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Conceptual Model of the planktonic food-web

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Executive Summary

A conceptual planktonic network for food-web bifurcations is proposed, based on partner expertise in different semi-enclosed seas (Black Sea, North Sea, Baltic Sea) and targeted mesocosm experiments with different nutrient conditions. This conceptual model of food-web interactions constitutes the basic frame for identifying the data needs for ecosystem analysis and the subsequent identification of nutrient thresholds for planktonic food-web disruptions.

1. Introduction

Coastal seas are valuable habitats for recreational activities and harvestable resources. Exposed to human pressures at sea and from the watershed, these areas constitute particularly ecologically sensitive and vulnerable zones.

Human activity (agricultural, industrial, household) modifies the nutrient environment of aquatic systems in both quantity and quality [e.g. changing the molar N:P:Si balance with respect to the 16:16:1 stoichiometry of coastal diatoms (Brzezinski, 1985); changing the balance between oxidized N and reduced N forms; increasing the delivery of organic with respect to inorganic forms]. These various nutrient changes induce shifts in the dominance of phytoplankton groups which differ in size and elemental composition and hence palatability for grazers. Such shifts in phytoplankton dominance, ultimately impact the food-web structure and nutrient cycling in the water column and at the sediment-water interface (Lancelot et al., 2002). At the top level of the food-web, fishing activity, especially overfishing, also induces cascading food-web disruptions (Guccu, 2002).

Our overall objective is to develop nutrient thresholds for food-web bifurcation based on a comprehensive ecosystem analysis of historical data in coastal systems where regime shifts were observed, making use of Flow Network Analysis and mechanistic modeling (sensitivity analysis).

One first and crucial step towards this achievement consists in establishing an agreed conceptual food-web structure describing trophic interactions that will serve as a basis for constructing the data base required for the ecosystem analysis.

2. Conceptual model of the planktonic food-web

Topology of aquatic food-web structures involves aggregation of aquatic species into trophic species (Cohen et al, 1990). However in some cases, different life history stages are separated into different trophic species to better resolving the food-web (e.g. Christensen and Pauli, 1992; Rousseau et al., 2000). Most of existing marine food-webs very often detail fish species due to obvious commercial reasons but include an extremely aggregated representation of the low trophic levels (Jason et al., 2005). Such food-webs are not suitable for the identification of nutrient thresholds for food-web disruptions due to the fact that nutrient changes primarily affect phytoplankters and bacteria.

Knowledge of the mechanisms linking food-web bifurcations to nutrient changes are only in its infancy. Observational evidence reports the following scenarios. Human-induced eutrophication results in an excess of N and/or P over Si with respect to the requirements of diatoms during spring. This excess stimulates spring-summer blooms of opportunistic non-siliceous phytoplankton. Blooming species differ between areas, but seem to have in common their resistance to copepod grazing. The common fate of the copepod grazing-resistant blooming species is lysis (natural and virus-induced). This mortality process releases significant amounts of organic matter, which is remineralised by bacteria in the water column or sediment. This supply of organic matter stimulates an active microbial network, which through regeneration processes maintains nutrients in the system. In turn this can stimulate the growth of voracious gelatinous omnivores, which possibly also feed on diatoms, copepods, fish eggs and larvae impacting most probably dramatically on the whole food-web structure. Being a prey for few organisms, at least in European seas, gelatinous predators constitute a trophic dead-end in concurrence with the upper part of the food chain leading to copepods and fishes. Consequently most their biomass is remineralised in the water column, retaining regenerated forms of nutrients in the coastal area. Due to their low nutritive values, gelatinous zooplankton have been often considered as unimportant. There are however at least two reasons for including them. First gelatinous are dominant predators of zooplankton and larvae (Purcell, 1986). Second, the majority of trophic cascades are induced by gelatinous (Verity and Smetacek, 1996).

Based on discussions with Thresholds partners, Fig. 1 shows an idealized representation of the marine food-web developed for addressing nutrient-driven shifts in marine food-webs. In this representation, circles are used for trophic species and nutrients while interactions are represented by arrows. Nutrients include all forms of major inorganic nutrients [NO₃, NH₄, Si(OH)₄, PO₄] and organic nutrient [particulate (POM) and dissolved (DOM) organic matter]. The aquatic food-web of Fig.1 can be seen as a network composed of 3 main branches each with a different trophic efficiency and role in nutrient remineralisation process. These are:

- the so-called linear food chain composed of diatom (DIA) ? copepod (MZOO) ? fish
- the complex microbial network composed of bacteria (BAC), auto- (NAN) and heterotrophic flagellates and microzooplankton (μ ZOO) with the latter as a key organisms linking the microbial network to the linear food chain;
- the gelatinous realm including autotrophs (e.g. *Phaeocystis* colonies), carnivores (Ctenophores and jelly fishes GEL) and omnivores (e.g. *Noctiluca* NOC) often lacking predators and considered as trophic dead-ends.

The food-web is closed by one unique fish compartment but, depending on data availability, we might consider two trophic groups: the plankton-feeding fish and the carnivorous fish feeding on them. Recent observational evidence suggests that the latter group is fished down, leading to increased biomass for the former.

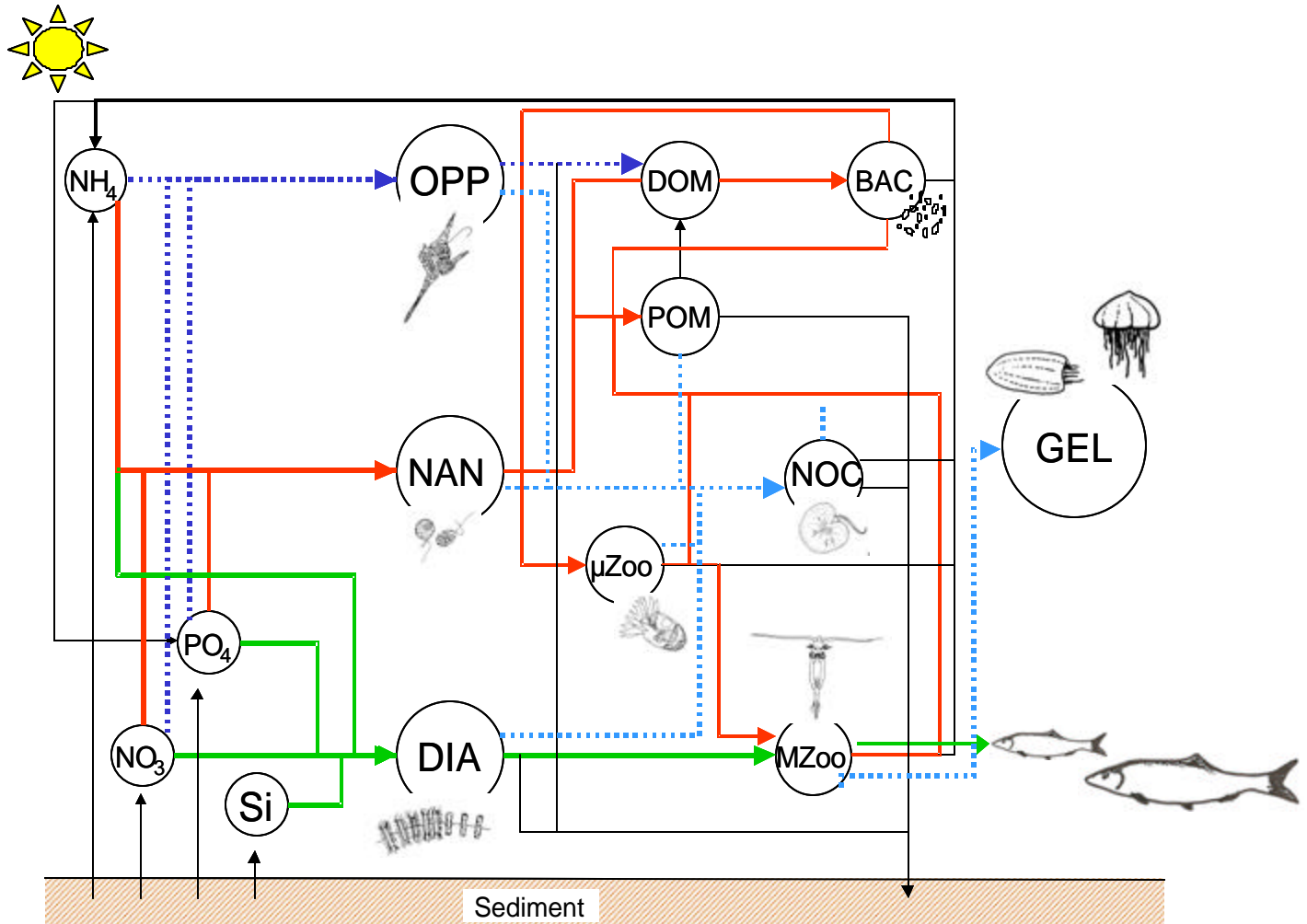


Figure 1: Idealized food-web structure: Si: $\text{Si}(\text{OH})_4$; DIA: diatoms; NAN : nanoflagellates ; OPP : Opportunistic phytoplankton ; μZOO : microzooplankton ; MZOO : copepods ; BAC : bacteria ; POM : Particulate organic matter ; DOM : dissolved organic matter. NOC: Noctiluca; GEL: Carnivorous gelatinous. In this representation, heterotrophic nanoflagellates have been aggregated with μZoo .

3. Ecosystem analysis

Methodology will combine analysis of the network structure of complex food-webs (equilibrium assumption) and mechanistic models. Thresholds will be viewed as critical qualitative and quantitative changes in the trophic structure after quantitative changes in the nutrient input. Food-web changes will for instance correspond to a shift in dominance between competing trophic species and hence a shift from a fish- to a gelatinous-dominated system. For this analysis, we will compare different ecosystems by the means of structural and functional properties. These are mainly the Black Sea that demonstrated a high sensitivity to nutrient changes over the past 40 years (Lancelot et al., 2002) and the *Phaeocystis*-dominated North Sea which does not show any apparent changes in community structure in spite of important increasing or decreasing trends in nutrient loads over the past 50 years (Billen et al., 2005; Lancelot et al. submitted). Depending on availability of historical data we think that the Baltic Sea will be an additional relevant ecosystem for supporting our analysis.

Due to the added top-down effect of fisheries on food-web structures, we will also test our methods on published mesocosm experiments with varying nutrient additions but for which the higher trophic levels are absent (e.g. COMWEB project; Olsen et al., 2001).

3.1 Structural analysis of networks – Topological networks

This matrix-based method (Jordán et al., 2005; Vasas and Jordán, submitted) gives information on the relative strength of influence each trophic species has on the others, through pathways of different length. Results heavily depend on actual data quality but comparative analyses of data bases similarly constructed show reasonable agreement. The network analysis will be based on correlations between change in biomass resulting from change of the input of a nutrient with a certain time lag. Thresholds will be derived, based on comparison of results obtained for different periods (before and after a non desirable shift)

3.2. Flow network analysis

This matrix-based method involves carbon and nutrient budget reconstruction making use of inverse modelling techniques. This method is based on equilibrium assumption and thresholds will be derived from comparison between at least two contrasted situations (i.e. before and after a non desirable shift) for each marine ecosystems. Input data are time series data on biomasses and biological activities. Outputs are average fluxes between the compartments and trophic species.

3.3. Mechanistic modeling

Mechanistic models incorporating explicitly the basic knowledge on processes directing the structure of the planktonic system and their forcing functions are valuable tools to investigate ecosystem stability, resilience to change or point of non-return. Such models have been developed for the Black Sea ecosystem (BIOGEN, Lancelot et al., 2002) and for the *Phaeocystis*-dominated ecosystem of the North Sea (MIRO, Lancelot et al., 2005). Model results will be first validated by comparison with existing time series. Sensitivity experiments with changing nutrient loads will be conducted in both coastal seas

to better understand the dynamics of the ecosystem and identify critical nutrient thresholds above which shifts in trophic structure and efficiency are simulated.

4. Required data

Tables 4.1 and 4.2 show an exhaustive list of physico-chemical and biological data required for time series analysis. Table 4.3 gives a list of annual averages that should be collected for contrasted years (before and after a shift). For each station, the coastal sea, the geographical position and sampling date should be indicated.

Table 4.1 Physical, optical and nutrient required data

Physical & optical characteristics	Water residence time (day) Depth (meter) Light extinction coefficient (meter^{-1}) Euphotic:mixing depth
Nutrient loads & concentrations	N, NO ₃ , NH ₄ , P, PO ₄ , Si (kg or T day^{-1}) NO ₃ , NH ₄ , DON, PO ₄ , DOP, Si (μM)

Table 4.2 Biomass and biological activity required data

Biomasses	Chl a (mg m^{-3}) Biological compartments (mg C m^{-3}) Diatoms, pico- and nanophytoplankton, Opportunistic phytoplankton, microzooplankton, Copepods, Noctiluca spp, jellies, fish Bacteria
Biological activities	$\text{GC m}^{-2}\text{d}^{-1}$ - gross primary production - net primary production - diatom growth rate - nanoflagellates growth rate - opportunistic phytoplankton growth rate - copepod grazing rate - microzooplankton grazing rate - bacterial production

Table 4.3 Time series of annual average

Annual average	- nutrient loads (N, P, Si, T year^{-1}) - biomasses (mgChla m^{-2} , $\text{mgC m}^{-2} \text{year}^{-1}$) - fish catch ($\text{kg C m}^{-2} \text{year}^{-1}$) - each prey consumed/total prey consumed ratio for each predator - biomass consumed by each predator/net production for each prey
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5. Conclusions

The proposed conceptual model of food-web interactions constitutes the basic frame for identifying the data needs for ecosystem analysis and the subsequent identification of nutrient thresholds for planktonic food-web disruptions. Results obtained will heavily depend on actual available data from partners and on data quality. These data are being collected and will be available for month 18

6. References

- Billen, G., Garnier, J., Rousseau, V., 2005. Nutrient fluxes and water quality in the drainage network of the Scheldt basin over the last 50 years. *Hydrobiologia* in press
- Christensen, V. and Pauly, D. 1992. ECOPATH-II- A software for balancing steady-state models and calculating network characteristics. *Ecological Modelling* 61: 169-185
- Cohen, J.E., Briand, F., and Newman, N. 1990. *Community food-webs: data and theory*. Springer-Verlag NY
- Guccu, A. 2002. Can overfishing be responsible for the successful establishment of *Mnemiopsis leidyi* in the Black Sea ? *Estuarine Coastal and Shelf Science*. 54: 439-451
- Jordán, F., Liu, W.C., Wyatt, T. (2005) Topological constraints on the dynamics of wasp-waist ecosystems, *J Marine Systems*, in press.
- Lancelot, C., Staneva, J., Gypens, N. 2002. Modelling the response of coastal ecosystem to nutrient change. *Oceanis*
- Lancelot, C., J. Staneva, D. Van Eeckhout, Beckers, J.M. & Stanev, E. 2002. Modeling the response of the northwestern Black Sea ecosystem to changes in nutrient delivery by the Danube river after its damming in 1972. *Estuarine Coastal and Shelf Science*. 54: 473-499
- Lancelot, C., Spitz, Y., Gypens, N., Ruddick, K., Becquevort, S., Rousseau, V., Lacroix, G., Billen, G., 2005. Modelling diatom and Phaeocystis blooms and nutrient cycles in the Southern Bight of the North Sea: the MIRO model. *Mar. Ecol. Prog. Ser.* 289, 63-78
- Lancelot, C, Gypens, N, Billen, G. ,Garnier J. and Roubeix, V. Linking marine eutrophication to land use: an integrated river-ocean mathematical tool: The Southern Bight of the North Sea over the past 50 years. Submitted to *J. Mar Syst.*
- Olsen, Y., Reinertsen, H., Vadstein, O., Andersen, T., Gismervick, I., Duarte, C., Agusti, S., Stibor, H., Sommer, U., Lignell, R., Tamminen, T., Lancelot, C., Rousseau, V., Hoell, E. and Sanderud, K.A. 2001. Comparative analysis of food web based on flow networks: effects of nutrient supply on structure and function of coastal plankton communities. *Continental Shelf Research*. 21: 2043-2053.
- Rousseau, V., S. Becquevort, J.Y. Parent, S. Gasparini, M.-H. Daro, M. Tackx and C. Lancelot. 2000. Trophic efficiency of the planktonic food-web in a coastal ecosystem dominated by Phaeocystis colonies. *J. Sea Res.* 43:357-372.
- Vasas, V. and Jordán, F. Topological keynote species in ecological interaction networks: considering link quality and non-trophic effects. Submitted to *Ecological modelling*.
- Verity, P. and Smetacek, V. 1986. Organism life cycles, predation, and the structure of marine pelagic ecosystems. *Mar. Ecol. Progr. Ser.* 130:277-293