Title: Changes in the zooplankton in the Bay of Marseille over the past two decades and impact on the functioning of the ecosystem. (Acronym: ZOO-INDEX)

Introduction

Zooplankton communities are essential components of marine ecosystems because of their role in marine food webs and their impact on the carbon cycle. Zooplankton communities are sensitive to climate change through hydrographic and ecosystem changes in the pelagic environment. They are able to quickly respond to any ecosystem variability. Long-term plankton time series analysis is important for detecting such environmental changes and their impacts on population dynamics and community structure at different time scales. Time series analyzes of zooplankton generally focus on inter-annual variability in zooplankton abundance and the identification of underlying mechanisms (climatic, hydrological, ecosystem, and even anthropogenic) that interact most with the zooplankton community. This makes it possible to evaluate significant events inducing shifts in these communities. The cascade impact to higher trophic levels is rarely considered in these studies, although it has long been known that ontogenic changes in plankton species can potentially induce a "mismatch" with predators (sensus Cushing, 1969 in Cushing, 1972).

In recent years, it has been proposed that planktivorous fish dynamics are not only related to the dynamics of planktonic community stock (seasonality), but also to their qualitative variations. These include morphological and behavioral characteristics, but also the biochemical and therefore energetic content. Chen (2019) shown that prey selection was important for planktivorous fish and they targeted particular species with energetic values among the highest of the prey of the medium falling within the catchable size range. This new knowledge encouraged us to follow in addition to the classical parameters of plankton community structure (biomass, specific composition, size spectrum), new morphological quality parameters (size and shape of species) and biochemical composition (proteins, carbohydrates, lipids and energy content). All these elements could allow the introduction of a new trophic indicator of plankton that would take into account both qualitative and quantitative aspects.

Presentation of the Zooplankton time series by Solemio

The temporal series of zooplankton in Marseille concerns bi-monthly samples from 2003. For these samples, taxonomic analyzes (binocular) and size spectrum (ZOOSCAN) have been processed, and biomasse (dry biomass weighing) by size classes has been measured. The taxonomic classification has been carried out under a binocular microscope since the years 2003 with however periods of untreated samples, and for other periods sample treatment carried out by different observers. A work of standardization of this database will be necessary.

For the whole of this period, SOLEMIO environmental data (SOMLIT http://somlit.epoc.u-bordeaux1.fr): temperature (T, ° C), salinity (S, PSU), oxygen (O_2, ml L -1), nitrates (NO_3, µmol L-1), phosphates (PO_4, µmol L-1), chlorophyll *a* (Chl *a*, µg L-1), particulate organic carbon (COP, µg L-1), particulate nitrogen particulate organic (NOP, µg L-1) and particulate matter in suspension (SPM in mg L-1), as well as pico and nanophytoplankton counts (estimated by flow cytometry) and microphytoplankton counts, associated with the weather and biogeochemistry models of the Bay of Marseille, allow to interpret these data in their hydrological and environmental context.

The SOLEMIO station is under several influences that follow one another depending on the hydroclimatic conditions, that with inputs of the Ligurian current from the south east side, that of the plume of the Rhone deriving from the west under special conditions of Mistrals, and that of the city of Marseille during heavy rains. In addition, the contributions of the Cortiou treatment plant in Marseille can be trained within the Bay of Marseille but have undergone a major qualitative change following the implementation of microbiological treatment in 2008. The human impact is also to be taken in account because it has induced a drastic decrease of MES, PON, POC, Chl *a* after 2008, with observed repercussions in the planktonic food web up to the zooplankton, especially in the cold season (Bănaru et al., 2014) and during intrusion episodes of the Ligurian current in the bay of Marseille (Millet et al., 2018).

Objectives:

To understand the temporal variation of the specific composition as well as of the quantity and quality of zooplankton in relation to hydrodynamic, environmental and anthropic pressure factors and to establish a trophic indicator of plankton.

Assumptions:

The assumptions of this work are that there have been potentially changes in: 1) specific composition (beyond normal seasonal and inter-annual variation); 2) biomass by size class of zooplankton; 3) the average size of individuals for different species of zooplankton; 4) sources and / or trophic levels of zooplankton of different size classes; 5) the energy value of zooplankton of different size classes.

Work program

1) Analysis of historical series data and additional biochemical analyzes on historical samples

a). Abundance, specific composition (diversity), size of organisms

Comparisons of the annual cycles of the global stock of zooplankton (biomass, abundance) of size fractions and of key species dynamics will be performed. Statistical treatments will be applied to identify the major trends and shifts of the different parameters during the period 2003-2022. Trend detection and major shifts in time series of various environmental parameters (atmospheric, hydrographic), ecosystem and zooplankton structure parameters (abundance, diversity, size of key species) will be achieved through different tests and methods that have been proven on other time series analyzes. Then the differences between identified periods of the values of environmental parameters and of zooplankton structure variables will be the subject of other multivariate tests (e.g. Redundancy Analysis - RDA). The analytical methods that were performed on the historical samples are listed below (part 2).

Finally, the analysis of the data to extract the bioenergetic evolution of the plankton as a function of the climatic and anthropic environment will lead to define an index of the functioning of the pelagic food web (part 3).

b. Stable isotopes and biochemical composition to define the energy quality of zooplankton and its origin

The dried samples of SOLEMIO zooplankton since 2003 by size class are available, and their conditioning makes it possible to carry out complementary analyzes of stable isotopes ($\delta^{13}C$, $\delta^{15}N$) and biochemical assays (proteins, carbohydrates and lipids) allowing to estimate their energy content (Chen et al., 2019; Harmelin-Vivien et al., 2019). Such analyzes will be undertaken over key years and seasons (spring, summer) to identify potential changes in the energy content of zooplankton size fractions. Stable isotope analyzes should allow us to see if a change in sources and trophic levels has occurred, as well as the organization of the zooplankton food web by size class before and after 2008 (the establishment of microbiological treatment of the Cortiou wastewater treatment plant).

2) Two Year Sampling with Additional Parameters for the Zooplankton Community

During 2 years (Oct 2020-oct 2022), the student will participate in the different steps leading to the production of the data: zooplankton sampling, ZOOSCAN and FLOWCAM treatment, taxonomic recognition, biochemical measurements (protein, carbohydrate and lipid measurements and energy content estimation) and stable isotope analyzes ($\delta^{13}C$ and $\delta^{15}N$) of samples.

3) Data analysis and establishment of a plankton trophic index.

The first objective of this component will be the processing of data for the detection of possible shifts in the planktonic community: abundance, biomass, biomass spectrum. The analysis of the environmental context in the Bay of Marseille will also be based on modeling tools for hydrodynamics and the dynamics of the pelagic ecosystem available at the MIO (Fraysse et al., 2013).

The second objective of this synthesis will be to highlight a possible long-term bio-energetic evolution (2003-2022) of plankton as a function of the climatic and anthropic environment in relation to the dynamics of size fractions (energy spectrum vs size) and target species for planktivorous fish. Data on the temporal evolution of the body condition of fish will come from the literature (Saraux et al., 2019) for the Gulf of Lion and thesis of C.T. Chen for the Bay of Marseille (Chen, 2019). By accessing different zooplankton trophic levels via stable isotopes for the different size classes (Banaru et al., 2014; Hunt et al., 2017), the dynamics of the biomass trophic spectrum (Gascuel et al., 2005) can be analyzed.

These results should make it possible to set up a regional index of the functioning of the pelagic food web based on the energy spectrum of zooplankton vs size, in order to better understand the close relationships between energy flows and structure at the level of zooplankton, and which, in the long term, could be related to the evolution of the trophic niches of planktivorous fish.

Broader context:

Mesozooplankton is the major source of food for both adult and juvenile planktivorous fish in the region (Bănaru et al., 2019). These species represented up to a few years ago about 50% of the catches of French Mediterranean fisheries (Demaneche et al., 2009). However, because of their poor body condition which has reduced their growth, body condition and size (Brosset et al., 2016), and probably related to the change in their diet (Le Bourg et al., 2015), their captured biomass has continuously decreased since 2007 (Saraux et al., 2019) with a significant reduction in the fishing activity of pelagic trawlers in the French Mediterranean and socio-economic consequences.

The production of zooplankton which feeds these fish is supported by the production of phytoplankton, itself supplied by nutrient inputs. In the Gulf of Lions the Rhone River represents the main source of enrichment for the planktonic community. However, during the last decades, the improvement in the efficiency of wastewater treatment and the reduction of phosphates in agriculture has greatly reduced Rhone river phosphate inputs. More locally, in the Bay of Marseille, recent papers link the improvement of the efficiency of wastewater treatment of Cortiou (1987 - implementation of physico-chemical treatment, 2008 - establishment of microbiological treatment) to the reduction of biomass of planktivorous fish between 1980 and 2012 and between 2007 and 2015 (eg Ourgaud et al., 2015, Cresson et al., 2019).

Hypotheses on bottom-up mechanisms with potential modifications of zooplankton have been made, but were not retrospectively demonstrated. The results on the temporal variability of the quality and quantity of plankton will be particularly useful on a broader scale (Gulf of Lion, Catalan Sea, NW of the Western Mediterranean and other regions). The results of this thesis and the new pelagic index could be of great interest for local managers: Calanques National Park, Marseille City Council, PACA Region, Water Agency, as well as national (IFREMER), and international (CGPM - General Fisheries Commission for the Mediterranean). This new indicator of trophic quality of plankton could be proposed for monitoring MSFD "zooplankton" in connection with D4 "food web" and extended to all the maritime facades of Europe (Rombouts et al, 2013). In fact, through the effect of plankton modification, propagated in food webs to exploited fish and fisheries, which can be shown through coupled trophic models (Diaz et al., 2019), these issues seemingly show that plankton should be viewed from a broader point of view Ecosystem Management of Ecosystems also considering their socio-economic effects in a context of global change.

Thesis project related to the themes of Team 5 - EMBIO of MIO (Mediterranean Institute of' Oceanology) www.mio.osupytheas.fr which offers a particularly favorable context for the candidate to develop thematic interactions related to the subject on various aspects: (1) of the marine ecosystem functioning, (2) the dynamics of planktonic food webs approached by varied analytical methods, and (3) on data analysis methodologies (statistics and modeling).

Selection procedure:

Candidates will send their CV and a motivation letter for the proposed PhD project to F. Carlotti (francois.carlotti@univ-amu.fr) and to D. Bănaru (daniela.banaru@univ-amu.fr) at the latest 15 Mai 2020. One candidate will be chosen by F. Carlotti for based excellent records during in Master degree. This candidate will make a presentation to defend the PhD proposal and show her/his capabilities to achieve the proposed work. The oral session will take place in Marseille early July 2020. 20 candidates will present their thesis subject and an half will be granted.

References:

Bănaru D., Diaz F., Verley P., Ballerini T., Campbell R., Navarro J., Yohia C., Oliveros-Ramos R., Mellon-Duval C., Shin Y.J. (2019) Implementation of an end-to-end model of the Gulf of Lions ecosystem (NW Mediterranean Sea). I. Parameterization, calibration and evaluation. Ecological Modelling, 401, 1-19.

Bănaru D., Carlotti F., Barani A., Gregori G., Neffati N., Harmelin-Vivien M. (2014) Seasonal variation of stable isotope ratios of size-fractionated zooplankton in the Bay of Marseille (NW Mediterranean Sea). J Plankton Res 36(1):145-156.

Brosset P., Le Bourg B., Costalago D., Bănaru D., Van Beveren E., Bourdeix J. H., Fromentin J. M., Ménard Frédéric, Saraux C. (2016). Linking small pelagic dietary shifts with ecosystem changes in the Gulf of Lions. Marine Ecology Progress Series, 554: 157-171.

Chen C.-T., Bănaru D., Carlotti F., Faucheux M., Harmelin-Vivien M. Biochemical and energy content of plankton based on a size class approach in the Bay of Marseille, NW Mediterranean Sea. Submitted *Journal of Marine Systems 199: 103223. https://doi.org/10.1016/j.jmarsys.2019.103223.*

Chen C.-T., 2019. Alimentation des Poissons planctonophages de la REgion Marseillaise (Nord-Ouest de la Méditerranée Occidentale). Thèse de doctorat en Océanographie, Aix-Marseille Université, 423 p.

Cresson P., Le Direach L., Rouanet E., Goberville E., Astruch P., Ourgaud M., Harmelin-Vivien M., (2019). Functional traits unravel temporal changes in fish biomass production on artificial reefs. Marine Environmental Research. https://doi.org/10.1016/j.marenvres.2019.02.018

Cushing D. (1972) The production cycle and the numbers of marine fish. In: Symp. Zool. Soc. Lond., p 213–232.

Demaneche, S., Merrien, C., Berthou, P., Lespagnol, P., 2009. Rapport R3 Méditerranée continentale, échantillonnage des marées au débarquement. Méthode d'élévation et évaluation des captures et de l'effort de pêche des flottilles de la façade Méditerranée continentale sur la période 2007-2008. Programme P6 AESYPECHE "Approche écosystémique de l'halieutique" Projet Système d'Informations Halieutiques SIH, IFREMER, France, 54 pp.

Diaz F., Bănaru D., Verley P., Shin Y. (2019). Implementation of an end-to-end model of the Gulf of Lions ecosystem (NW Mediterranean Sea). II. Investigating the effects of high trophic levels dynamics on nutrients and plankton fields and associated feedbacks through a two-way coupling approach. Ecological Modelling, 405: 51-68. https://doi.org/10.1016/j.ecolmodel.2019.05.004.

Fraysse M., Pinazo C., Faure V.M., Fuchs R., Lazzari P., Raimbault P., et al. (2013) Development of a 3D Coupled Physical-Biogeochemical Model for the Marseille Coastal Area (NW Mediterranean Sea): What Complexity Is Required in the Coastal Zone? PLoS ONE 8(12): e80012. https://doi.org/10.1371/journal.pone.0080012.

Gascuel D., Bozec Y-M., Chassot E., Colomb A., Laurans M. (2005). The trophic spectrum: theory and application as an ecosystem indicator. e ICES Journal of Marine Science, 62: 443-452.

Harmelin-Vivien M., Bănaru D., Dromard C., Ourgaud M., Carlotti F. (2019). Biochemical composition and energy content of size-fractionated zooplankton in Kerguelen waters (KEOPS2 survey): importance for upper level predators. Polar Biology, 42(3): 603-617. DOI 10.1007/s00300-019-02458-8.

Hunt B. P.V., Carlotti F., Donoso K.,, Pagano M., D'Ortenzio F., Taillandier V., Conan P. (2017). Trophic pathways of phytoplankton size classes through the zooplankton food web over the spring transition period in the north-west Mediterranean Sea. J. Geophys. Res., 122: 6309-6324, doi:10.1002/2016JC012658.

Le Bourg B., Bănaru D., Saraux C., Nowaczyk A., Le Luherne E., Jadaud A., Bigot JL., Richard P. (2015). Trophic niche overlap of sprat and commercial small pelagic teleosts in the Gulf of Lions (NW Mediterranean Sea). Journal of Sea Research, 103, 138-146.

Millet B., Pairaud I., Bănaru D., Pinazo C., Pagès R., Guiart P. (2018) Unexpected spatial impact of treatment plant discharges induced by episodic hydrodynamic events: modelling lagrangian transport of fine particles by Northern Current intrusions in the bay of Marseille (France). PLoS ONE, 13(4):1-25. e0195257.https://doi.org/ 10.1371/ journal.pone.0195257

Ourgaud M., Ruitton S., Bell J. D., Letourneur Y., Harmelin, J. G., HarmelinVivien M. L. (2015). Response of a seagrass fish assemblage to improved wastewater treatment. Marine Pollution Bulletin, 90(1): 25-32.

Rombouts, I ., Beaugrand, G., Fizzala, X., Gaill, F., Greenstreet, S. P. R., Lamare, S., Le Loc'h, F., McQuatters-Gollop, A., Mialet, B., Niquil, N., Percelay, J., Renaud, F., Rossberg, A. G. & Féral, J. P., 2013. Food web indicators under the Marine Strategy Framework Directive : From complexity to simplicity ? Ecological Indicators 29, 246-254.

Saraux C., Van Beveren E., Brosset P., Queiros Q., Bourdeix J.-H., Dutto G., Gasset E., Jac C., Bonhommeau S., Fromentin J.M. (2019).Small pelagic fish dynamics: A review of mechanisms in the Gulf of Lions. Deep Sea Research Part II: Topical Studies in Oceanography, 159: 52–61.