A New Trait-Based Auto-Emergent Model for Zooplankton and Confrontation with Size-Structured Observations from the Bay of Biscay

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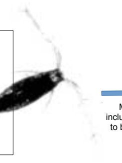
Scientific Context



ZOOPLANKTON

Highly diverse groups:
Taxonomy
Size range
Ecosystem functions

Models need to include some diversity to be representative

How to include this diversity in models?

- Size structure of zooplankton community
- Various feeding behaviour

Link primary production to top consumers

Complex interaction with particles flux
Regulate biogeochemical cycles

Importance of size and feeding types:

- Metabolic rates follows allometric laws (on the form $Y = ax^b$) linked to size (x)
- Optimal prey size depends on predator size and feeding types
- Size of fecal pellets scales with size of organisms
- Coprophagy/coprorhexy linked to feeding type
- Feeding of early life stage of pelagic fishes highly dependent on the size structure of the zooplankton community

Zooplankton is a highly diverse group of organisms covering many order of size (from 20µm to the largest jellyfish), taxonomic groups and behavioural diversity. However, most aquatic ecosystem models typically contain only one or two state variables, i.e. micro- and meso-zooplankton for the most common, that represent the role of all zooplankton forms within the pelagic ecosystem. Yet, for ecosystems and biogeochemical models to be representative it is needed to include diversity in their components [1,2,3]. So far such diversity was mainly integrated in the phytoplankton compartment [1,4] by generating species with randomly drawn traits allowing properties of the system to emerge. Such auto-emergent trait-based models have proven to be suitable for use in large scale global 3D models and shown promising results.

As for zooplankton models, recent improvements were made in characterizing and modelling one of their most important trait, i.e., their size structure [5,6,7,3], some of them being integrated in 1D or 3D biogeochemical models [7,3]. The size of zooplanktonic organisms strongly determines their metabolism as well as their interactions with their prey. Moreover, the size distribution of zooplankton is of great importance to determine available food of top predators such as fish. Yet, other traits than size matter for zooplankton and for modelling their functions in the ecosystem. An important trait in this sense is the feeding behaviour of zooplankton. While the predator:prey size ratio seems strongly determined by the size of the predator, the prey type has also a strong effect [8]. E.g., optimal prey for copepods of same size could varied by a factor of 100 if they are carnivores rather than detritivores [fig3 in 8].

The objective of the present work is to proposed a new way of modelling zooplankton by including their diversity through a random draw of their traits – here the size and the diet, yet other traits could be easily randomly drawn. A number of zooplankton species is then generated, each having different characteristics. The model is included in the 3D biogeochemical model MARS3D [9] on a test case representing a simplified view of the Bay of Biscay. Auto-emerged patterns are then confronted to observations to assess the ability of such models to best represent the reality.

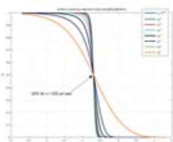
Biological Model

From the model EcoMars3D [10] → 3 phytoplankton – particulate and dissolved detritus – Nitrate / Phosphate / Silica

Zooplankton → n species defined by a size and a degree of herbivory:
Partitioned between 4 extremes on a 2D space (see scheme on the right side)

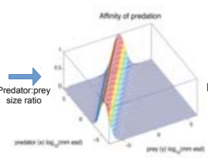
High degree of herbivory (A and B)
- Small → feed on pico/nano phytoplankton
- Large → feed on micro phytoplankton

Threshold: 200µm esd



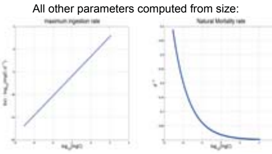
Low degree of herbivory (C and D)

Predator:prey size ratio



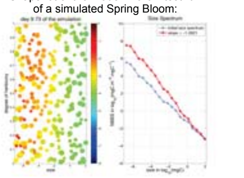
Prey available?
- no: Small → feed on detritus (heterotrophic flagellates)
- yes: Large → feed on other zooplankton

All other parameters computed from size:

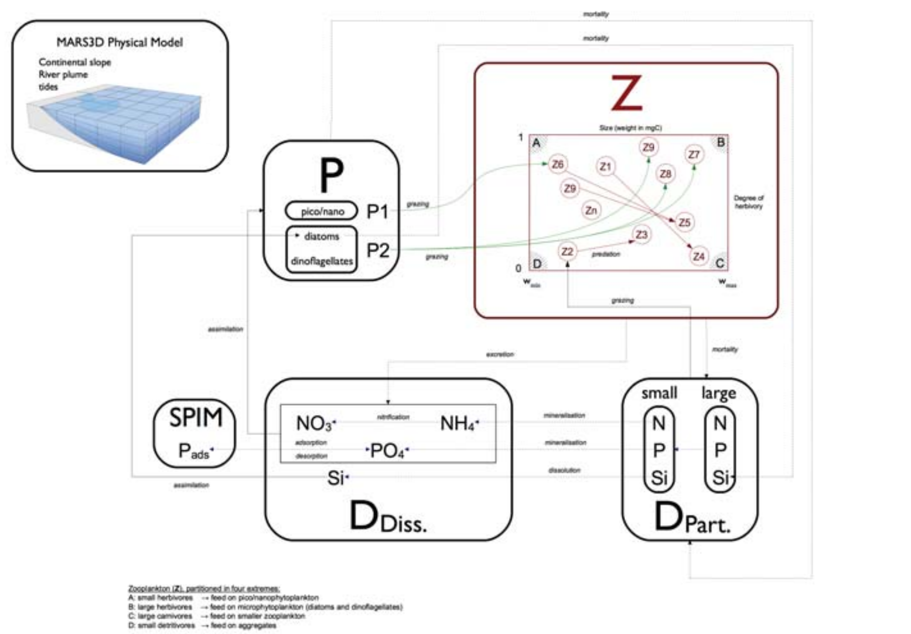


Additional traits:
We have added an additional random trait for the example. Species could have a higher assimilation efficiency but this is associated to a higher mortality rate. This mimics the *r* and *K* strategies.

Snapshot of the model in a 0D test run of a simulated Spring Bloom:



- Colors represent the biomass of each generated species → red indicates largest biomass and success of these species
- Size of points accounts for different strategies → small have a better assimilation efficiency but higher mortality rate

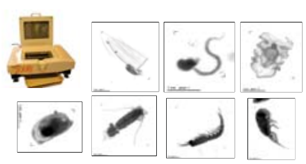


Zooplankton (Z), partitioned in four extremes:
A: small herbivores → feed on pico/nanophytoplankton
B: large herbivores → feed on microphytoplankton (diatoms and dinoflagellates)
C: large carnivores → feed on smaller zooplankton
D: small detritivores → feed on aggregates

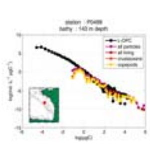
Observations of the *in situ* size structure of the zooplankton in the Bay of Biscay

The zooplankton (meso, from 0.2 to 2 mm esd) was observed during the spring-time cruises Pelgas and Pelacus (on board *NO Thalassa*) from 2005 to 2012. The size structure was measured at some locations from plankton net samples (WP2 net) using the ZooScan [11,12] imaging system. Size spectra were extrapolated to other locations using statistical correlations with the size structure of all particles measured with the LOPC [13] and environmental variables (Vandromme et al. In prep).

The dominant pattern is a strong coastal gradient with higher biomass and steeper spectra near the coast and river plumes.

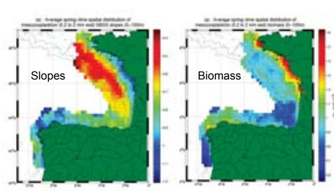


ZooScan and examples of zooplankton images



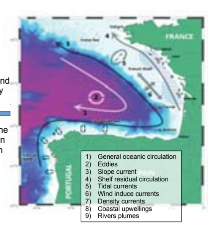
Zooplankton size spectrum measured at one station by the ZooScan from net sample and by the LOPC

Climatological map



Hydrology and bathymetry features

Impact on the zooplankton distribution



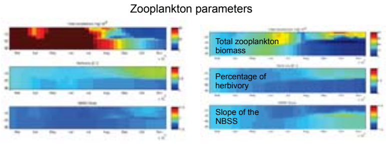
1) General oceanic circulation
2) Eddies
3) Slope current
4) Shelf residual circulation
5) Tidal currents
6) Wind induce currents
7) Density currents
8) Coastal upwellings
9) Rivers plumes

3D simulations

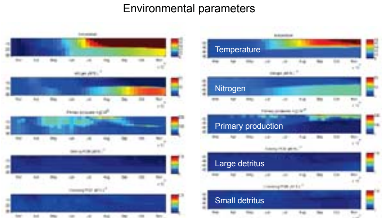
Seasonal dynamics
(March to November)

Coastal | Off-shore

Zooplankton parameters



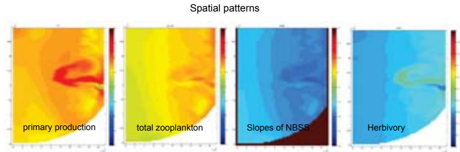
Environmental parameters



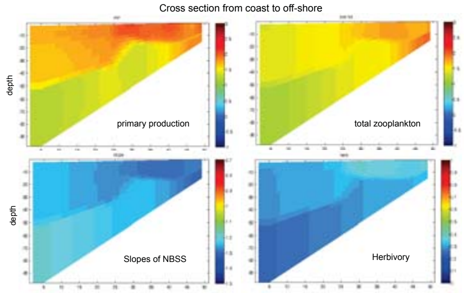
Simulation on a 50x100 grid with 20 vertical layers
100 zooplankton species generated
1 year of simulation → 48h on 256 CPU

Snapshot in Spring

Spatial patterns



Cross section from coast to off-shore



Conclusion

We have developed a trait-based auto-emergent zooplankton model that we implemented into a 3D biogeochemical model. Two main traits are randomly drawn: the size and the degree of herbivory. A large number of zooplankton functional types is then generated and the most adapted to environmental situations encountered in the model will emerge. To demonstrate the flexibility of the model we included another random traits that accounts for *r* and *K* types strategies (higher assimilation and mortality rates vs. lower ones).

The model was tested in a simplified case representing the Bay of Biscay main features, i.e., a continental shelf, a river plume, tides and mean environmental forcing (seasonal cycle of light and temperature, stratification, mixing). Main observed patterns of the zooplankton community emerged from the model: higher biomass and steeper spectra at the coast and within the river plume. However modelled size spectra are steeper than observed ones (in Spring offshore modelled slopes of -1.2/-1.3 vs. -0.5 for observed ones, coastal modelled slopes of -1.3/-1.4 vs. -1.1/-1.2 for observed ones). For total zooplankton biomass the differences between observed and modelled is lower. Further optimization work is needed. Yet, the model shows the ability to produce a complex dynamic with only few parameters - 12 parameters were necessary here, mostly for allometric scaling with size – and the ability to be integrated into 3D biogeochemical models, yet, extensive simulations are still limited by the computational cost.

The zooplankton is a complex and diverse element of the ecosystem difficult to properly formulate in biogeochemical models. Recent models have included its size distribution [e.g., 3,5,6,7], yet, despite the strong scaling of metabolic as well as predator:prey interaction with size, other traits are not fully determined by it. This is the case of the diet, organisms of same size could behave opposite. We choose to develop a flexible model that allows to include and study the effect of various traits of the zooplankton in an auto-emergent fashion in the sense of previous models made for phytoplankton mostly [1,4]. Such approach open a large array of new possibilities to model and study the effect of zooplankton in pelagic ecosystems.

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