimatic conditions). Based on this typology of species-specific contribution to seascape features, we have developed an original trait-based modelling workflow to capture potential shifts in seascape features. This work lays the first steps towards a species-habitat traits database to systematically qualify (or quantify) benthic species contribution to seascapes. Consolidating of such generic trait-based rules related to benthic seascapes offers perspectives to project future habitat changes in coastal ecosystems, as well as flow-on effects on broader community structure and dynamics.

The Nutrient-Unicellular-Multicellular (NUM) approach to zooplankton modelling

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Abstract

Understanding the impact of climate change on fisheries production requires that we understand how changes in primary production affect fish. However, fish do not feed on primary production directly; they rather on mesozooplankton, including copepods. Current modelling of mesozooplankton is imprecise as zooplankton is mainly considered as a closure term for the phytoplankton. A complicating aspect of a better representation of copepods is their life cycle where they grow a factor 100 in mass from nauplii to reproducing adult copepod. This life cycle is important because it introduces a lag between the production of offspring until adult copepods appear. Here I introduce the "Nutrient-Unicellular-Multicellular" modelling concept to resolve copepods. The NUM model is a size- and trait-based model which represent copepods via the traits adult size and feeding mode. I will show examples of the model in chemostat, water column, and global setups, and present a computational library for easy application of the NUM model.

Recent and future biogeochemical trends in the Atlantic Ocean: a look into the importance of structural uncertainty

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Abstract

With the increase of computational power, global coupled ocean models have increased their horizontal resolution, that has now reached the point where shelf dynamics can be properly represented. To do so, standard global models need to improve their representation of coastal processes, both the hydrodynamical ones (e.g. tides) and the biogeochemical ones (e.g. riverine nutrients inputs). Assessing the impact of the addition of these new processes on the dynamics of the model and the resulting trend is vital to help in understanding the impact of structural uncertainty on model-based assessments.

In this work, we use two global configurations of the coupled NEMO-ERSEM model at 0.25 degrees of resolution: the reference NEMO configuration is taken from the on-going development of the ocean component of the next UK contribution to the Coupled Model Intercomparison Project, while the advanced one includes an explicit representation of barotropic tides, a new turbulence scheme and vertical coordinate system, and a time varying freshwater input. In both configurations NEMO is coupled to the ERSEM and time varying input of biogeochemical tracers from rivers and atmospheric deposition have been added. Both configurations have been run in hindcast mode (1990-2019) and the trends and variability of main biogeochemical indicators are compared to assess the impact of the improvements on the physical set-up on biogeochemistry.

Furthermore, the reference configuration is being used to project future trends under different climate change scenario as projected by two different CMIP6 models. Future trends as projected by the ocean only model are compared to those projected by the native CMIP6 model to assess the impact of downscaling on future projections.

Predicting North Atlantic right whale distribution from currents seascapes

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Abstract

North Atlantic right whales are currently classified as a critically endangered species. In recent decades, ship strikes and fishing gear entanglements have been the identified causes of most deaths. Meanwhile, the main prey population of historical right whale habitats, mostly large *Calanus* species, is decreasing. In correlation, right whales have been observed further north of their usual summer feeding areas, in the Canadian waters, where they are especially vulnerable to vessel activities.

Given this situation, several departments of the Canadian government within the SmartWhale initiative have allocated funding for research and development projects focused on the North Atlantic right whale. Among these projects is SIMBA, developed by Arctus, which aims to use models and satellite derived information to predict right whales' movements on the Northwest Atlantic shelf.

As the location of right whales in their summer habitat is closely linked to that of their prey, the objective of my PhD thesis is to build models that predict potential aggregation areas of right whale prey in their main summer habitat. *Calanus* species, as well as other zooplankton taxa, are transported by currents but can voluntarily change depth through vertical migration. The different depths these species choose lead to different vertically stratified currents, resulting in significantly different distributions over time.

We created individual-based models that simulate the prey trajectories from their depth distribution linked to the environment and a 3D currents prediction model. Potential aggregation areas are computed from those trajectories. These models will help to study the role of advection in the distribution of zooplankton at a sub-mesoscale level (~5km - ~8 days) and could be a useful tool to understand the foraging strategies of the North Atlantic right whales.

Investigating the hydrodynamic connectivity of eelgrass *Zostera marina* population along French Atlantic coast to help management and conservation effort

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Abstract

Marine seagrasses can support among the most productive ecosystems on Earth. They provide a variety of ecosystem services but they are highly vulnerable to human activities and rank among the most threatened marine ecosystems. Their global decline has led to significant decreases in the ecosystem services and functions they provide. Conservation and restoration efforts aim to mitigate or revert decline in seagrass habitat, and to compensate for losses in associated ecosystem services.

Thus, consolidating knowledge about drivers of local population dynamics, including connectivity with other seagrass sites, is key to maximise restoration success. Connectivity within meta-population is a critical mechanism for enabling and maintaining evolutionary processes of seagrass species, by favouring genetic diversity and improving resistance, adaptation and ability to recover after a disturbance.

Along the Northern Atlantic European coastline, seagrass meadows are mainly represented by the *Zosteraceae* family, and more particular by the eelgrass species *Zostera marina* (Linnaeus, 1753) which is the most common and abundant in this region.

Biophysical modelling approaches, through the simulation of propagules movement at the surface-ocean boundary layer, can inform on potential dispersal and help define broad-scale connectivity. In the present study, we investigate the long-distance dispersal capacities of *Z. marina* meadows along the western French coastline using MARS3D hydrodynamical model and estimate the mean pattern of oceanographic connectivity and the eventual annual or seasonal variability.

Genetic analyses were although available for some of the studied meadows and allow to explore the genetic signature among and between populations. The combination of genetic analyses and biophysical modelling offer a valuable approach to robustly investigate marine connectivity. Thus, facing both genetic and modelling approaches, allow us to determine similarities and differences between the two connectivity patterns.

Finally, we identify from the outcomes, local populations of primary interest for the maintain of the entire meta-population and therefore important for stakeholders/in a management and conservation context.

Refining Temperature-Dependent Phytoplankton Growth Functions in Global Ocean Models: Insights from the REcoM Model

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Abstract

Phytoplankton, accounting for nearly half of global net primary production, serves as a vital energy source for marine ecosystems through carbon fixation via photosynthesis. In the context of global ecosystem models who’s aim is to replicate historical trends and anticipate future changes in net primary production, precise calibration of phytoplankton dynamics is essential.

Given the anticipated shifts in ecosystem functioning due to anthropogenic climate change, particularly the pervasive rise in global temperatures, a critical aspect is understanding the temperature-dependent mechanisms governing phytoplankton growth and adapting functions to these relationships.

This study addresses the imperative to refine the temperature-dependent phytoplankton growth functions within the global ocean biogeochemistry model REcoM, developed at the Alfred Wegener Institute (AWI). The model distinguishes three phytoplankton functional groups, each expected to respond differently to temperature constraints. Our objective is to align the model's temperature-dependent phytoplankton growth functions with the latest scientific insights from laboratory studies. Furthermore, most ecosystem models use exponential increases in phytoplankton growth no matter the increase in temperature. This seems infeasible, especially in tropical regions where species are often already close to their thermic maximum. As such, we investigate the validity of adding a thermal stress mortality term that would counteract the exponential increase in growth rate with temperature, above certain thresholds. This will become more and more relevant in the future ocean as the gradual climate warming increases in the next century.

The proposed methodology involves comparing various model simulations against primary production time series data. By comparing model outputs with observed data, we aim to validate the accuracy of the modified phytoplankton growth parameterization in REcoM. This approach ensures a comprehensive evaluation of the model's performance in representing the intricate relationship between phytoplankton growth and temperature, contributing to the refinement of global ecosystem models.

Trait-based modelling in the eddy world

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Abstract

Trait-based models, rooted in biophysical principles, provide an interesting avenue for slim models with less parameterization that may allow for an increased understanding of ecosystem structure and adaptation. One particularly simple representative of this model type is the "Nutrient-Unicellular-Multicellular" (NUM) model which is a mechanistic model fully based on biological first principles. Here we explore and test the NUM model's ability to adapt to spatial and temporal scales at eddy resolution across the shelf-open ocean gradient. We do this by embedding NUM into the Regional Ocean Modeling System in a simplified shelf-open ocean model setup. With this setup, we get a nuanced understanding of the interactions of plankton sizes and traits across the shelf within mesoscale structures. Specifically, we investigate the model's responsiveness to nutrient gradients and eddy generation along the shelf break front, driven by upwelling favorable winds and deep counter currents. In the presentation, we evaluate the necessity of eddy formation in obtaining a realistic ecosystem structure. This study provides valuable insights into the theoretical fitness of the NUM model and the possibilities of using trait-based modeling for evolutionary and adaptation studies.

Assessing the influence of numerous river discharge on the modulation of shelf circulation in the Ganges-Brahmaputra-Meghna estuary

Tasin Sumaia Khan

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Abstract

Bay of Bengal is a continuum receiving multiple large rivers including the Mahanadi, the Godavari, the Krishna, the Kaveri, the Ganges, Brahmaputra and many more others. These river outputs are significantly influenced by the energetic shelf circulation system. As expected, the freshwater flux is caused by rivers results in lower salinities and shallower mixed layers. However, the influence of this additional freshwater flux into the bay is rather counterintuitive. Meanwhile, the large freshwater discharge from these rivers alters the density structure and dynamic height of receiving seas, which may have an impact on shelf circulation. Multivariate empirical orthogonal function decomposition and heterogeneous correlation analyses are applied to numerous observational, reanalysis, and satellite datasets, including river discharge data, temperature, salinity, density wind stress curl and chlorophyll datasets collected from various sources. It highlights that Classic estuarine two-layer circulation during monsoonal period is one of the significant consequences of river plume influence on continental shelf. Coriolis force, monsoonal effect and buoyant river plumes are what makes this discovery so significant. The buoyant river plumes were primarily responsible for changing the vertical structure of shelf circulation during monsoon period. This study also suggests that the strongest SSS variability appears off the mouths of the major rivers (Ganges-Brahmaputra in the northern BoB, and Irrawaddy which is in the northern Andaman Sea) and to a lesser degree along the western boundary of the basin. The results show a large increase in surface salinity along the Bangladeshi coast especially in the eastern part in near future, which may affect the area of fresh water plume because precipitation also shows an influence in the inter-annual variation of circulation pattern and the region of fresh water plume. The fresh water plume will move from the northeast to the west due to the rapid decreasing precipitation and the accompanying wind stress curl in the eastern half of interannual precipitation data during the time period between 2016 and 2020. This study contributes to a better understanding of how oceanic forcing affects the rich marine habitats in the BoB and the destiny of riverine materials there.

As good as it gets: Exploring the role of different data sets for global biogeochemical model calibration

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Abstract

The complexity of global biogeochemical ocean models varies between only few components to more than 20. With increasing complexity, the number of biogeochemical constants (parameters), that have to be specified, increases. These parameters are subject to a large uncertainty, in contrast to physical parameters such as the gravitational constant. The wide range of model complexity and the large range of parameter uncertainty render model calibration and skill assessment important, but, because of the models' high computational cost, also challenging. Moreover, data sets for model calibration at the global scale are usually sparse, and often heavily influenced by episodic events on small scales.

We present results of global global biogeochemical model calibrations against a variety of data sets (including both organic and inorganic tracers). For the representation of only the global distribution of nutrients and oxygen, model complexity seems to be of secondary importance. However, fitting simulated to observed global inorganic tracers typically requires long spin-up times, of the order of thousands of years. Calibration of a model of intermediate biogeochemical complexity against data sets of organic tracers (for example, plankton or particulate organic matter) can help to provide a good estimate on the optimum particle flux length scale after shorter spin-up times, and can thus increase the efficiency of model calibration, even though much of the improvement comes through a reduction in bias (and not the pattern error). Here, especially observations of deep particle flux could provide a powerful constraint.

Modeling the Sinking Dynamics of Tyre-wear Microplastics in an urban fjord in western Norway

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Abstract

The ocean floor has been a major sink for microplastics, yet the intricacies of their sinking behavior and the ultimate fate of these microplastics remain ambiguous. The semi-enclosed basin of Byfjorden in Bergen, Norway, is an urban fjord with well-established sources *(Haave et al., 2019)* of microplastics and creates a viable scenario for modelling particle transport within this region.

In this study, we investigate the particle dynamics of tyre-wear microplastics that come from road traffic across two major bridges in Byfjorden, namely the Nordhordland Bridge and the Askøy Bridge. We employ a Lagrangian particle tracking framework, OpenDrift, with background horizontal velocities from the Bergen Ocean Model (BOM), paired with a vertical sinking velocity obtained from Stokes law to track individual particle paths along the flow field until they reach the seafloor. The sinking velocity is picked from a distribution that is designed based on results from point source experiments, enabling us to cover the particle dynamics for a spectrum of sinking velocities. The basis of this study lies in using the variability in ocean currents, by conducting multiple experiments with distinct initial locations and release times to understand the similarities and differences in the footprint. In the particle simulation, the horizontal velocity experienced by individual particles depends on release time which is related to when in the tidal cycle the particle is released. The outputs from the model runs correspond to all possible scenarios, thereby providing a full overview of the model's behavior. We seek insights to discover potential aggregation zones and their corresponding gradients along the bottom of the fjord. We plan to shed light on 'how particle dynamics change when we vary the sinking velocity'. These results could be applicable in identifying the mechanisms behind particle transport in fjords and can assist in designing sampling campaigns.

Exploring the impact of fragmentation and diel vertical migration on particle sinking (in a mechanistic model)

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Abstract

The biological carbon pump plays a crucial role in regulating the Earth's carbon cycle and mitigating climate change. However, the export efficiency of this pump depends on a multitude of processes that can affect the sinking speed of particulate organic matter (POC). The uncertainty surrounding factors that promote particle aggregation, remineralisation, zooplankton consumption and fragmentation (e.g. coprophagy) has led to inconsistent estimates and future predictions for global export flux amongst earth system models. Two of the most unaccounted-for and least understood processes for constraining these simulations of POC flux are fragmentation and diel vertical migration (DVM) by zooplankton, with the majority of CMIP6 model omitting these from their frameworks. Fragmentation rates can be physically-mediated (e.g. turbulent shear) or biologically-mediated (e.g. "sloppy feeding" by zooplankton) and influence remineralisation and thus flux attenuation. Another zooplankton activity, DVM, also impacts export flux. DVM, where organisms nocturnally migrate to surface waters to feed and descend during the day, has great implications for biogeochemical fluxes of nutrients and provides a mechanism for POC to bypass potential transformation via fecal pellet production at depth. Here, we use a 1-dimensional particle model (SISSOMA) that includes mechanistic descriptions of key particle transformation processes (aggregation, remineralization, fragmentation etc.) to explore the potential consequences of fragmentation and DVM on POC flux. The SISSOMA model enables study into the formation and fate of particles in the mixed layer, producing a range of particle size distributions of the flux exported similar to observations. Through sensitivity tests on the drivers of fragmentation rates, constrained by Underwater Vision Profiler (UVP) and Biogeochemical-Argo floats observations, we determine the impacts of fragmentation and DVM on particle size distribution and carbon fluxes through the twilight zone. We also develop a DVM component to SISSOMA, informed by ecological observations of migrating zooplankton (e.g. depths migrated), to investigate the extent to which this process contributes to export flux. We will present on-going work with results imploring future modelling and observationally-based studies related to constraining the biological pump to consider these processes when designing their research.

Addition of faecal pellets processes in a biogeochemical model

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Abstract

Mesozooplankton play a crucial role in pelagic ecosystems by linking primary producers to higher trophic levels, and controlling the biological carbon pump (BCP) through the production of particles sinking into the deep ocean, including sloppy feeding, faecal pellets, moults, and carcasses. However, the quantification of their impacts on the carbon cycle remains difficult. For example, the contribution of faecal pellets to the POC flux varies between a few % and 30% depending on the studies, with more than 80% in some areas depending on the season. Usually, faecal pellets' contribution is assessed using data from sediment traps or from laboratory studies followed by extrapolations. But faecal pellets collected by sediment are often not well preserved or not representative of fresh faecal pellets produced in natural conditions. The use of novel imaging *in situ* tools, such as the Underwater Vision Profiler (UVP), could be a way to acquire data on both fresh and older faecal pellets in concert with their producers, which in turn could be used to better understand important pathways of the BCP and parameterise biogeochemical models. This way, we might be able to reduce the uncertainty around the faecal pellets' contribution to the global carbon flux.

Here we are identifying faecal pellets produced by mesozooplankton from *in situ* images, in particular by copepods in the Arctic, and parameterise a new detritus category in the global biogeochemical model PISCES. We also wish to include links between mesozooplankton producing these particles and all the categories possibly feeding on them. The impact of these changes on carbon export will be investigated. Benefiting from the work already done on copepods and faecal pellets images in Baffin Bay (imaged using a UVP during the GreenEdge campaign and analysed in a previous study), we will be able to constrain this new parameterisation in PISCES. We hypothesise that a better representation of faecal pellets could lead to a better estimate of their contribution to the total carbon flux of the BCP in productive parts of the Ocean.

Interpreting the seasonal succession of Prochlorococcus phenotypes and Synechococcus near Bermuda

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Abstract

Observations have revealed a seasonal succession of picocyanobacteria at the Bermuda Atlantic Time-series Station (BATS) linked to the deep, late winter mixing. The *Synechococcus* population increases, and the *Prochlorococcuspopulation* declines, during the period of mixing, high nitrate supply, and low light intensity (DuRand et al, 2001). Characterization of *Prochlorococcus* reveals that, curiously, nitrate using types increase in abundance and comprise a larger proportion of Prochlorococcus during the summer when nitrate is low and are almost absent in the mixing period when nitrate is high (Berube et al., 2016), opposite to the dynamics of *Synechococcus*. We use a trait-based model to explore the possible mechanisms that lead to this observed succession. The model resolves *Synechococcus*, two Prochlorococcus types, and a population of grazers, with ammonium and nitrate supply and light input. The seasonal succession between *Synechococcus* and *Prochlorococcus* not only reflects their size-dependent differences in nutrient affinity and maximum growth rate, more importantly, our study suggests that different limitations by nitrogen resources and incident light between *Prochlorococcus* and *Synechococcus* are required for the asynchronized abundance fluctuations between them and the observed pattern in the proportion of nitrate using *Prochlorococcu*s types. In addition, an additional cost on growth rate for nitrate utilization which is more expensive for nitrate using *Prochlorococcus* than *Synechococcus* allows for more evident asynchronized fluctuations. We further discuss hypotheses for the possible underlying physiological basis.

To be or not to be mixotroph? How niche modeling can help to inform the distribution of dinoflagellate trophic strategies in marine ecosystems.

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Abstract

Dinoflagellates are ubiquitous unicellular eukaryotes that frequently dominate marine planktonic communities. They fill diverse ecological roles (primary producers, consumers, decomposers) and show a wide physiological diversity. Most lineages are capable of mixotrophy, i.e., realizing both phototrophy and phagotrophy within the same cell through different metabolic processes, making them particularly interesting for the study of such an adaptive trait. Nutritional mode depends on multiple factors, which can be intrinsic (e.g., evolutionary history of the lineage and how the trophic mode(s) are acquired) and extrinsic (e.g., light, nutrient and/or prey availability). Currently, it appears that this trophic type is widely underestimated in model-based studies for understanding global biogeochemistry or protists ecology. By focusing on abiotic factors, this work aims to build the current biogeography of dinoflagellate associated trophic types. Using omics data and multivariate statistics, the determinants of community structure are highlighted and then the distributions of species and their traits are projected at a global scale with species distribution modeling methods. Nutrient availability, light and temperature gradients discriminate communities efficiently and distinguish coastal, eutrophic, sub-polar environments from oligotrophic, open ocean, tropical waters. The coexistence of the 3 trophic types represents more than half of the global oceanic surface, and phototrophs, which are less ubiquitous, do not occur alone. Conversely, phagotrophs can exist alone across higher latitudes ecosystems (temperate to sub-polar), and coexist with mixotrophs to a lesser extent. Results must be considered regarding to the trophic assignment of dinoflagellates. Indeed, a higher precision in the trophic assignment and a larger species sampling could contribute to a better understanding of the determinants of these distributions, useful for future predictions and potentially biogeochemical modeling. This work paves the way for further studies that highlight the spatiotemporal mechanisms and patterns of mixotrophy in oceanic ecosystems, whether at the functional trait scale or at the level of the planktonic community. Indeed, the continuation of this work is particularly dedicated to modeling the mixotrophic trait among dinoflagellates based on molecular data.

Coupling ocean biogeochemistry to a global Earth System model

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Abstract

Over the past decade, the NASA Ocean Biogeochemical Model (NOBM) has transitioned from a stand-alone model of ocean biogeochemistry to a component within the Global Earth Observing System (GEOS) , a major development effort. NOBM is a three-dimensional global model that includes a biogeochemical model and an Ocean and Atmosphere Spectral Irradiance Model (OASIM, Gregg and Carder, 1990; Gregg, 2002; Gregg and Casey, 2009). The surface downwelling irradiance that forces NOBM originates either from the GEOS's Solar Radiation Component or the atmospheric component of OASIM (Slingo, 1989; Gregg and Carder, 1990; Gregg and Casey, 2009) in the GEOS "Data Atmosphere" (ocean only) mode. Here we compare the performance of the two sources of radiation with respect to primary production in the ocean. Two experiments with the same configuration were run one forced by OASIM and the other coupled to the GEOS solar radiation. We found that the two experiments exhibit strong similarity in the magnitude and distribution of the primary production. These results are promising in using a dynamical, coupled Earth System Model, to push the boundaries of how ocean and atmosphere respond to climate.

Characterization and evolution of micronektonic biomes and feedbacks on biogeochemical cycles

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Abstract

Micronekton is a group of mid-trophic marine organisms characterized by a size range of 2-20 cm, containing a wide diversity of taxa dominated by crustaceans, fish and molluscs. It is responsible for an important active carbon export to the deep ocean because of the diurnal vertical migration (DVM) it performs. With this behavior, micronekton presumably aims to forage in the surface layer at night while minimizing predation risk and returning at depths to hide from predators during the day (Benoit-Bird et al., 2009). The study carried out here focuses on micronekton modeling in its environment, by coupling the numerical model of micronekton population dynamics SEAPODYM-LMTL (Lehodey et al., 2010, 2015) and the biogeochemical model PISCES, which estimates carbon fluxes in the lower trophic levels (Aumont et al., 2015). This innovative coupling developed in 1D, thus modeling a simple water column, enables the estimation of micronekton's impact on biogeochemical cycles, and the resultant retroactions. Then, this 1D coupled model will be applied in homogeneous micronektonic biomes with regional parametrizations. In this preliminary study, we aim to identify and characterize micronekton heterogeneous functioning patterns from environmental variables. We define bio-physical biomes based on environmental variables widely used when considering micronekton: temperature of the ocean surface, stratification, and net primary production. At global scale, 6 biomes are defined (tropical, subtropical, eastern boundary coastal upwelling systems, oceanic mesotrophic systems, polar and sub-polar biomes) on the period 1998-2019. We investigate the differences in micronekton characteristics between these biomes in terms of biomass and vertical structure modeled by SEAPODYM-LMTL. This analysis demonstrates that micronekton biomass is structured according to biomes-driven patterns mainly following the primary production, but also the temperature that discriminates the less productive biomes. Finally, the validation of the biomes' boundaries with acoustic data shows that our regionalization delimitates more homogeneous areas in terms of acoustic vertical structure, and also distinguishes areas with significantly different acoustic data distributions. This presentation will focus on the definition and characterization of the micronektonic biomes and will introduce the first results on the coupling of SEAPODYM-LMTL with PISCES.

Dining in danger: Resolving adaptive fish behavior increases realism of complex ecosystem models

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Abstract

Animals occupying higher trophic levels can have disproportionately large influence on ecosystem structure and functioning, owning to intricate behavioral responses to their environment, but are often not well represented in ecosystem models. The principle of optimality provides a framework for representing animal behavior that is relevant for complex models, and can provide a stabilizing effect on model dynamics.

Here we develop a model of optimal fish behavior within the Water Ecosystems Tool (WET), a contemporary end-to-end aquatic ecosystem model. The model predicts an emergent functional response similar to Holling type III, but with richer dynamics and a more rigorous theoretical foundation.

We show how our optimal behavior model increases model stability, has profound effects on trophic control and food web structure, and allows for an overall more realistic response of the model system to environmental perturbations.

We discuss how approaches like this one may benefit ecological modelling in general and aquatic ecosystem models in particular. Our study further highlights how concepts from theoretical ecology can be successfully implemented in complex operational models resulting in improved dynamics and descriptive power.

A biogeochemical model including toxic and allelopathic interactions among marine plankton

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Abstract

Several species of phytoplankton produce toxins that mediate interactions between phytoplankton and zooplankton in the marine environment. Allelopathy and grazing deterrence have been identified as the key chemically-mediated processes that influence the interactions, respectively, between phytoplankton species, and between phytoplankton and zooplankton. . The consequences of these interactions have been linked to revenue loss in aquaculture, mortality in higher trophic organisms and health problems in humans. Although the impact of toxins in phytoplankton-zooplankton dynamics have been studied in variants of NPZ models, large-scale ocean biogeochemical models currently in use do not include interactions of plankton with the biotoxins in marine environments. This limits the models' ability to simulate harmful algal blooms and their future prevalence. This study aims to fill the gap by incorporating the toxin-mediated interactions into an established ocean biogeochemical model (MEDUSA 2.0), Each of the two phytoplankton classes in MEDUSA 2.0 is divided into toxic and non-toxic groups and allelopathic interactions among them are incorporated using appropriate functional forms. Grazing deterrence to two groups of zooplankton, and the dynamics of algal toxins are further incorporated. The updated model has been coupled to the General Ocean Turbulence Model (GOTM) through the Framework for Aquatic Biogeochemical Models (FABM), and applied, initially, at the L4 station as a case study. Sensitivity analysis is conducted to determine the impacts of the newly incorporated processes on the model's biogeochemical output for L4.   The roles of inter-specific competitions, grazing and allelopathy, in modulating the dynamics of harmful algae, are further investigated. Results that will be presented include model outputs on the average seasonality of key macronutrients and chlorophyll, timings of harmful and non-harmful algal blooms, and the spatio-temporal variation of cellular and extracellular concentrations of the prominent algal toxins at L4.

The impacts of adapting the light climate on nutrient levels in a 3D-ecosystem model for the Wadden Sea

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Abstract

The Wadden Sea is a narrow strip along the coastline which is characterised by an extremely wide range in water temperature and salinity. It is a highly productive area, due to an intense remineralisation rate, fuelling primary production. However, elevated suspended matter concentration (SPM) leading to a heavy attenuation can causes strong light limitation. While satellite data have greatly improved the representation of SPM concentration in the open waters, the application in the Wadden Sea is still restricted since the algorithms have problems to distinguish between Chlorophyll and SPM concentration. This study focusses on the Wadden Sea area along the coasts of the Netherlands, Germany, and Denmark, using a 3D-ecosystem model. We present a method of incorporating satellite data, by correcting for near-shore biases, using in-situ measurements.

A total of three scenarios was then run for the time span of 2014 to 2017, comparing three different light climates: constant and homogeneous Jerlov-Type III, as well as uncorrected and corrected satellite-driven background attenuation. The latter two thus also feature spatial and seasonal variability. The Jerlov-Type III had much higher net primary production rates than either satellite-based approach, leading to significantly lower levels of dissolved inorganic nutrients. Comparing the uncorrected and the corrected satellite-based schemes, increases in nutrient levels outside or further downstream of major estuaries were found. Changes in chlorophyll were mostly seen in the form of strong reductions in the estuaries, but only comparably small changes elsewhere. However, levels of dissolved inorganic nutrients in the satellite runs were significantly higher than in the Jerlov-Type III case, and more so in the corrected version. In the light of eutrophication problems, especially in near-coastal regions, these findings affect the assessment of ecological status and water quality management.

Zooplankton and Micronekton population dynamics based on a spatial ecosystem model using Yin-Yang grid

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Abstract

We present an approach to solve the transport problem in the Lower and Mid Trophic levels model of Spatial Ecosystem And POpulation DYnamic (SEAPODYM). Meso-zooplankton organisms (200µm-2mm) constitute the low-trophic level. These organisms are transported along with the water masses. Micronekton organisms, constituting the mid-trophic level, are bigger organisms (2-20cm) able to swim over short distances. SEAPODYM models the spatial and population dynamics of the LMTL population with a system of advection-diffusion-reaction equations. The vertical dimension is simplified into three layers (namely epipelagic, upper, and lower mesopelagic). Layers matches the vertical distribution of organisms that is observed. The six micronekton groups are defined according to their diel vertical migration from the surface at night to the deep ocean during the day. The legacy implementation of this model uses a regular latitude/longitude grid over the global domain which is moreover considered with closed boundaries at the north that is without considering the north fold. Then this implementation does not allow us to work at high latitudes, which is a limiting factor as the Arctic has become a region of great societal importance. At high latitudes, this latitude/longitude grids are severely distorted, and taking grid elements into account in the calculation is not sufficient, as it is marred by increasing numerical error the closer we get to the poles. This problem is well known in computational geophysics and several solutions exist. We present here a solution based on the use of a Yin-Yang grid with both numerical and practical advantages.

Higher-trophic fish and macrobenthos biomass models based on ECOSMO E2E compatible to multiple lower trophic level model hosts

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Abstract

This study presents a proof of concept illustrating the two-way coupling of higher-trophic (fish and macrobenthos; HTL) biomass models with lower-trophic level (LTL) models. Here we harness the conceptual advantage of the Framework for Aquatic Biogeochemical Models (FABM), which provides an interface for coupling ecosystem models of different types. The ECOSMO E2E model is a functional group type ecosystem model that seamlessly integrates both fish and macrobenthos into a N(utrient) P(hytoplankton) Z(ooplankton) D(etritus) LTL model. The model has been reprogrammed to separate fish and macrobenthos modules independently, which allows now to couple the functional groups for HTL to various LTL models of the same class as ECOSMO. The coupling is exemplified by employing three distinct LTL models: ECOSMO, ERSEM, and BFM. A 1D model configuration focusing on the central North Sea is utilised for this investigation. The 1D water column model based on the General Ocean Turbulence Model (GOTM) is used to simulate physics. This also means that we simplify the model by disregarding horizontal fish movement in a first approximation. We compare the model to estimates of fish biomass from the International Bottom Trawl Survey. The model is shown to reasonably replicate the observed annual cycle of fish biomass in the North Sea. Additionally, the case study explores the impact of the two-way coupling between HTL and LTL models on the biomass dynamics of the latter. This research contributes valuable insights into the intricate interactions within marine ecosystems. It also highlights the necessity to add HTL to marine ecosystem models not only to simulate fish biomass and its dynamical changes, but also to provide spatially-temporally explicit closure terms for the LTL parts of the ecosystem models.

Theme 4:

Digital Innovation

Keynote

Can digital twins help define a safe operating space for the seas? Transforming the regional seas: digital twin demonstrators

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Abstract

AI supported digital ocean twins can help transform marine ecosystem models into decision support tools that consider direct stakeholder input including management priorities and expert knowledge. Regional seas are especially challenged in terms of adopting management tools that support both resilient ecosystems and well-being of coastal communities.

The Digital Twins of the Black Sea and Marmara Sea are examples in practice. These are first examples of digital twin ocean demonstrators with real-time information from data lakes and smart observation setups, high-resolution, fully coupled sophisticated models of the sea and the watershed supported by artificial intelligence tools and socio-economic models. Such Digital Twins further our understanding of changes in regional sea ecosystems in response to changing climate and environmental stressors and can be used to test alternative blue economy and biodiversity conservation scenarios and support policy and management demands.

The Marmara Sea Digital Twin includes components that help optimize and test different scenarios that will lead the highly polluted, degraded, anoxic Marmara Sea ecosystem to shift above the hypoxic threshold with increased biodiversity and benthic and pelagic fauna. The Black Sea demonstrator includes an ensemble of integrated model simulations, as well as machine learning and cumulative risk assessment tools, to support the assessment of ecosystem state and resilience, and a better understanding of the compound risks on ocean derived ecosystem services. With these demonstrators different socio-economic and blue economy scenarios including sectoral analysis are tested with and for stakeholders through living labs across the basin. Thus, the digital twins will directly contribute towards defining the safe operating space where the ecosystem service dynamics are well understood and support resilient coastal communities.

New reanalysis for ecosystem indicators with ensemble-based uncertainty estimates in the UK regional waters

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Abstract

We developed ensemble representation of a state-of-the-art physical-biogeochemical model of the North-West European Shelf (NWES) and implemented a new ensemble-variational data assimilation system on the NWES. Using this system we produced reanalysis of a selected class of ecosystem indicators (for productivity, carbon export, hypoxia, acidification). We compare it with the reanalyses produced by the state-of-the-art variational system used operationally at the Met Office, and validate both the ensemble spread and the ensemble mean with observations. We discuss the uncertainty of the indicators, as well as their observability by the satellite total chlorophyll, being the most robust biogeochemistry data-set on the NWES. This allows us to derive some suggestions for future observing system design on the NWES. We discuss the remaining challenges of the ensemble approach and the future directions.

Evaluating the skill of hybrid statistical species distribution models trained with mechanistic model output

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Abstract

Predicting the change in the distribution pattern of organisms is critical for assessing and mitigating risks associated with climate change and environmental variability. Statistical species distribution models (SDMs), which relate species' abundances to environmental data using machine learning methods, are particularly useful for generating such predictions as they do not require *a priori* insight into the complex species' dynamics. Although statistical SDMs are typically developed using *in situ* environmental observations, their predictions are commonly created by forcing SDMs with environmental information generated by mechanistic models. This hybrid data-model approach can expand the temporal and spatial domain of the projections. This, however, may decrease the SDM prediction skill because of biases associated with the mechanistic model output. We test the hypothesis that training SDMs using environmental mechanistic model output may enhance model prediction skill by compensating for biases in the mechanistic model. We train SDMs for seven estuarine algal taxa observed in the Chesapeake Bay (U.S.A.) using both multi-decadal *in situ* environmental observations and mechanistic environmental output provided by a 3D coupled hydrodynamic - biogeochemical model. Training the SDMs using mechanistic model output, rather than *in situ* data, improves the model prediction skill by more than 10 %. This demonstrates that although errors in SDM predictions can be caused by using imperfect environmental fields derived from mechanistic models, these uncertainties may be diminished by training SDMs using these same environmental fields.

A dual machine learning and mechanistic approach to modelling future zooplankton prey for forage fish

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Abstract

We present results from a dual machine learning and mechanistic approach to modelling future zooplankton prey energy available to forage fish. Patterns of zooplankton abundance, phenology and species composition in the Northeast Atlantic have changed over the past 60 years. The drivers are not fully known but thought to be associated with changes in ecosystem productivity and range shifts due to warming temperatures (e.g. Schmidt et al., 2020; Edwards et al., 2021; Olin et al., 2022). It is imperative to understand how this is will continue and the consequences for keystone predators such as seabird, salmon and cetaceans whose food webs are supported by zooplankton prey.

To investigate the drivers of past variability in zooplankton, we use two approaches. First, Random Forest machine learning algorithms are trained on historical Continuous Plankton Recorder (CPR) data for key zooplankton taxa in forage fish diets, converted from abundance to energy and corrected for differential catchability by the CPR. Potential predictors are derived from a biophysical ocean model reanalysis for the Northeast Atlantic. The models are assessed for their ability to extrapolate in space and time, and we discuss approaches to obtaining mechanistic understanding from the "black box" of machine learning techniques. Second, the same data are used to parameterise the mechanistic trait-based zooplankton community model Coltrane (Copepod Life history Traits and Adaptation to New Environments; Banas & Campbell, 2016). Coltrane is a mathematical framework for layering multiple levels of mesozooplankton biology on top of oceanographic models, resolving individual life history, population dynamics and community composition. Climate projections of zooplankton communities are then obtained by driving the machine learning and mechanistic models with an ensemble of biophysical ocean climate models under emissions scenario RCP8.5.

We discuss approaches to comparing and synthesising the results of these two approaches in the context of future population viability of seabirds (ECOWinds project Ecowings) and salmon post-smolts (Missing Salmon Alliance's Likely Suspect Framework), both of which prey on planktivorous forage fish species.

Parameterizing 3D Marine Biogeochemical Models: Surrogate-Based Optimization for Parameter Estimation and Performance Enhancement.

Hoa Nguyen[1,2], Sebastian Krumscheid[3], Linus Seelinger[3], Ute Daewel[1], Corinna Schrum[1].

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Abstract

In marine biogeochemical modelling, it is crucial to obtain model parameterisations that allow the model to reproduce observed and measured data. However, this has long been a challenging task. One reason is that a biogeochemical model often contains a large number of parameters, and traditional approaches such as try out all possible parameter combinations (or brute-force) to determine parameter values can quickly become extremely computationally expensive. Recently, several 1D marine ecosystem modelling studies have introduced and demonstrated the effectiveness of optimization methods for estimating the model parameters. However,when it comes to 3D models, which take much longer to run, these robust optimization methods in 1D models often become unfeasible. Nevertheless, 3D models are generally used to study the impacts of climate variability and human activities on marine ecosystems. Here, we present the Surrogate-based Optimization (SBO) method, which accelerates optimization processes by using surrogates for application with high computational demand, such as the 3D marine biogeochemical model. We implement the SBO method in the biogeochemical model ECOSMO E2E coupled to the 3D hydrodynamic model HAMSOM in the Framework for Aquatic Biogeochemical Models (FABM) for the North Sea region. We validate the coupled model and quantify the corresponding model uncertainty using long-term physical, hydro-chemical, and biological measurements. We aim to demonstrate that the SBO method successfully identifies parameter sets that significantly enhance the performance of the 3D HAMSOM-ECOSMO E2E model. Importantly, the SBO procedure is developed to becompatible with the FABM, thus facilitating seamless implementation across diverse model systems availablewithin the framework, and is, therefore, a promising tool for calibrating biogeochemical models in regional and global contexts.

Delineating robust cores in marine spatial structure: Applications to Atlantic sea scallop (*Placopecten magellanicus*) connectivity

Karsten Economou, Wendy Gentleman

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Abstract

Effective management of marine species requires knowledge of their geographic distribution and connectivity at present and in the future. For many species, including the Atlantic sea scallop (*Placopecten magellanicus*), such spatial structure is predominantly influenced by advection during a planktonic larval stage. Interpreting simulated larval dispersal as a transport network, where pieces of the ocean (nodes) are connected by larval exchange, facilitates spatial structure assessment using network science. Namely, the community structure of a transport network is the natural decomposition of the species' geographic distribution into spatially-disjunct subpopulations that are weakly interconnected. While maps of detected community structure provide a powerful synoptic view of connectivity, they may be misleading; characterizing the statistical significance of results is necessary to ensure the stability of community structure when small perturbations are applied to the network, representing uncertainty and/or temporal evolution. This consideration is largely neglected in existing literature but is imperative to responsibly inform management.

Using *P. magellanicus* connectivity as a case study, we aim to demarcate significant node assignments to communities from statistical noise by identifying groups of nodes that are robust to network perturbations. We utilize bootstrapping to generate artificial networks with small variations in relative larval transfer from the real network. We then use a novel recursive significance clustering scheme to repeatedly search for the largest set of nodes that persistently cluster together in the perturbed networks, forming a robust core. This approach not only delineates geographical "fuzzy borders" of the marine spatial structure but also filters this noise to enable quantitative comparisons of structure among different transport networks.

Benefit of assimilating BGC-Argo observations for investigating the air-sea CO2 flux in the Southern Ocean

Andrea Rochner, David Forc

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Abstract

Estimating the air-sea flux of carbon dioxide (CO_2) is a challenge for both ocean-biogeochemical models and observations due to the range of drivers contributing to its variability on various temporal and spatial scales. Here we use biogeochemical data assimilation (DA) to assess the ability of different observation sources – Biogeochemical-Argo (BGC-Argo) floats, ship-based, satellite-based – to constrain the CO_2 flux estimates in an ocean-biogeochemical model. The focus is on the Southern Ocean as a region of large uptake of anthropogenic CO_2 but also large uncertainty. A 3D-variational method (NEMOVAR) is updated and tuned for this purpose, i.e. to optimally assimilate data from the different sources. Previous capabilities of biogeochemical DA with NEMOVAR, which were limited to satellite and synthetic in situ data, are extended towards new variables and actual observations. The effect of the DA on the biogeochemical fields depends on the characteristics and coverage of the observation type. Only BGC-Argo data is able to have a coherent effect on surface and interior biogeochemical fields in the DA. These coherent changes are important to understand the interior drivers of variability of the CO_2 flux. The adjustments by the DA to the biogeochemistry point to shortcomings in the underlying physical simulation, which the biogeochemical DA does not correct but can highlight. In contrast, ship-based data has localised effects, while the DA of ocean colour data only constrains the surface fields. These results therefore demonstrate the ability to use biogeochemical DA to inform model development and represent a further step towards creating a biogeochemical reanalysis, and additionally stress the importance of having regular observational coverage for biogeochemical data as provided by BGC-Argo.

A solution for autonomous, adaptive monitoring of coastal ocean ecosystems: Integrating ocean robots and operational forecasts

David Ford[1], Shenan Grossberg[2], Gianmario Rinaldi[2], Prathyush Menon[2], Matthew Palmer[3], Jozef Skákala[3], Tim Smyth[3], Charlotte Williams[4], Alvaro Lorenzo Lopez[5], Stefano Ciavatta[6]

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Abstract

This study presents a proof-of-concept for a fully automated and adaptive observing system for coastal ocean ecosystems. Such systems present a viable future observational framework for oceanography, reducing the cost and carbon footprint of marine research. An autonomous ocean robot (an ocean glider) was deployed for 11 weeks in the western English Channel and navigated by exchanging information with operational forecasting models. It aimed to track the onset and development of the spring phytoplankton bloom in 2021. A stochastic prediction model combined the real-time glider data with forecasts from an operational numerical model, which in turn assimilated the glider observations and other environmental data, to create high-resolution probabilistic predictions of phytoplankton and its chlorophyll signature. A series of waypoints were calculated at regular time intervals, to navigate the glider to where the phytoplankton bloom was most likely to be found. The glider successfully tracked the spring bloom at unprecedented temporal resolution, and the adaptive sampling strategy was shown to be feasible in an operational context. Assimilating the real-time glider data clearly improved operational biogeochemical forecasts when validated against independent observations at a nearby time series station, with a smaller impact at a more distant neighboring station. Remaining issues to be addressed were identified, for instance relating to quality control of near-real time data, accounting for differences between remote sensing and *in situ* observations, and extension to larger geographic domains. Based on these, recommendations are made for the development of future smart observing systems.

Review of the Copernicus Marine Service Global biogeochemical reanalysis : modelling, Ocean Color and Carbonates data assimilation and validation against BGC-Argo-based in situ datasets

Coralie Perruche, Julien Lamouroux, Nabir Mamnun, Elodie Gutknecht, Alexandre Mignot, Giovanni Ruggiero

Mercator Ocean, Toulouse, France

Abstract

The operational production of data-assimilated biogeochemical state of the ocean is one of the challenging core projects of the Copernicus Marine Service. In that framework, Mercator Ocean is in charge of developing a global ¼° biogeochemical reanalysis simulation, covering the period from 1993 to the present.

The system supporting this reanalysis simulation, to be commissioned in 2025, is based on the biogeochemical model NEMO-PISCES, in an offline coupling with the dynamical ocean (1/12° coarsened to 1/4° resolution) from the Mercator Ocean global physical reanalysis system (embedding physical data assimilation). This BGC simulation shall benefit from the assimilation of satellite Ocean Colour data (Chlorophyll concentration), and from Machine-Learning-extended-SOCAT-based Carbonates surface data (dissolved inorganic carbon and total alkalinity). In addition, a climatological relaxation is required to mitigate the impact of some misconstrained processes (vertical velocities) in this physical data-assimilated forcing.

The aim of this presentation is to give an overview of the developments made in this 30-year global biogeochemical simulation, from the modelling and coupling specifications, the data assimilation performances and limitations, to the use of novel metrics based on the BGCArgo Neural-Network-extended dataset, to provide a global 4D exploration and validation of the biological Carbon pump, the Carbon uptake and Oxygen-related key biogeochemical processes.

New opportunities to develop, test and share process models in a common framework

Jorn Bruggeman

Bolding & Bruggeman ApS, Asperup, Denmark. Plymouth Marine Laboratory, Plymouth, United Kingdom

Abstract

The Framework for Aquatic Biogeochemical Models (FABM; https://fabm.net) is widely used for write-once, run-anywhere development of marine ecosystem models that move seamlessly from light-weight testbeds to operational model systems such as the Copernicus Marine Service. Here I provide an overview of two recent developments in FABM, supported by a number of EU projects (https://www.neccton.eu, https://ocean-icu.eu, https://seamlessproject.org). First, the development of a series of efficient testbeds, from Python-based box models, to 1D water columns, to global 3D circulation – all capable of running on single laptops or workstations, and some with built-in support for sensitivity analysis, calibration and data assimilation. Second, the emergence of common standards for exchanging and coupling process models, covering the carbonate system, spectrally resolved irradiance, suspended particulate matter, higher trophic level models with two-coupling to biogeochemistry, and more. Taken together, these two developments have the potential to reduce development time, to facilitate integration of new and improved process understanding into operational model systems, and to make it easier to exchange components among marine ecosystem models.

Ensemble Assimilation of Satellite-derived Carbon Measurements into a Global Model

Yumeng Chen[1,2], Dale Partridge[3,2]

[1]University of Reading, Reading, United Kingdom. [2]National Centre for Earth Observation (NCEO), Leicester, United Kingdom. [3]Plymouth Marine Laboratory, Plymouth, USA

Abstract

To improve the numerical prediction of the marine models, data assimilation (DA) methods combining observations with model forecasts are used to obtain an estimate of the true state of the system. Within the community model NEMO there is limited functionality for data assimilation, with the inclusion of variational approaches developed by some user groups. To enable greater functionality of data assimilation within NEMO, it has been coupled with the Parallel Data Assimilation Framework (PDAF, https://pdaf.awi.de).

PDAF is open source software providing generic functionality for data assimilation, allowing ensemble filters and smoothers, variational schemes, as well as ensemble simulations and associated diagnostics and tools. For computational efficiency the coupling to NEMO was performed by inserting a few subroutines in higher-level routines of NEMO, which call functions of PDAF. This scheme allows for an in-memory exchange of model fields with the data assimilation software in order to avoid excessive file outputs and model restarts.

In this study, we utilise PDAF to construct an ensemble DA system for the coupled ocean-biogeochemistry model, NEMO-MEDUSA, for the eORCA 1° global ocean setup over the period of 2015 to 2018. Focusing solely on the assimilation of biogeochemical variables, we compare the ensemble approach to the traditional NEMO-VAR approach, with the added benefit of a fully flow-dependent uncertainty estimate of the model forecast.

Most biogeochemical observations are phytoplankton chlorophyll data derived from satellite ocean colour observations. In recent years, ocean colour data has been used to derive phytoplankton carbon data (CITE BICEP). Using the ensemble system, we investigate the effects of assimilating phytoplankton carbon data compared to phytoplankton chlorophyll data, along with the impact of assimilating both types of phytoplankton data in the same setup.

Ensemble Programming for Oceanic Modelling

Michal Grossowicz, Nitsan Avni

Gigablue Ltd., Caesarea, Israel.

Abstract

In this talk, we'll share our way of working that we've developed at Gigablue, that includes Ensemble Programming in a cross-functional team, GenAI, and Continuous Delivery. Gigablue is an mCDR startup, where we effectively export CO2 to the deep ocean for thousands of years using contained microalgae growth in engineered particles. Our multidisciplinary team includes scientists and engineers from different fields like oceanography, biology, and chemistry.

We use a variety of oceanic models to steer our technology development. In our modeling team, we use Ensemble Programming. Ensemble Programming is, as Woody Zuill puts it, "All the brilliant minds working together on the same thing, at the same time, in the same space, and at the same computer" . This helps us get work done quickly and effectively. In addition, we use the latest generative AIs to prototype our models and accelerate models' development.

We've instituted a feedback loop that binds our modeling, lab modifications, and marine trials into a cohesive system. Our models direct experimental designs, while lab advancements and trial outcomes refine the model through real-world data. This synergy sharpens the accuracy of our simulations, ensuring our particle deployment strategies are both effective and reflective of oceanic complexities.

To give one example, at Gigablue, we conduct ocean experiments that are guided by our "Particle Dispersal" Lagrangian model, developed using our methodology. This model helps us plan our experiments by determining the optimal number and placement of particles in the ocean. Using the Parcels package, we create 2D and 3D simulations to understand how these particles move under strong ocean currents, specifically for our studies near New Zealand. The model is designed to be user-friendly, allowing team members with varying levels of programming skills to adjust settings and interpret results through simple graphs, tables, and visualizations. This approach streamlines our research process, making it easier for our team to work together and make informed decisions about our ocean experiments.

Developments in operational biogeochemical modelling at the UK Met Office

Susan Kay[1,2], David Ford[1], Andrea Rochner[1]

[1]Met Office, Exeter, United Kingdom. [2]Plymouth Marine Laboratory, Plymouth, United Kingdom

Abstract

The Met Office provides a daily 5-day forecast and a multi-decadal reanalysis for chlorophyll, primary production, nutrients, oxygen and pH, covering the North Sea and other parts of the North West European Shelf. Both are produced by running the European Regional Seas Ecosystem Model (ERSEM) coupled to the Nucleus for European Modelling of the Ocean (NEMO), with assimilation of ocean colour chlorophyll, sea surface temperature and temperature-salinity profiles. The forecasts are available as a dedicated Met Office service and the reanalysis can be obtained from the Copernicus Marine Service.

We provide an update on current developments and future prospects for these products. Recent work has focussed on data assimilation: a move from assimilation of total chlorophyll to plankton functional type chlorophyll in the reanalysis, assimilation of sea level anomaly both on and off the shelf, and introduction of revised error covariances for ocean colour chlorophyll. We have also been investigating a problem with unrealistically large increases in modelled nutrient values in the Southern North Sea and Irish Sea, which seems to be associated with changes to ocean colour products. For the future we will be focussing on a move from 7 km resolution to 1.5 km: the Met Office already runs an operational physical model at this resolution and we discuss progress towards introducing a biogeochemical component, which has much higher computational demand. We are also developing the capability to assimilate biogeochemical data from gliders and other new platforms as they become available, and assessing the impact of this new data.

We are always interested to hear from users and potential users of our products, and we would welcome any feedback from AMEMR attendees about the usefulness of our products and what you would like to see in future.

Model Calibration: Treating Selected Parameters as Random Variables

Volkmar Sauerland[1], Claudine von Hallern[2], Iris Kriest[1], Julia Getzlaff[1]

[1]GEOMAR Helmholtz Center for Ocean Research, Kiel, Germany. [2]Universität Hamburg, Hamburg, Germany

Abstract

Processes in marine ecology often depend on uncertain parameters, influencing the prediction accuracy of associated models. A common approach to address this uncertainty is parameter tuning, with the goal of achieving a better match between model simulations and real-world measurements. In practice, during the tuning process the majority of model parameters is kept constant while a subset of parameters --- depending on the research question—-- is changed to reduce the model-data misfit.

However, when parametric uncertainties arise due to simplified model equations, it might be preferable to treat associated model parameters as random. For instance, the quadratic loss of zooplankton captures a spectrum of characteristics across various zooplankton species and encompasses diverse processes such as cannibalism within the highly aggregated zooplankton compartment, predation by fish and higher trophic levels, and density-dependent population control through viral infection.

We introduce an optimization algorithm that enables the declaration of selected parameters as random, while optimizing others that are assumed to be constant values.

The efficacy of this new algorithm is tested using a global biogeochemical circulation model to quantify the impact of zooplankton mortality on the underlying biogeochemistry. Compared to the deterministic version of the algorithm we converge to a solution that better suits the credible range of the zooplankton mortality parameter, even with less computational effort.

Improved understanding of eutrophication trends, indicators and problem areas using machine learning

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Abstract

Nitrate is an essential inorganic nutrient limiting phytoplankton growth in many marine environments. Eutrophication, often caused by nitrogen deposition, is a reoccurring problem in coastal regions, including the North-West European Shelf (NWES). Despite of their importance, nitrate observations on the NWES are difficult to obtain and thus sparse both in time and space. We demonstrate that machine learning (ML) can generate, from sparse observations, a skilled, gap-free, bi-decadal (1998-2020) surface nitrate data-set. We demonstrate that the effective resolution (scales on which the data-set is skilled) is slightly coarser than the 7 km and daily resolution of the product, but still completely sufficient to analyse nitrate dynamics on a monthly scale. With such a data-set we can address questions that would be otherwise hard to answer: (i) We show that nitrate-limited regions on the NWES, potentially vulnerable to eutrophication, extend beyond the eutrophication-problem areas already identified by the monitoring bodies (i.e. OSPAR). The newly identified regions include southern Irish coastline and parts of Irish Sea, indicating that these areas could become problematic under sub-optimal policy, or management changes. (ii) We demonstrate that bi-decadal 1998-2020 trends in coastal nitrate, responding to long-term policy-driven reduction in riverine discharge, are mostly modest with a notable exception of the Bay of Biscay. (iii) We show that winter nitrate plays relatively minor direct role in the phytoplankton bloom intensity the following spring, which can have some implications for using winter inorganic nitrogen as eutrophication indicator (as often included by OSPAR).

EnsAD: Assimilation of hyperspectral satellite data into the marine ecosystem model HBM-ERGOM using optical plankton classes

Johannes Timm[1], Ina Lorkowski[1], Dagmar Müller[2], Kerstin Stelzer[2], Annika Grage[1], Karin Heyer[1], Jorge García[2], Ana Ruescas[2], Carsten Brockmann[2], Eefke van der Lee[3]

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Abstract

Hyperspectral remote sensing technologies will transform our understanding of marine ecosystems by facilitating exceptionally detailed plankton observations. The EnsAD project aims to incorporate hyperspectral satellite data, converted into optical plankton classes, into the HBM-ERGOM ecological model. These optical plankton classes define the structure of the ecological model.

We differentiate five primary optical plankton classes: red and blue cyanobacteria, cryptophyta, spectral green plankton and spectral brown plankton. We further distinguish certain sub-groups, namely Coccolithophyceae, *Phaeocystis sp*. and *Noctiluca sp*. The satellite classification model distinguishes between plankton classes based on their hyperspectral signatures using machine learning techniques trained on a data-based iterative algorithm. Objective comparisons with in-situ plankton data are achievable since these optical classes generally correspond with taxonomic groups.

The optical classes establish the foundation of the ecosystem model, which differs from traditional approaches. Access to hyperspectral data is presently scarce. However, we anticipate the PACE satellite will lead to more readily available data in the near future.

Here we present the methodology and conceptual framework of the ecosystem model used in EnsAD.

Expanding the ecosystem model by incorporating optical groups provides a more ecologically detailed depiction of the plankton community by encompassing underrepresented groups, such as cryptophyta. Additionally, we circumvent the use of a complete bio-optical model and translation layer in the biogeochemical model by directly modelling observable plankton groups.

Assimilating hyperspectral data into the ecosystem model will enable the nowcasting of harmful algal blooms (HABs), leading to better-informed stakeholders. Other findings from this modelling approach may assist in the assessments required by EU Directives.

The EnsAD project is ongoing, with the potential to redefine how we see and model plankton communities.

The two-echelon covering tour problem with varying coverage: application in carbon storage monitoring.

Parisa Torabi, Guttorm Alendal, Anna Oleynik, Ahmad Hemmati

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Abstract

Carbon Capture and Storage (CCS) is a technology and process designed to mitigate the release of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere, helping to combat climate change. CCS involves capturing CO_2 emissions from industrial processes, power plants, and other sources, transporting it, and securely storing it underground to prevent its release into the atmosphere. Here we consider offshore geological sites.

Although a leakage of injected CO_2 is considered unlikely, in order to comply with regulatory requirements and gain public acceptance, monitoring of the storage sites is essential. To reduce the associated costs, the monitoring program must be designed with optimal use of the equipment.

In this regard, the article "Covering tour problem with varying coverage: Application to marine environmental monitoring" was recently published, where the authors consider an Autonomous Underwater Vehicle (AUV) with limited battery capacity to move among a set of locations/nodes and take measurements. The repeated measurements, along with the ocean currents, help detect a signal of leakage from a distance, resulting in a time-varying coverage. The optimal route for the AUV is sought, with the objective to maximize the weighted combination of the coverage of nodes and the cost of moving and staying in the nodes.

We improve upon this by considering a more realistic case, whereby a survey vessel will carry multiple AUVs to be sent on missions. This way, the AUVs can be recharged and dispatched for multiple missions, and the flexibility of the monitoring plan increases significantly. This results in a two-echelon covering tour problem with varying coverage (2-CTPVC).

The mathematical model for 2-CTPVC is developed and tested on instances. However, considering the complexity of the problem, and since the problem needs to be of at least a certain size in order for the levels of transportation and coverage to be meaningful, the exact method proves to be rarely useful. Therefore, a meta-heuristic approach is developed to solve the problem in realistic sizes. We also give managerial insight regarding the effect of the number of available AUVs and their capabilities on the solution quality.

Incorporating a spatially varying attenuation coefficient improves the simulation of the summer blooms in the southern Red Sea

Yixin Wang[1], Matthew Mazloff[2], Ariane Verdy[2], Ivana Cerovecki[2], Marianthi Pateraki[1], George Krokos[1,3], Ibrahim Hoteit[1]

[1]King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia. [2]Scripps Institution of Oceanography, La Jolla, USA. [3]Institute of Oceanography, Hellenic Centre for Marine Research, Anavyssos, Greece

Abstract

Remote sensing chlorophyll data have revealed the existence of summer blooms in the southern Red Sea, which previous biogeochemical modelling efforts have found challenging to capture. Here, by incorporating a spatially varying diffuse attenuation coefficient (K_d) in a coupled physical-biogeochemical (MITgcm-NBLING) model, we successfully capture the summer blooms through simulating the highly turbid water in the southern Red Sea characterized by shallow light penetration (i.e., shallow lit-layers). Shallow lit-layers prevent deep nutrients depletion before physical processes (such as vertical mixing and upwelling) lift these nutrients to shallower depths, promoting shallow blooms which can theoretically be detected by remote sensing. An increased model vertical resolution also contributes to the simulated summer blooms through improved representation of the nutrient-rich Gulf of Aden Intermediate Water (GAIW) intrusion during summer. The model simulation also reveals that the GAIW facilitates stronger blooms along the east coast than the west coast in the southern Red Sea due to the east-coast upwelling and the eastern-intensified pathways of GAIW. Overall, our results demonstrated that a constant K_d tuned for clear open ocean water is not suitable for the turbid southern Red Sea as it results in fast deep nutrient depletion, highlighting the importance of incorporation of spatially varying K_d for Red Sea biogeochemical modelling.

Global patterns of marine calcite production resolved using machine learning models

Nicola Wiseman[1], Joost De Vries[1], Fanny Monteiro[1], Levi Wolf[1], Alex Poulton[2]

[1]University of Bristol, Bristol, United Kingdom. [2]Heriot-Watt University, Edinburgh, United Kingdom

Abstract

Calcium carbonate production (CP) by marine plankton is a key component of the marine carbon cycle, influencing both the biological carbon pump, which sequesters carbon in the deep ocean, and the carbonate counter pump [which does xyz]. Global estimates of CP have primarily been derived from satellite products, which are limited to the surface open-ocean, and are adapted to the marine coccolithophore, *Emiliania huxleyi*. These estimates lack depth resolution or contribution from other marine coccolithophores, and other calcifying organisms such as foraminifera and pteropods.

Recent efforts to improve our understanding of the global magnitude and regional variability of CP have included field campaigns to measure CP in-situ using Carbon-14 tracing, however, this data is still sparse in coverage. Machine-learning models can help fill this gap where traditional interpolation methods fail and, unlike satellite products, are also able to resolve depth distributions and represent all calcifying groups.

Here, we present a global estimate of marine calcite production for the top 200m of the open ocean at a monthly, 1 degree horizontal resolution which was generated with a machine-learning ensemble trained on in-situ CP data. We show that previous estimates have underestimated the globally integrated annual CP due to the lack of depth resolution and focus on single species signals in satellite productions. We also highlight regions of high uncertainity and high predicted CP as areas of interest for future CP field campaigns. Lastly, we compare the depth distribution of CP to new species distribution models for coccolithophore species to investigate the relative role of individual species to global CP.

Photo Gallery

Presentations and discussion session

Modelling Workshop, Friday 12th.

The ECR Organising Committee, L-R Rebecca Millington, Deniz Desa, Samantha Grusd, Helen Powley, Yaru Li, Javier Porobic Garate.

Sundays ECR gathering

The conference dinner at the National Marine Aquarium

The conference poster hall