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**Position paper “Scientific Challenges”. Meeting between
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Eur-Oceans, Marine Genomics Europe and MarBEF;
Working Group 1.**

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► **To cite this version:**

J. Mark Cock, D Paterson, Paul Tréguer, P Wassman. Position paper “Scientific Challenges”. Meeting between the European Union Networks of Excellence: Eur-Oceans, Marine Genomics Europe and MarBEF; Working Group 1.. [0] Gatty Marine Laboratory, St Andrews, Scotland. 2006. hal-03446760

HAL Id: hal-03446760

<https://hal.science/hal-03446760v1>

Submitted on 2 Feb 2022

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The three marine Networks of Excellence (NoEs), **Eur-Oceans**, **Marine Genomics Europe** and **MarBEF**, jointly set out their position on the...

Scientific Challenges

By Mark Cock, David M. Paterson, Paul Tréguer & Paul Wassman of Working Group 1 (Scientific Challenges)

During a meeting held in Paris in November 2005 between the three marine Networks of Excellence (EUR-OCEANS, MarBEF and Marine Genomics Europe) the decision was taken to make a joint effort to promote and develop the concept of a long-lasting, multi-site institute. Four joint working groups were created to address the following topics:

- 1 Identifying the new scientific challenges for marine sciences;
- 2 Establishing a European Doctoral School (PhD Programme);
- 3 Sharing of scientific facilities;
- 4 Mobility of personnel.

This report relates to the first of these ambitions. The final title, scope and method of operation of the proposed institute is still very much open to discussion and the role of the working group (WG1) is to identify the current and imminent future scientific challenges which remain relevant by whatever mechanism the institute is promoted. While the political climate changes continually, the scientific challenges that must be addressed on a European and global level remain germane, whether they are addressed at a pan-European, regional or even national level. WG1 recognises this changing political background but asserts that the identification of scientific goals over the medium to long term remains an essential

contribution to the development of European marine science.

It is important to recognise that marine science is still developing and we do not inherently understand the ocean in the same way as we understand our own habitat, the terrestrial environment. For us, the oceans are foreign habitats which we may enter but not yet inhabit. We recognise the terrestrial "landscape" as our home but have no similar terms of familiarity for the oceans. Our understanding of the oceans comes from abstractions derived from the collection and interpretation of data and largely remote observations.





2 Scope and vision

WG1 consider that the medium-term scope of the vision is a 10-year view of the future in terms of major areas of science that represent the key challenges arising. It was agreed that the science domains of relevance be limited to the areas of expertise undertaken by the three NoEs (taking this requirement to include previous international programmes).

One important aim of this working group is to propose ways in which expertise from the three current European NoEs can be combined. Combining varied experience and knowledge by merging fields of science will not only increase the synergy between our current fields of expertise but may result in entirely new paradigms, since the most interesting progress usually occurs at the crossroads between approaches. To address this lack of knowledge and understanding we need to combine expertise from all three current NoEs in Europe.

3 The scientific challenges

In identifying scientific challenges, several approaches were discussed. Challenges can be identified in a number of ways and the group particularly recognised key areas of scientific scholarship where the coherent application of existing skills can be used to address the knowledge deficit in marine systems. The WG also recognised that no outline should constrain the flexible development of new areas of research. Support of innovative programmes is essential, as these usually produce valuable and unexpected information. These may be unusual or novel in terms of approach, geography (deep ocean, arctic, cave) or purely curiosity-driven.

3.1 Key areas of scholarship

3.1.1. Global climate change

Although there is now strong evidence for changes in the global climate, the medium-term and long-term effects on the marine environment are still open to debate. Marine systems, from polar ice to coral reefs, represent charismatic systems which are highly vulnerable to temperature, sea-level and storm frequency changes. Evidence of migrational response to climate by the examination of marine population distributions are accumulating and act as an "early warning" to the nature of community alteration in the face of global change scenarios. Studies of modifications to ecosystem variation and functionality resulting from climate change must remain of the highest priority over the coming 10 years.

3.1.2. Anthropogenic impacts apart from global warming

The oceans have been used as a means of transport, resource acquisition and disposal for centuries. While the attitude to the exploitation of the seas are changing, there is still a requirement to understand and manage the transport pathways and the effects of pollutants from ocean exploitation. These pathways include run-off of contaminants from the land, direct input through liquid and solid waste from vessels and accidental addition of



xenobiotic material. Research has often focused on single stressor approaches, but multi-stressor systems and modelling are still required. This area of work has particular implications and overlap with stress resulting from environmental change, and such linkages should be promoted.

Marine exploitation carries with it a number of responsibilities toward environmental management. Biodiversity impacts include those caused by introduced invasive species and consequent biodiversity and functionality effects. In addition, fisheries practice (e.g. benthic trawling) has the capacity to cause major localised and regional impact of the shelf ocean systems. In terms of non-fisheries impacts, study of the diverse impacts (noise, habitat disturbance, resource removal) caused by commercial companies (gravel extraction, dredging, oil industry) must continue to be a central issue in protecting oceanic systems.

3.1.3. Meta-genomics

A major paradigm shift occurred in microbiology in the mid-1980s with the realisation that standard microbiological techniques of culturing often only provide access to a very small part of the microbial diversity in natural ecosystems. This problem can be particularly marked in some aquatic environments where viable cell numbers, obtained by staining, can exceed plate counts by 4 to 6 orders of magnitude. This "dark matter" of unculturable organisms often includes key components of an ecosystem, either because they are the major organisms present or because they have important ecophysiological roles. Moreover, the unculturable portion often includes organisms that are of interest from an evolutionary or biotechnological perspective, such as new phylogenetic groups and/or organisms with novel physiological characteristics and products.

Metagenomics (or environmental sequencing) represents one way to address this problem. This approach involves extraction and high-throughput sequencing of genetic information, in the form of nucleic acids, from populations of organisms derived from a specified biosystem/ecosystem and can be applied directly to organisms collected in the field without a need for culturing. Analysis of the sequence data produced provides not only an overview of the organisms present in the

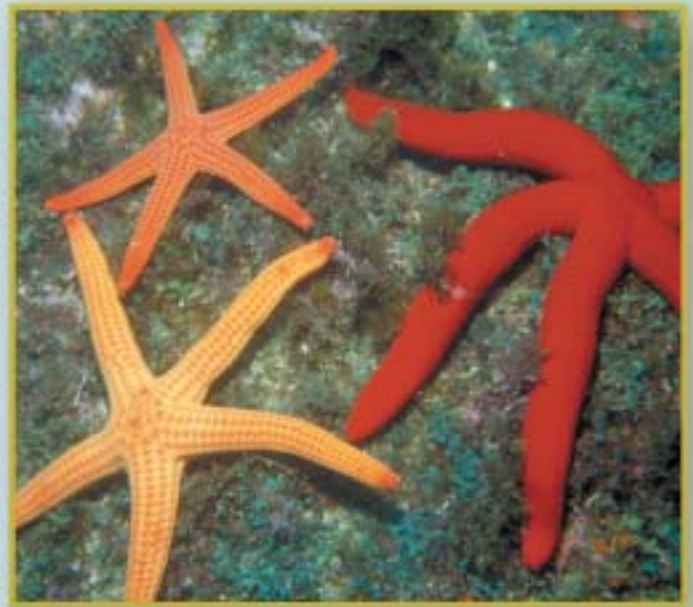


ecosystem and their taxonomic diversity (by phylogenetic comparison with sequences of cultured organisms) but also provides information about the physiological reactions that are likely to be going on within the ecosystem (by prediction of the functions of the genes identified). Once more complete sequence information is available for the organisms that make up a particular ecosystem, more sophisticated methodologies can be applied, for example based on micro-array technology that allows rapid assessment of taxonomic diversity in multiple samples and measurement of gene expression in different ecological niches.

Because of the high cost of meta-genomic approaches, it is important that work in this domain in Europe be focused and concerted. The choice of target ecosystems for sequencing will be critical and should take into account factors such as the interest of the ecosystem either from an environmental or biotechnological point of view and the complexity of the ecosystem. Parallel efforts should also be made to improve methodologies for isolating and culturing organisms from field samples. Advances have been made in this latter domain over the last few years and improvements in isolation and culturing techniques will obviously be highly complementary to studies involving direct environmental sampling.

3.1.4. Viruses in the marine environment

Viruses are the most abundant and genetically diverse organisms in the marine environment. In total, the planet's oceans are thought to contain about 4×10^{30} virus particles, probably including pathogens of most, if not all, other marine organisms. Although estimates of the extent of the impact of viruses on populations of important marine organisms (such as plankton organisms, for example) are still quite approximate, it is clear that they cause a significant amount of mortality. This, in turn, has a significant impact both on the flow of carbon up the food chain (by killing food organisms at low trophic levels) and on the global biological carbon pump (by lysing organisms at the surface layer that would otherwise sink to the



ocean floor, trapping fixed carbon). In addition to this role in global geochemical cycles, marine viruses also include pathogens of higher organisms, including viruses with poorly understood impacts on aquaculture. The enormous variety of marine viruses may also represent a source of potential human diseases. Some marine caliciviruses, for example, are thought to cause disease in humans, but little is known about the potential of marine viruses to infect terrestrial organisms. An important priority for future research will be to obtain a more complete picture of the genetic diversity inherent in populations of marine viruses. These studies should be coupled with functional analyses that will enable a better understanding of their impact on ecosystems and, indirectly, on geochemical cycles.

3.1.5. Bloom control

The recurrent blooms of HAB in European coastal waters have serious implications for food quality and for the livelihoods of the coastal zone population, and threatens the sustainable development of tourism. The initiation of HAB and the development of toxicity are not well understood. Physical forcing, introduction of species and eutrophication are important causes. Bloom control is only understood at a rudimentary level, as most research has not been carried out at the ecosystem level. HAB are an expression of the entire ecosystem response and the results of cascading effects that demand a systematic ecological approach involving various categories of oceanographers. As examples, the role of virus, the role of grazers of phytoplankton blooms and the effect of over-fishing on the plankton development are all factors that may contribute to HAB.

3.1.6. Biodiversity-ecosystem function relationships

Our understanding of the relationships between biodiversity and ecosystem function in aquatic ecosystems still lags behind that of terrestrial

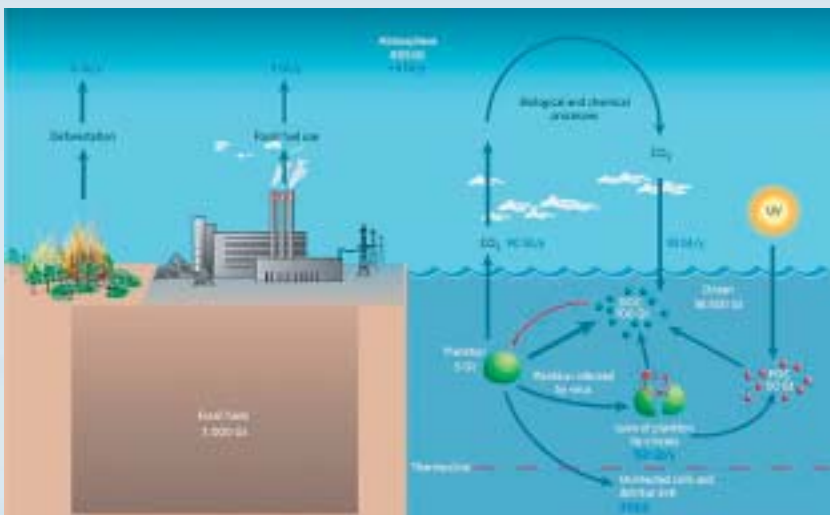


Figure 1. Our understanding of the effect of viruses on global systems and processes continues to unfold, overthrowing the idea that viruses and virus-mediated processes are side-bars to global processes. From C.A. Shuttle (*Nature*, 2005) Viruses in the sea.



systems. Yet aquatic systems lend themselves to experimental manipulation. Work on bio-diversity/ecosystem function should be continued in marine systems covering the range of habitats, regions and communities to either establish new theory or validate terrestrial approaches. This work is highly significant to the management of systems and the development of sustainable strategies for marine exploitation. This includes the key questions of assessing biodiversity at varying functional levels (genomic, species, functional group, and ecosystem)

3.1.7. Marine biotechnology: sustainable exploitation of the marine environment and bio-prospecting

Two major challenges can be identified in the field of marine biotechnology. The first is to develop an efficient procedure and structure for the discovery of novel biomolecules in the marine environment. The high level of biodiversity of marine organisms makes them a prime target for bio-prospecting and a wide range of novel biomolecules are produced by these organisms, ranging from bioactive molecules and enzymes of interest for medicine to biopolymers with diverse industrial applications. Some of the elements necessary to efficiently exploit this resource on a European level already exist, including marine stations with extensive biological expertise and sample collection facilities and companies with the facilities to develop novel biomolecules for industrial applications. An effort is required to couple these elements via the promotion of bioprospective analysis of marine samples and the creation of intermediate structures such as biomolecule collections and screening facilities to bridge the gap between the biologists and their potential industrial partners.

The second challenge is to obtain the basic knowledge about marine ecosystem function necessary to allow intelligent management of industries (such as aquaculture, for example) that already exploit marine resources. In this respect, our knowledge of the effects of the interactions between such industries and marine ecosystems lags far behind our knowledge of the relationship between terrestrial agriculture and the environment. Improving this basic knowledge is important with regard to sustainability (environmental impact) of these industries but additional benefits, such as a better understanding and control of disease and productivity, can also be expected.

3.1.8. Marine biology and the evolutionary perspective

Humans are the product of a long process of evolution and it is only from an evolutionary perspective that their biology can be fully understood. Most of this evolutionary process occurred in the oceans and a number of marine organisms, in particular organisms from basal metazoan lineages, represent important "simplified" models for the study of the evolution of developmental processes. Moreover, marine organisms have adapted to a wide range of niches, a process that has often involved radical modifications of developmental programs (as, for example, in the adult, sedentary stage of tunicates). Comparisons of organisms adapted to different habitats and life strategies can provide important general insights into basic mechanisms of development. Such studies are not only of interest from a fundamental point of view but are also relevant to human health (cancer research, for example).



On a broader scale, the animals are only one of several major eukaryotic taxa, all of which originated in the sea. These different major eukaryotic groups have been evolving independently over extremely long periods of time and, as a result, each has acquired its own unique characteristics. For example, the recently completed sequence of the marine diatom *Thalassiosira pseudonana*, the first complete genome from the heterokont group, revealed an unusual cellular metabolism that combines features found in both animals and green plants. The enormous biodiversity across the various eukaryotic groups represents an important resource for genomic research, but currently most of these groups remain very poorly explored at the genomic level. Future research should be directed towards providing a better coverage of eukaryotic diversity by applying a phylogenetic criterion in addition to criteria such as environmental or economic importance.





3.2 Multidisciplinary studies

Multidisciplinary studies are often cited as an approach which would provide great benefit, but they are difficult to organise and control. The WG suggests that this is a worthwhile approach that must be further supported but in a strategic and more targeted way to provide maximum advantage.

3.2.1. Integrated assessment of key species

The three areas of expertise of the NoEs are often applied to different species and habitats independently of each other. Also, information is often unevenly distributed and crucial information may be lacking from many regions where other information is abundant. A mechanism for improving the approach and gaining maximum benefit is to identify key species having a particularly important role or function within a system and provide a multidisciplinary assessment using a combination of molecular, functional and biogeochemical approaches. Many examples are possible and include the role of copepods in planktonic systems or the role of kelp/seagrasses in shallow subtidal systems, but this integrated approach has rarely been achieved. Key species might also include invasive species and harmful algal bloom species. Integration would provide:

- Genomic questions – identity, evolution, variation, plasticity
- Geochemical questions – role in fluxes, coupling, transformation
- Ecological questions – ecosystem function, diversity effects, functional plasticity.

3.2.2. Integrated assessment of key regions

During the last decades, massive effort has been devoted to a better understanding of the biogeochemistry and ecosystem functioning of key provinces of the world's oceans, selected on the basis of their sensitivity to global change or of their relevance to the cycle of carbon. This includes the polar oceans and oligotrophic central gyres. While this effort should be continued at international level, during the next ten years other key ecosystems should also be considered, including:

- the ultra-oligotrophic waters of the world ocean (e.g. the central gyre of the south Pacific) where our knowledge of its biogeochemistry is in its infancy
- the large, extended, minimum-oxygen zones of the world ocean (mostly in equatorial and subtropical zones of Atlantic, Indian and Pacific Oceans) which are of major interest for the cycles of nitrogen and for electron-transport systems
- the coastal upwelling zones (e.g. in the eastern boundary currents of the Atlantic and Pacific Oceans as well as in the northern Indian Ocean) which are among the most productive ecosystems of planet Earth. More generally, increased priority should be given to the understanding of the processes that control the biogeochemical fluxes in the twilight zone (100-1000m).

3.2.3. Scientific linkages

The WG recognised that there were many areas where appropriate linkages between disciplines were still weak. Any future organisation should promote the better integration of scientific knowledge and approaches across fields. For example, genomic studies often use "organisms of



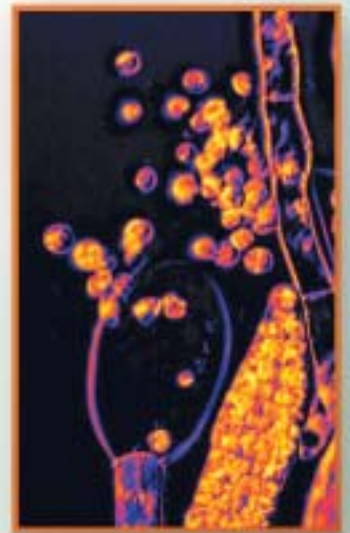
convenience" but the use of key species (see 3.1.1.) would enhance the value of the work and might then naturally attract scientists from other disciplines. This would provide a better transfer of information, e.g. model organism to the environment. In addition another key area in terms of linkages is the relevance of experimental systems and their correct interpretation in terms of the dynamics of natural environments.

4 Key science tools/approaches

The scientific challenges mentioned above have to be seen not only from a purely scientific point of view, but also be interpreted in a socio-economic context. As mentioned above, over-fishing and eutrophication may result in cascading effects that ultimately result in HAB. Thus agricultural and industrial activities may affect people's livelihoods in coastal zones that, in combination with over-fishing, may result in serious losses of species, habitats and revenue. Approaches have to be selected that combine agriculture, fishing, biodiversity obligations and tourism in order to minimise losses and maximise revenue and ecosystem quality.

The implementation of the above approaches will require a reinforcement of European marine biology facilities in several key areas. Efficient use of genomic approaches will require improved access to high-throughput sequencing, for example via a reinforcement of links with European sequencing centres such as the Genoscope. In addition, improved facilities for other genomic approaches, such as micro-array analysis, will be important, as will the development of appropriate bioinformatics tools to allow efficient analysis and mining of genomic data. At the infrastructure level, there is also a need to reinforce the capacity of marine institutes to study marine organisms in the laboratory as a means to carry out in-depth studies on key organisms of marine ecosystems or in order to facilitate the link between marine research and biotechnological exploitation. Such facilities should also allow the sharing of marine resources at the European level, for example via the establishment and maintenance of culture collections and by supplying marine model organisms.





5 Warning for the future

Sir Nicholas Stern, Head of the UK Government Economics Service, recently published his report "*On the Economics of Climate Change*." This report represents a further significant step in the acceptance of the problems of climate change. However, aspects of the debate (e.g. the "tipping point" after which further remedial action on our part will be of little or no value) are contentious. Scientific progress is required to support or reject such concepts.

Other converging factors are putting an increasing strain on global ecosystems, resulting in an augmentation of the risk of major environmental problems occurring within the first half of the 21st century, with direct and possibly catastrophic consequences for human populations. These factors include increases in the global human population itself and the rate of resource consumption per capita by that population, accelerated use of both renewable (such as forests and fish stocks) and non-renewable (e.g. oil) resources and indirect effects on climate induced by human activity. The marine environment is implicated in this process at several levels, for example as a major source of protein for the world's population through fisheries and aquaculture and as a sensitive indicator of the effects of global warming.

Our ability to respond to the effects of the factors described above will depend to a large extent on the depth of our understanding of the threatened ecosystems, this understanding being crucial both for the identification of potential problems in their early stages and for the development of appropriate responses to problems as they arise. A particular effort is required in marine science because this domain is still developing and we do not inherently understand the ocean in the same way as we do the terrestrial environment. The aim of this document is to highlight key areas of marine research that need to be developed in order to improve our understanding of the marine environment both in a global sense and from the more specific point of view of sustainable exploitation of marine resources for food or medical and biotechnological applications.

Annex 1: Useful resources

IMBER Science Plan

http://www.igbp.kva.se/uploads/IMBER_SPIS_17March05.pdf

Establishing a framework for implementation of marine biodiversity research in Europe

http://www.esf.org/esf_publications_list.php?section=4&language=0&type=2&category=10

A European science plan on marine biodiversity

http://www.esf.org/esf_publications_list.php?section=4&language=0&type=2&category=4

Stern Review on the Economics of Climate Change

http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm