Complexity and efficiency of the biological pump

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1. Scientific context, scientific questions 3
2. Objectives for the next four years and specific actions 4
2.1. Scientific objectives 4
2.2. Interdisciplinarity and synergies between teams 6
2.3. International visibility 7
2.4. Leveraging effect 7
2.5. Governance 8
3. Answers to CSI recommandations 8
4. Implementation plan and resources 9

Complexity and efficiency of the biological pump

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List of participating laboratories:

- LEMAR – UMR 6539 (Laboratoire des sciences de l'Environnement MARin), UBO, CNRS, Ifremer, IRD
- DYNECO (DYNamiques de l'Environnement Côtier), Ifremer
- LOPS - UMR 6523 (Laboratoire d'Océanographie Physique et Spatiale), Ifremer, UBO, CNRS/INSU, IRD
- Laboratoire d'Informatique Industrielle (Li2, Ecole **N**ationale d'Ingénieurs de Brest, Technopôle Brest Iroise, 29280 Plouzané)

1. Scientific context, scientific questions

The set of processes that transports particulate organic carbon (POC) to the deep sea and sediments is collectively known as the "biological pump" and includes the primary production of POC and its packaging via coagulation or other processes, into large, rapidly sinking particles versus its recycling or entrainment into marine food webs. A quantitative understanding of these processes, will allow to better evaluate the role of the biological pump in the oscillation of atmospheric CO_2 concentrations over interglacial and glacial cycles and how the biological pump will respond to (or could be harnessed to sequester) the CO_2 added to the atmosphere by humankind.

At present, there is no detailed understanding of the mechanisms that control the efficiency of the biological pump, which is known to vary dramatically, both spatially and temporally, at different scales. Therefore, the complexity of these mechanisms, residing at the intersection of ocean dynamics, biogeochemistry and ecology, has not yet been successfully incorporated into ocean models. Among our axis, we seek to address the complexity involved in the production, export and fate of biogenic materials by working at different scales, from individual particles and organisms up to ecosystems. To this aim, we combine field studies, experimental and modeling approaches (e.g. micro- and mesocosms, Dynamic Energy Budget, inverse modeling). The end goal is to make significant progress with the challenging endeavor of constraining complexity at the individual level and then incorporating it into ecosystem scales models.

During Phase 1, substantial knowledge has been acquired on the environmental (e.g. nutrients limitation impact on aggregation and dissolution), and ecological (e.g. influence of grazers on silicification, biodiversity impacts on ecosystem productivity) controls of the production and fate of the biogenic materials through different research actions described in great detail in a companion document (Phase 1 report).

Some projects initiated during Phase 1 are still ongoing and need to be taken a step further to deliver their full scientific expectations. In particular, substantial efforts will be made to assess the impact of trace metals on the biological pump, in terms of co-limitation, reassessment of their sources, or modifications in a context of climate change. Efforts will also be made towards the investigation of the role of higher trophic levels and vertical migration on the production of particles and their fate in the water column. Finally, new initiatives are being nurtured within our axe and are foreseen to develop as major scientific questions in the next few years such as the impact of alternative trophic mode on the ecosystems and biogeochemical cycles.

This combination of matured and innovative projects does not affect the main purpose of our axis which remains unchanged for the second phase of LabexMER (i.e. studying the complexity and efficiency of the biological pump). However the internal structuration will evolve to take into account the significant and challenging topics which emerged from the prospective exercise performed at the axis scale.

Proposed scientific structure of the axis is now organized around three overarching questions:

- How do marine microorganisms and ecosystem functioning diversity impact the efficiency of production?
- How do trace metals control the operation and structure of these ecosystems?
- What are the controls on the Carbon export efficiency?

We will pay a particular attention in funding projects that directly relate to these questions.

2. Objectives for the next four years and specific actions

2.1. Scientific objectives

The detailed research actions linked with our three overarching questions are detailed in this section.

Emphasis will be put on the insertion of the research themes of Nicolas Cassar, who has been granted an international Chair (starting early 2016), among our axis specific actions. His research projects, designed in collaboration with axis members, will aim to better understand the influence of the microbial community particular structure on the carbon export, through experiments and observations on N_2/Ar cycle and on nitrogen fixation. His project, in line with our scientific objectives, is expected to favor new collaborations within our axis and at the international level.

- **How do marine microorganisms and ecosystem functioning diversity impact the efficiency of production?**

Scientific actions that directly relate to the concept of "diversity", in the broadest sense, are merged under this general issue, and are linked to axis 6 activities. These actions will indeed concern many facets of this generic term that is diversity: (i) the species and / or size class diversity and (ii) the functional mode trophic diversity including the emergence of the study of the mixotrophy (capacity of organizations to use two trophic modes).

Scientists from our axis and from the newly appointed international chair team will study the biodiversity of marine microorganisms and Plankton Functional Types (PFTs), through the use of taxonomic and meta-barcoding analyzes, in order to assess their impact on carbon production and ultimately its export. Observations will be carried out at sites of varying environmental conditions, ranging from the Iroise Sea to the Senegal (e.g. co-funded LabexMER missions) or California upwelling systems. Modeling studies based on a continuum of size classes and PFTs will complement this set of observations. Axis 2 and 1 ambition to take the leadership in the study of very fine scale ocean dynamics impacts on ecosystems structure (F. Chenillat LabexMER postdoc).

Finally, a particular attention will be given to an innovative theme in connection with the functioning of trophic diversity of marine organisms which is called mixotrophy. Mixotrophy is a nutrition mode allowing certain species of primary producers to synthesize organic matter from solar energy (or chemical) but also to use organic compounds by osmotrophy and / or phagotrophy. Historically, mixotrophy has been regarded as an important mode of nutrition for phytoplankton in eutrophic areas, but it proved to occur in many ecosystems throughout the world ocean. The study of the assimilation of the organic matter by autotrophic communities will help to quantify the relative importance of this mode of nutrition using a panel of complementary tools such as meta-barcoding, modeling or isotopic techniques.

- **How do trace metals control the operation and structure of these ecosystems?**

Phytoplankton growth, which is a major player in the biological pump, requires carbon, light and macronutrients (nitrates, phosphates and silicates). In addition, within ecosystems, trace elements play a key role in the ocean: some are essential for living organisms (e.g. Fe, Mn, Cu, Ni, Zn, Co), while others are toxic (eg Pb and Hg). Some may also be used as tracers of ocean circulation (G. LeGland thesis) or physiological processes, and others are proxies of environmental conditions (e.g. $\delta^{11}B$ for acidity of water). Studying their biogeochemical cycles has thus direct implications for the carbon cycle, climate change, ocean ecosystems and environmental contamination. Several members of the Axis 2 are very active in the GEOTRACES international program that aims to improve the understanding of biogeochemical cycles, large-scale distribution of trace elements (and their isotopes) in the marine environment and calibration of proxies.

In this context, several members will participate to oceanographic cruises (e.g. Convergence Zone Brazil-Malvinas cofunded by the LabexMER, Southern Ocean SWINGS, TransARCII Arctic, GREENEDGE Canadian Arctic) in order to better understand the distribution and the biogeochemical cycles of the trace elements in these key areas of the world ocean.

Moreover, laboratory cultures that consider the potential impact of co-limitation (eg Mn / Fe, light) and acidification will be performed. The impact of acidification will also be studied with respect to its impact on the pelagic calcification of coccolithophores and, thus, the carbonate pump. This theme will be linked to the development of emerging proxies of the physicochemical conditions of the surface water.

Finally, the impact of the often overlooked sedimentary particulate Fe on marine ecosystems will be investigated through innovative laboratory and modeling experiments. A team of modelers and observers will tackle this issue together, by designing tailored experiments to feed the first realistic modeling exercise documenting global impacts of the sedimentary particulate iron, this source being arguably overlooked by most studies. Co-funding to the ANR and LEFE program has already been requested (ANR BISI/LEFE MOBIDIC).

- **What are the controls on the Carbon export efficiency?**

Actions linked to this question will help to determine the fate of biogenic materials sinking as aggregates and fecal pellets by studying degradation processes inside sinking particles and the interaction between these particles and organisms.

Silification, as well as aggregation and incorporation to fecal pellets processes, can impact the biogeochemical cycles of carbon. Therefore, it is proposed to document the impact of the main micro-environment characteristics encountered by phytoplankton when producing biogenic particles on silicification. To explore this question, specific laboratory studies will focus on the impact on silicification and its variability based on the stress encountered during growth (grazers, competition). The presence and composition of the dissolved organic matter excreted by different microorganisms on biogenic silica dissolution (ANR BioPSis) will also be investigated. Moreover, experiments on aggregation processes will be performed under different micro-environment conditions (e.g. iron limitation, presence of microplastics).

Processes affecting the efficiency of carbon export from the ocean surface also include the behavior of zooplankton on the transfer of organic matter from surface to the deep ocean. On one hand, experimental approaches will be designed in order to study the zooplankton impact on aggregate formation, destruction and sedimentation (with D. Vincent, CRCT in LEMAR). On the other hand, modeling studies will be performed in order to quantify the carbon transport that is actively performed by zooplankton during their nycthemeral migration. Two different modeling setups will be used. The first one, which is based on a size class DEB ecosystem model (NEMO/APECOSM), is used to derive the ratio between migrants and strictly epipelagic zooplankton community as well as an estimation of the organic matter produced at depth by migratory zooplankton. The second one will use a NEMO/PISCES configuration, to assess the long term impact of vertical migration on biogeochemical cycles (J. Martinez LabexMER Postdoc).

2.2. INTERDISCIPLINARITY AND SYNERGIES BETWEEN TEAMS

The scientific themes of our axis helped to unite a group of 42 researchers. Interdisciplinarity is inherent to our axis as adressing the complexity and efficiency of the biological pump requires acquiring knowledge in physical, chemical and biological oceanography.

Interdisciplinary projects emerged during Phase 1 and collaborations between researchers with physical and biogeochemical expertise will continue to be supported, reinforcing links between our participating laboratories. Moreover, the fact that LabexMER sets a "flexibility" envelope, will help to encourage the funding of interaxes projects through specific calls. Such interactions are already in place with axes 1 (F. Chenillat LabexMER postdoc) on plankton diversity and dynamics in submesoscale frontal structures, and 6 (PhD M. Cadier) on phytoplankton diversity in the Iroise Sea.

Moreover, the wide range of tools used to adress common scientific questions also fosters synergies between the axis members. Most of the scientific projects supported by the axis have been and will continue to be designed to use the full range of tools (i.e. *in-situ* sampling, laboratory experiments and numerical models) available.

Also, the recruitment of an international chair will surely continue this long-lasting tradition of interdisciplinarity by involving personal from the LOPS, the LEMAR, the LM2E but also from the PSO (whether for analysis of trace metals in the major oceanic provinces or proxy calibration). Morever, the chair is expected to offer new routes for collaborations and participation to oceanographic cruises at the international level (NASA EXport from Processes in the Ocean Remote Sensing program).

2.3. International visibility

Some scientific actions benefit from strong international collaborations with renowned institutions such as Scripps (M. Maldonado), Bigelow (S. Baines) and WHOI to name a few, which participates to the international visibility of the axis activities.

In addition, the creation of a chair in ecology and biogeochemistry to strengthen research themes developed by Axis 2 was addressed this past year. Nicolas Cassar (Duke University) will be recruited next February for 3-years period which will undoubtedly increase the international visibility of LabexMER and will broaden our research themes, in particular through potential collaborations within the EXPORTS program.

Finally, in Phase 2, we will continue to support the organization of summer schools on important topics to our scientific questions such as AIMEN (2013) and SILICAMICS (2015) that also improve our international visibility. Thus, it is planned to organize a summer school GEOTRACES in 2017 or 2018. Some researchers are heavily involved in this community and have a strong network of collaborators abroad. This summer school will aim at teaching the skills and knowledge necessary for a good understanding of the biogeochemical cycles of trace metals. It will also allow doctoral students and early career researchers to see how their work fits within the international community of GEOTRACES. This event will gather numerous international students and world renowned scientists in Brest fostering the international visibility of LabexMER.

2.4. Leveraging effect

During the second phase of the LabexMER, three calls for innovative projects will be organized, and supported by a total of 135 k€. These projects will generate data and publications and will likely favor the funding of ambitious projects for the ANR, Région Bretagne, CNRS or ERC. In this early Phase 2, our axis already fostered the maturation of

ANR and LEFE projects: e.g. ANR BISI, BioPSis; CNRS-LEFE MOBIDIC, M2BIPAT, EXPATE.

Also, it has to be noted that in its Phase 2, the LabexMER will continue to support actions at sea or missions whose objectives will be linked to key themes identified by our axis, especially when these actions are used to initiate new collaborations or projects.

Finally, it is anticipated that the arrival of a researcher on international chair (N. Cassar) will stimulate the funding options. Indeed, researchers of our axis may be associated to large NSF projects such as the NASA EXPORTS whose observation campaigns are planned between 2017 and 2021.

2.5. Governance

Close to the end of Phase 1 (fall 2014), former Axis 2 coordinators (O.Aumont, LOPS and P. Pondaven LEMAR) hand over responsibilities to H. Planquette (LEMAR) and T. Gorgues (LOPS), who took over the axis coordination, including writing Phase 1 report, carrying out discussions of future Phase 2 and presenting to the CSI the summary of Phase 1 activities. In addition to the two scientific coordinators, Axis 2 has a scientific committee (SC) with members representing the main Research Units (LOPS, DYNECO, LEMAR, LABSTIIC) as well as different expertise in ecology, biology, trace metals chemistry and biogeochemical modeling. Upon N. Cassar’s arrival, we will ask him to be part of this board. All decisions are subject to discussions by the SC which meets on demand - e.g. preparation of internal calls, evaluation of PhD proposals.

Axis 2 plans to be more active with respect to its communications. For more formal communications, an active mailing list has been created at the beginning of 2015, to which interested researchers have subscribed. This mailing list is used as a primary vehicle (in parallel with the LabexMER website) to disseminate information about Axis 2 events, activities, and project calls. In order to stimulate discussions within our axis and to encourage the emergence of new projects within the community, we propose to organize two annual scientific half-days to which all members of the axis will be invited. During these meetings, the latest findings, interpretations and new issues will be discussed. Moreover, it is envisionned to organize inter-?axes meetings to continue research efforts on the impact of the sub-mesoscale dynamics on the physical-biological interactions initiated with Axe 1, or with the Axis 6, in connection with research on biodiversity.

3. Answers to CSI recommandations

The International Scientific Council recognized the high quality science supported by Axis 2 and recommended developing further studies on the “*impact of trace metals, higher trophic production and fate of particles*”. This recommendation has been fully taken into account by our implementation plan detailed above, and is reflected in the scientific directions our axis will take during Phase 2.

Unlike in most of the other axes, Axis 2 leadership had to change prior to the end of the Phase 1 of the LabexMER, and the new coordinators led with success Phase 1 report, Phase 2 prospectives, scientific animation and chair recruitment process with a special care on adequacy of scientific thematics with Axis 2 activity. Each of these actions were well received and positively evaluated. We therefore consider that we do not need a mentor.

4. IMPLEMENTATION PLAN AND RESOURCES

We propose to launch three calls for exploratory projects in March 2016, 2017 and 2018. The budget for these projects is 135 k€, and will be open to all members of our axis. During Phase 1, 15 projects were funded, between 2 and 20 k€ each, and proved to be very efficient in delivering top quality science and publications. Therefore, we decided to increase the budget dedicated to these projects. There will not be a call in 2019 in order to provide enough time to projects to have successful outcomes in terms of publications and/or conference participations?.

Axis 2 will cofund a new PhD project beginning in Fall 2016. A call for Axis 2 PhD project proposals will be launched early 2016, from which one will be selected on the basis of scientific excellence and relevance to Axis 2 scientific questions.

The remaining budget will be dedicated to Axis 2 operational costs (1000€ / year), and an envelope of 8000 euros will be used to provide support for Postdocs or PhD students (e.g. conference attendance).

Finally, we recently created a mailing list within our axis so that the information is relayed more effectively. This action will be accompanied by short "Labex lunchs" bi-annually in which a couple of projects (starting or ongoing) will be presented informally.