Marine Genomics Europe

# The European Flagship in Marine Sciences for a Sustainable Future

Creating a strong Marine R&D leadership for Europe to benefit society and industry

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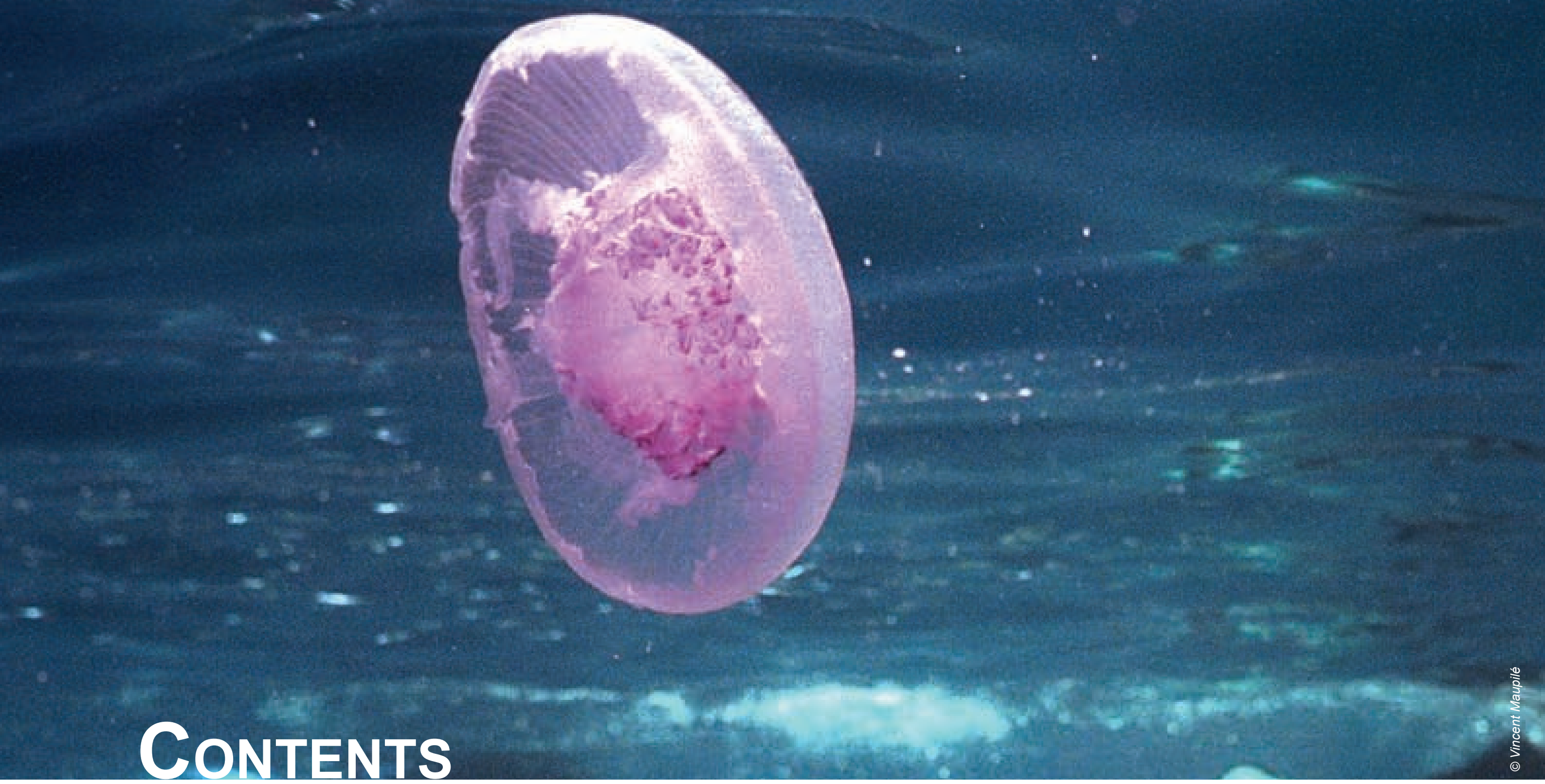



# CONTENTS

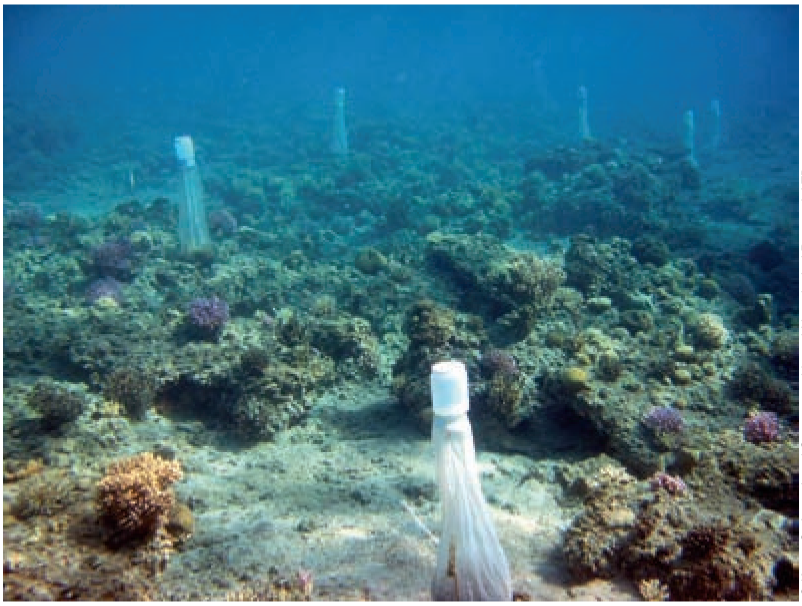
**The Network of Excellence (NoE) Marine Genomics Europe (MGE; 2004-2008) integrates European interests in fundamental research on marine genomics, transfers knowledge and technology, cooperates with policy makers and enters into dialogue with society.**

The oceans, the cradle of life, contribute fundamentally to the Earth's functioning through their productivity, biomass, diversity and sheer mass. Over 95% of the volume of the biosphere, including a wide range of extreme environments is occupied by marine organisms, which have evolved mechanisms for adaptation and survival. Inshore and offshore waters provide resources and services estimated at 60% of the total economic value of the biosphere, two thirds coming from coastal ecosystems. The physics, chemistry, and the living organisms of the oceans drive global climate. **A comprehensive knowledge of marine life is essential for sustainable resource management and the economic support of human societies.**

The science of genomics - the study of the structure, function, evolution and diversity of genes, and related approaches - is significantly changing our perspective of the living ocean and is providing us with the opportunities to understand the fundamentals of life by studying diverse and numerous marine ecosystems, organisms and populations, together with the evolution of development, biochemical and physiological functions. **Genomics opens the doors to answering complex questions**, many never imagined before or if considered, were virtually unanswerable. Genomics serves as a focus to integrate biogeochemistry, evolution, climate, resource management and the socio-cultural identity of mankind. Developing and spreading the use of genomics for the investigation of the biology of marine organisms are the aims of the European NoE *Marine Genomics Europe*.

MGE is a major initiative funded over five years by the European Community, involving 44 partners and linking life sciences, environment, ecology, bioinformatics, and high through-put genomic technologies within a multilateral European environment. MGE is devoted to the development, utilization and spreading of high through-put approaches for the investigation of the biology of marine organisms. This ambitious undertaking has made possible the integration of a previously fragmented scientific community by sharing skills and platforms, as well as through teaching and training. Benefits include large scale sequencing projects, phylogenomic studies and the application of genomics technologies to functional, comparative and environmental issues in marine biology.

Briefly, *Marine Genomics Europe* is involved in:
- The collection of **fundamental knowledge** on the functioning of the oceans;
- **Knowledge transfer** and technology translation between high-throughput genomics, marine biology, oceanographers, industry and society;
- Cooperating with **policy makers**;
- Transparency and dialogue with **society**.




▲ **A field of plankton traps.**

MGE's priorities are embedded in short-, medium- and long-term **strategic priorities** of Europe and are **focusing** on the **understanding** and **sustainable** exploitation of the ocean.

> We have identified four strategic priorities of special interest over the next decade in order to understand the complexity of marine ecosystems and to serve the world community.

**1. Changing environments:** the ocean and its biota are changing continuously, be it under the influence of natural events or the growing impact of man. Particularly the latter is of increasing concern for society. Here knowledge is the key to decision and mitigation. Genomics has become critical for understanding biogeochemical processes.

**2. Evolution of biodiversity:** the rate of change in global biodiversity is increasing at an alarming rate. Either species disappear or novel species (exotics) are reported in new habitats. The genome is a repository of historical change and hence a source for predicting future developments. Marine ecosystems are composed of species whose interactions affect the innumerable goods and services that benefits man. Genomics is a practical tool to reveal the many unseen biota.

**3. Living resources:** the ocean is a huge source of food. Most crucial, it guarantees a minimum level of subsistense for the world's poor. Unfortunately, most (shell)fish stocks are overexploited and some are close to collapse. New fisheries management approaches can greatly benefit from genomic information.

**4. New biological resources:** biomedical, industrial and societal applications can expect much from blue biotechnology. So far the potential locked in the ocean has failed to be fully exploited. Marine genomics provides a new approach to unlocking new resources from microbes to whales.

> The realisation of these strategic priorities demands a number of steps.

**A. Integrated science:** with the growth of molecular sciences, inter- and trans-disciplinary approaches are key, e.g., between marine genomics, ecosystem sciences (oceanography, global earth observation) and health. Joint projects, small and large alike, realised through joint funding, are essential for success. Systems biology is an example of how science is integrating.

**B. Technological support:** progress in (marine) genomics is based on sustained technological support. Topics which come to mind include the establishment of marine model systems, the exploitation of large metagenomic data sets, post-genomics research, bioprospecting and infrastructures for blue biotechnology and information management.

**C. Development of research capacities:** the increasing data flow on marine life through remote sensing, either from space or from semi-permanent stations in the ocean, offer ocean sciences immense opportunities for a better knowledge of poorly accessible environments. Automated monitoring, combined with onshore validation, experimentation and data processing will provide the necessary data to understand the significance of microbial remineralisation, ocean-wide primary productivity and the impact of removal of top predators through fishing.

**D. Links with society - education and training:** appreciation for the ocean will directly benefit from education and training in ocean sciences and management. Marine scientists are eager to promote their science and the environment they work in. As the ocean covers most of the globe, a critical mass of marine researchers is translated into larger numbers of marine scientists and policy makers.

**E. Science mediation:** organisations such as Marine Genomics Europe are perfect mediators between funding agencies, high-throughput technology platforms, specialist communities and the public.

# Why are the oceans so important for us?

## Our future lies in the Oceans…

### THE ISSUES AT STAKE

Oceans are the cradle of life, contributing fundamentally to the Earth's functioning through their sheer size, productivity, biomass and diversity! Over 95% of the volume of the biosphere is occupied by marine organisms and both inland and offshore waters provide resources and services estimated at 60% of the total economic value of the biosphere.

It is acknowledged that the ocean and its biota drive the global climate, yet we are only beginning to understand about the future of our planet and global climate change.

If we are to adequately address ocean issues at the local, national, regional and global levels, science cannot operate in isolation, but will need to integrate more fully with society at large.

There must also be changes in the way we regulate marine activities, in our social goals and our attitudes to ocean governance. If we are to make the right decisions, we must understand how things "work" in the oceans and how they interact; and we must recognise the role of the oceans in our life-support system and its value for humankind.

This will require excellent science, together with the technology for pursuing it, as well as the support of individuals and governments. Ultimately, it calls for a vision of the planet that embraces land, sea, the atmosphere and human societies in all its interactions.

Marine genomics has an enormous potential to improve our lifestyles and prosperity, to enhance the competitiveness of European industry, and to guarantee global sustainability.

### A CALL FOR ACTION….

In order to make immediate progress with these pressing issues which directly affect our future, the EU and its member states urged to take further action.

In keeping with this, the EU Network of Excellence Marine Genomics Europe (MGE) focuses on:
- technology transfer and technology translation between high-throughput genomics, marine biology, oceanography, industry and society;
- working with policy makers;
- transparency and dialogue with society.

Strategic priorities of Europe's main short-, medium- and long-term objectives in marine genomics are part of MGE's priorities.

We will focus on the understanding and sustainable exploitation of the ocean in order to:
- generate knowledge for the sustainability of Planet Ocean;
- promote the use of marine organisms

■ **An estimated 3-5% of Europe's Gross Domestic Product (GDP) is generated by marine based industries and services, without including the value of raw materials, such as oil, gas or fish** *(EU 2007)*.

■ **The goods and services from the ocean have been estimated as huge (e.g., marine habitat at US$ 577 /ha/yr for 36,302 106 ha = US$ 20,949 109 /yr) (Costanza et al. 1997). What is worrying is that there is an accelerated loss of species and disintegration of ecosystems, such that many services have become jeopardised** *(Worm et al. 2006, EU 2000).*

as models for a variety of problems and questions affecting daily life and for understanding our evolution and the secrets of life;
- promote sustainable exploitation of molecular products for the competitiveness of European industry;
- promote the sustainable exploitation of food products for the management and protection of our environment.

## The vision initiated by the Marine Genomics Europe Network, has been endorsed by the European Union:

**The Galway declaration identified the contribution of marine industries towards achieving the Lisbon objectives, and the role of marine science and technology in the seventh EU Framework Programme for Research and Technological Development (FP7) towards developing world class excellence in marine science and technology. The 2004 Euroceans conference emphasised that alongside marine and maritime research, there is an urgent need to support co-ordinated and sustained collection, archiving of and ready access to, comprehensive marine datasets"(EU 2005).**

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▲ **Laminaria fronds are the forests of the subtidal.**

# What is genomics?
## Entering into the secrets of life

The science of genomics is dramatically changing our perspective of the living ocean.

**> Genomics is the study of the structure, function, evolution and diversity of genes, gene products, and serves as a focus to integrate studies from biogeochemistry through climate to the socio-cultural identity of mankind.**

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▲UV microscopy of algal cells.

In the decoding of DNA we have been able to generate information on a huge variety of organisms (including the much neglected microbes) as well as starting to answer fundamental evolutionary questions such as "where do we come from?".
The earliest example of "genomics" and its related benefits occurred with the decoding of the human genome. We now know much more about heritable and infectious diseases and, consequently, diagnoses and treatments have dramatically improved.
The science of genomics is generally divided into functional, environmental and comparative genomics. The real benefit of genomic tools is that, as the available data sets become larger, more accessible and comparable global conclusions can be drawn about our surrounding environment and thereby permit a holistic approach to ocean management.

## What is the added value of Marine Genomics?

Fully in line with the so-called "Lisbon Strategy", Marine Genomics Europe provides society, industry and many other research fields with structured and advanced knowledge to:
- improve the **quality of life** for citizens
- boost European **Competitiveness**
- guarantee global **sustainability**
- reinforce the **scientific base** of many research fields

***Marine Genomics Europe* is responding to needs from society, industry and research:**

### > Responding to society's need for humankind

**- A natural heritage:**
The earth as we know it today is the result of a long evolution. Studying past changes in biodiversity and climate can help us predict the results of anthropogenic influences on our planet and thus plan measures for its protection and conservation.

**- An opportunity for human health:**
Biomedicine has enormous welfare and economic potential. The harvesting of the ocean for useful biomedical products and understanding the link between ocean function and human health will be accelerated by genomic approaches.

**- A social and cultural area:**
We have major responsibilities towards the marine environment as laid out in legal documentation, such as the United Nations Convention on the Law of the Sea. On the long term, education is probably the most important key for a full appreciation of the ocean, particularly with the rate of urbanisation continuing to increase with future generations becoming even more divorced from anything other than their immediate environment.

### > Responding to industry's need for economic competitiveness

**- An economic area - a competitive Europe**
The oceans are a massive economic resource area including fisheries, aquaculture, food, health and medical products, shipping, transport and energy, and so on.

**- An economic challenge through innovative technologies and unparallelled opportunities for industry:**
Humankind is concerned about sustaining and improving the future of society. One route includes the production of new marine technologies and accessing and developing new sources of raw materials from the ocean.

### > Responding to the needs of other research fields for innovation

**- A unique laboratory for basic research:**
The oceans provide unique opportunities to carry out scientific investigations of numerous marine ecosystems, organisms and populations to study the evolution of developmental, biochemical and physiological functions. This will enable, not only a better understanding of the fundamentals of life, but also of a variety of directly or indirectly related phenomena such as nutrient recycling,

**100.2 million tonnes (76%) of the world's fisheries and aquacultural production are used for direct human consumption, an equivalent of 16 kg per capita (2005). This amounts to 20% of the animal protein contribution for more than 2.6 billion people. The EU is one of the world's major fishing powers and the biggest market for processed fish products. Fishery production was 7.3 million tonnes in 2003. This includes fisheries and aquaculture in all world areas, and represents about 5% of world seafood production. Whereas fisheries production has declined by 7.6% in the last 10 years, aquaculture production in EU-25 moved from 0.97 to 1.37 million tonnes representing an increase of 30%. Whereas the number of EU fishermen has been declining in recent years, some 526,000 people are employed in the fisheries sector as a whole.** *(FAO, 2007)*

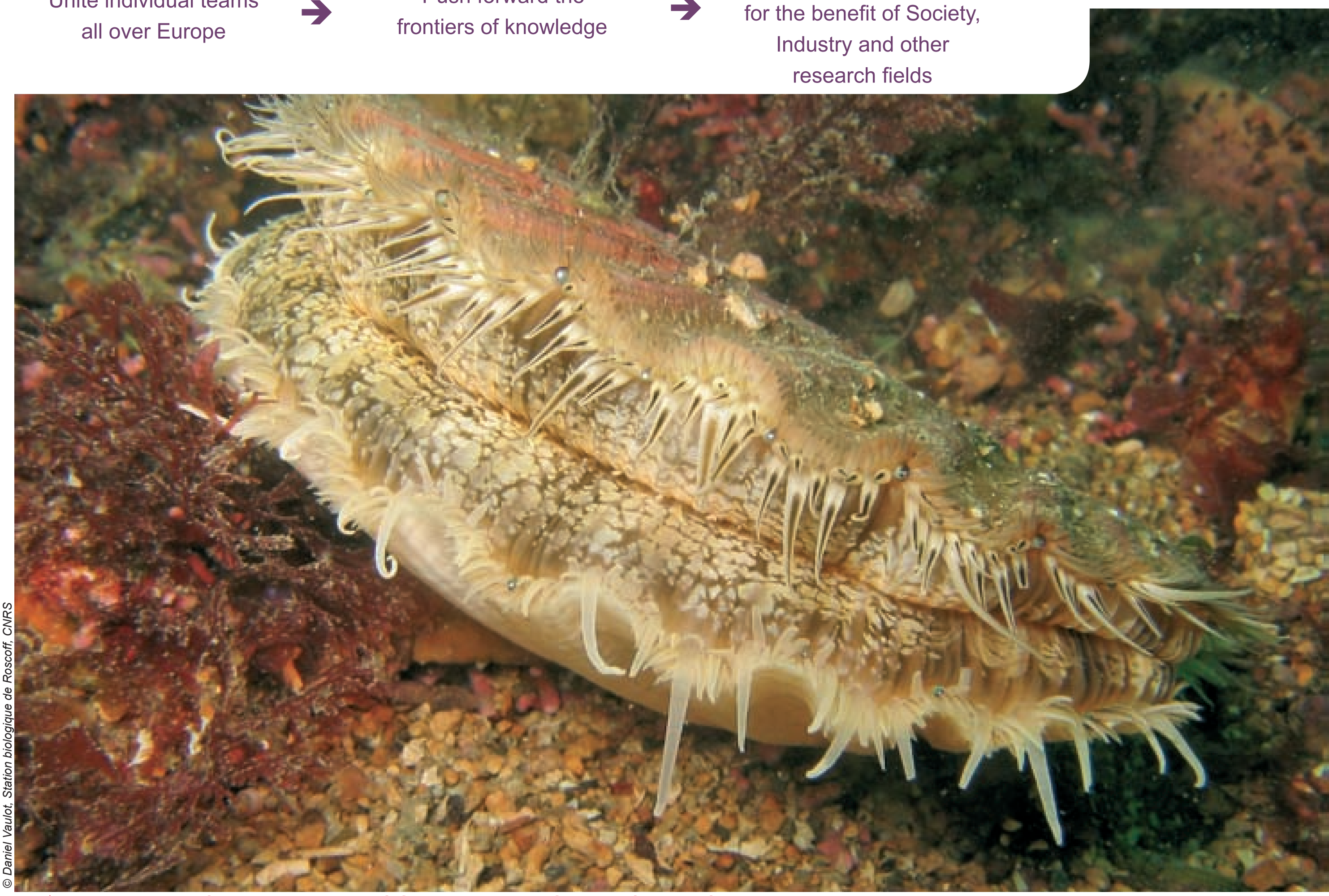
**The mission defines what the network plans to do in the future as described in the vision.**

## How can Marine Sciences help?

A comprehensive knowledge of marine life is essential for sustainable resource management and the economic sustenance of human societies.
In order to achieve this aim, Marine Genomics Europe will unite individual teams in their research efforts to attain world-wide excellence in the field of Marine Genomics. It will expand the frontiers of emerging research forward and make major breakthroughs.
This will be of particular use in other sectors such as health, fisheries, tourism, and agriculture.

**"In other words, the mission is to create strong Marine R&D leadership for Europe to benefit society, industry and other research fields"**

Unite individual teams all over Europe ➔ Push forward the frontiers of knowledge ➔ Exploit the results for the benefit of Society, Industry and other research fields



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▲ **King scallop (*Pecten maximus*) from the Bay of Brest (France).**


# Who is involved in the network?

The organisation of the Marine Genomics research community directly affects its efficiency and social impact. It is organised at various levels, from the field to the academic lab, to R&D, and implementation to the level of regulatory bodies providing national and international (e.g., EU) regulations.

**Main stakeholders involved in the network:**

**> Needs for knowledge:**

- Multilateral interests in genomics in marine research are not represented by any specific agency, but rather by groups such as the Food and Agriculture Organisation (FAO), the European Fisheries and Aquaculture Research Organisation (EFARO) and the network of Marine Research Stations (MARS) include genetic and genomic research in their remit. Marine interests are also represented by the International Oceanographic Council of UNESCO (IOC) and the International Council for the Exploration of the Sea (ICES), and professional organisations such as the European Federation of Marine Science and Technology Societies (EFMS - including 6000 members, 200 institutions), the American Society of Limnology and Oceanography (ASLO), the International Association of Genetics in Aquaculture (IAGA) and the Sustainable Farm Animal Breeding and Reproduction Technology Platform (FABRE TP).

**- Industry:** Large companies, SMEs,

**- Civil society:** Citizens, Associations,

**- Public Authority:** Policy makers.
Marine genomics and biotechnology also contribute to national law and international treaties such as the UN Convention on the Law of the Sea (UNCLOS) and the UN Convention on Biological Diversity.

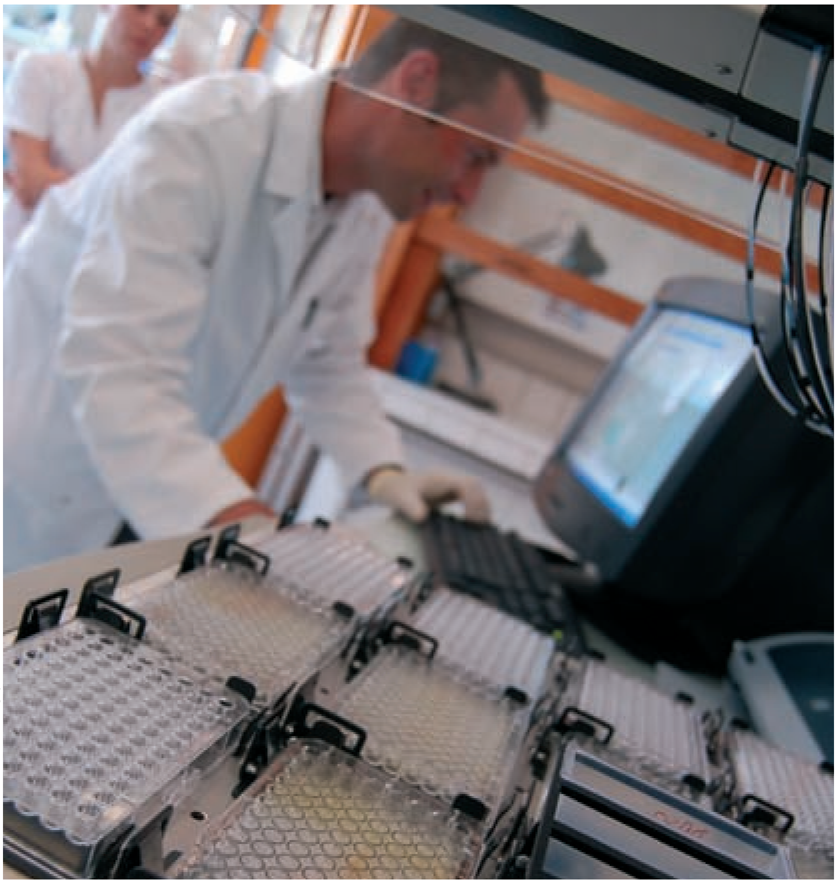
**> Generation of knowledge**:

- Knowledge and expertise in Marine Genomics is largely based in academic and government research agencies (e.g., CSIC - Spain, NERC - UK, CNRS - F, MUIR - It, MPI - D), and in a growing number of companies (e.g., all major pharmaceutical companies but also enterprises such as Prokarya, Biomérieux and Intervet) and in private foundations such as Volkswagen Foundation (Germany), Calouste Gulbenkian foundation (Portugal) and Solvay Foundation (Belgium).

- Traditionally sample collection depends on coastal biological stations and ocean going vessels, some of them designed for operating under demanding circumstances such as the deep-sea, open ocean and polar regions.There is an increasing interest in developing automated stations and remote sensing for both classical water chemistry measurements and novel methods (including genomics) of environmental monitoring. It is expected that such stations will be adapted to serve applications such as fisheries management and weather prediction, as well as more academic requirements.

- With regard to genomics, laboratories of all kinds in universities, biological stations (in which Europe has a particularly rich tradition) and government agencies provide capacity for genomic analysis. Most often, advanced high-throughput sequencing and structural analyses are provided by associated non-marine laboratories such as the Genoscope (Paris), the Sanger Institute (Cambridge) and the Max Planck Institute for Molecular Genetics (Berlin). These specialized laboratories provide a second pool of resources, which demand a high level of capital investment.

- Scientific information is communicated through various online



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▲ **High-throughput platforms handle thousands of samples per run.**

■ **The global market for marine biotechnology (genomics, bioinformatics and proteomics) products is US$ 2.4 billion (2002), a 9.4% increase from the previous year. The rise of the market is estimated at 6.4% average annual growth rate in non-US markets and might reach US$ 3.2 billion in 2007.**

■ **The Galway *(2004)* conference notes that:**

**> The application of science and technology to our seas and oceans presents new and exciting opportunities for economic growth and innovation in the maritime sector.**

**> The development of mutually supportive and complementary links between the marine industry sector (particularly SMEs) and the research community is essential in order to develop new exploration technologies, support the sustainable development of marine resources and to ensure the transfer, utilisation and commercialisation of research results.**

news groups, via list servers to peers at conferences (e.g., annual European Marine Biology Symposium, Marine Genomics 2006, International Marine Biotechnology Conference 2007) and in scientific journals (SCI publications between 2001-2006 under the key words marine/ocean*genomic/genetic reach > 3,500 references). In addition, communication to the R&D community is via newsgroups, professional journals (e.g., *Marine Biotechnology and Marine Genomics*) and websites (e.g., Federation of European Aquaculture Producers).

**> Transmission of knowledge:**
- Secondary education of school children
- Higher education of students and researchers
- Vocational and non-vocational education for adult groups, fishermen, developers, etc.

**> Exploitation of knowledge**
- Financial Community:
  National governments and international agencies are the main sponsors of these capital-intensive activities. Investors look for niche markets.
- Innovation supporters:
  Technology transfer, professional associations,
- Communication:
  Communications / interviews with journalists and the public at large through international press agencies (such as Reuters, BBC, AFP) and local media.
- Marketing.

# Acknowledged recognition …

**Acknowledged recognition of Marine Sciences**
The EU FP7 identifies priority research themes in areas such as environment, transport, food, agriculture, biotechnology and energy. It declares that special attention will be paid to priority scientific areas which cut across themes, e.g. marine related sciences and technologies with the objective of increasing coordination and integration of marine related research in FP7.
In its strategic objectives for 2005-2009, the European Commission declared "the particular need for an all-embracing maritime policy aimed at developing a thriving maritime economy, in an environmentally sustainable manner. Such a policy should be supported by excellence in marine scientific research, technology and innovation" *(EU 2005).*

**Acknowledged recognition of the Marine Genomics Europe Network**
By selecting the consortium in a highly competitive environment under the Sixth Framework Programme for Research and Development, the European Union has officially recognized the importance of the field of Marine Genomics and the high level of excellence of the consortium.

The Marine Genomics Europe Network has played a key leading scientific role and has already received international renown and recognition in this sector.

# What are the direct economic opportunities for investors in Marine Genomics?

**The expected return on investment….**
Exciting discoveries have to be developed so that they lead to a finished product suitable for development by a company.
The number of organisations active in bio-prospecting and aquaculture varies considerably across the EU. The development of pharmaceuticals and bio-active compounds necessitates huge capital investments and involves equally huge financial risks. There is a tendency by larger companies to integrate successful smaller players (start-up companies). Investments, however, are required to increase this aspect of marine exploitation, not least of which between academic researchers and small commercial pilot projects.
According to the Irish Marine Institute (*Anonymous 2005*), the marine sectors with most growth potential appear to be:
- marine aquaculture,
- marine biotechnology,
- renewable energy,
- submarine telecommunications,
- cruise industry,
- ports.

# "How can research help to implement the vision? "

## <Rationale>

Research needs to be further developed to implement the vision.
We are starting to address the dearth of knowledge on the oceans and how they function.
A brief survey reveals that less than 10% of biodiversity science publications and less than 0.1% of scientific articles about DNA are devoted to the marine domain.
This requires change. A comprehensive knowledge of marine life is essential for sustainable resource management and the economic sustenance of human societies.

## WHAT ARE THE STRATEGIC ACTIVITIES?

In order to implement this mission, the activities of Marine Genomics Europe are organised around the following three pillars of sustainability in the marine sector:
- mankind,
- environment,
- economy.

On this basis, the main topics to be further developed are:
- the economic area,
- our natural heritage,
- our Knowledge of the marine domain.

Taken together, there will be new opportunities in human health provisionas well as culture role and environmental enrichment.

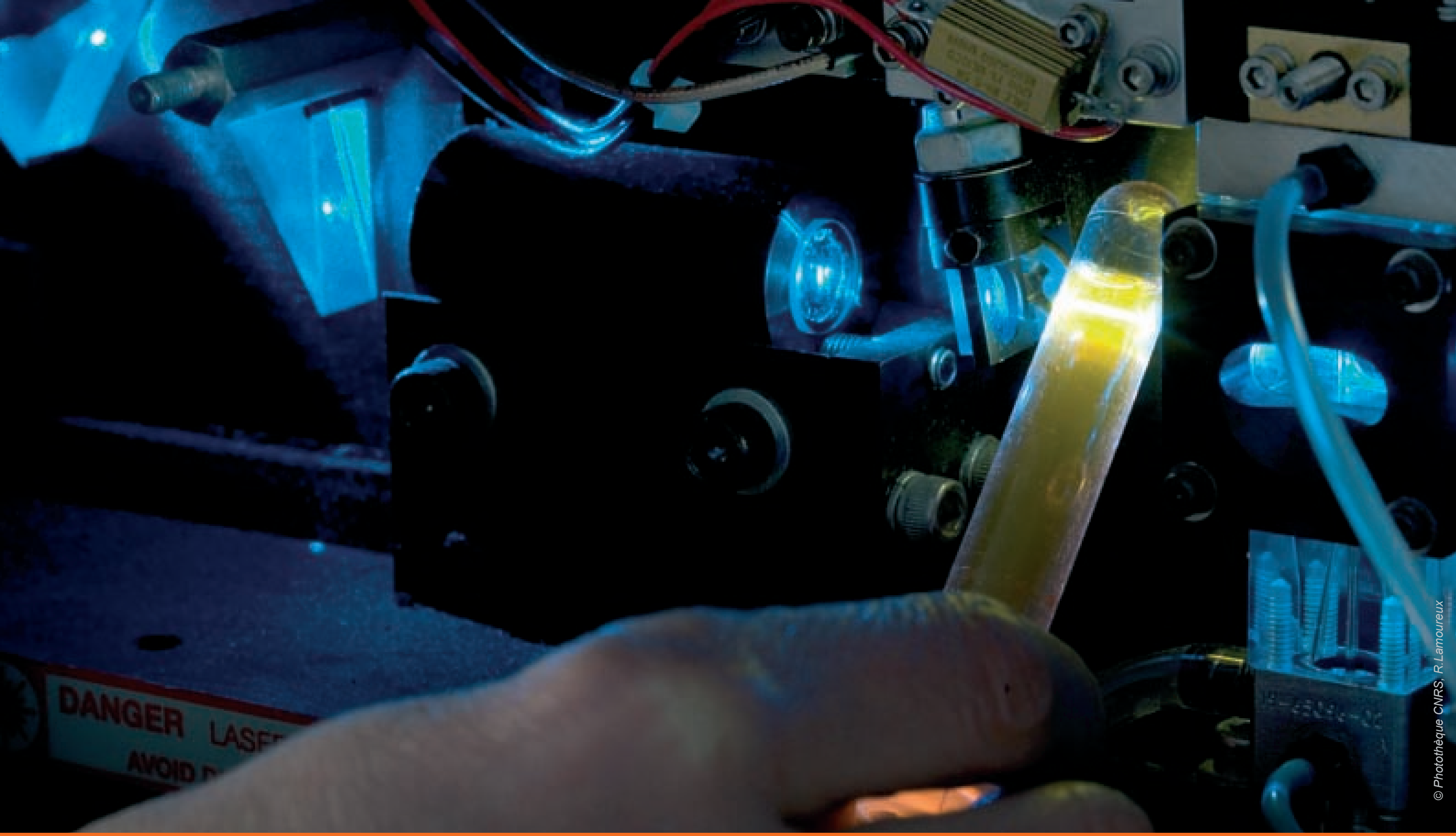
# "Agenda for genomic knowledge about the oceans"

Marine Genomics Europe, therefore, responds to three different strategic needs:

**> Responding to society's needs for humankind**
- A natural heritage – A distinctive Europe
- An opportunity for human health
- A social and cultural area.

**> Responding to industry's needs for economic competitiveness**
- An economic area - A competitive Europe
- An economic challenge through innovative and critical technologies and opportunities for industry

**> Responding to the needs of other research fields for innovation**
- A unique laboratory for basic research

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**SOCIETY**

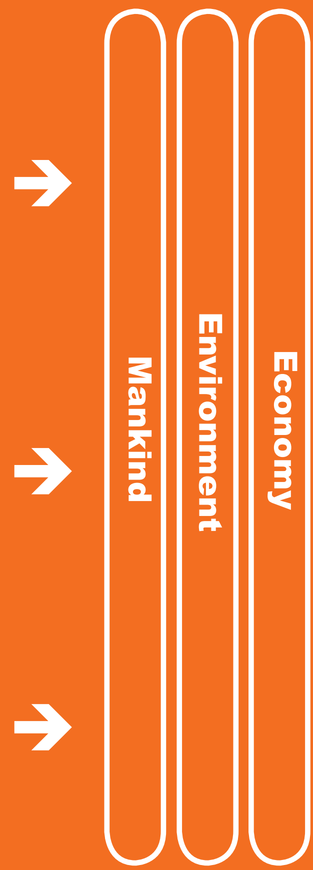
- The ocean provides opportunities for human health
- The ocean provides a social and cultural space – a distinctive Europe
- The ocean as a natural heritage

**INDUSTRY**

- The ocean as an economic area – a competitive Europe
- The ocean provides a challenge for innovative technologies and opportunities for industry

**RESEARCH**

- The ocean as unique laboratory for basic research



# The Ocean provides opportunities for human health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## PATHOGENS

Human pathogens are intimately linked to the ocean environment. for example, the cause of cholera remained a mystery for a long time until it became apparent that it was associated with tiny marine copepods *(Pascual et al. 2000)*. The full pathogenic dynamics became clear after the *Vibrio* genome was sequenced. Cholera outbreaks can be associated with climatic events, such as the El Niňo – Southern Oscillation. The realisation that pathogens switch hosts, and hence represent reservoirs that affect man, should be considered at sea.
Other links between climate and infections are further exemplified by harmful algal blooms (described p.25), as well as in the intercontinental dispersal of dust and associated pathogens.

## MARINE MODELS FOR HUMAN HEALTH

**Nervous system development**
Basic biological research within marine biology has long taken advantage of the "peculiarities"of marine "model" animals to understand basic developmental processes related to human health. For example, their nervous systems have been used to establish

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▲ **The genome of the sea squirt *Ciona intestinalis* has been fully sequenced.**

basic principals in neuroscience. Crab nerves and the squid giant axon featured the discovery of the mechanisms for nerve conduction, chemical neurotransmission and the marine mollusc *Aplysia* significantly contributed to our understanding of nerve signalling and memory. With the rapid advance of genomic tools, several prime new developmental and neurobiological models are emerging. These include our most primitive vertebrate relative, the sea squirt, *Ciona intestinalis*, to understand the basis of human development and the immune system.

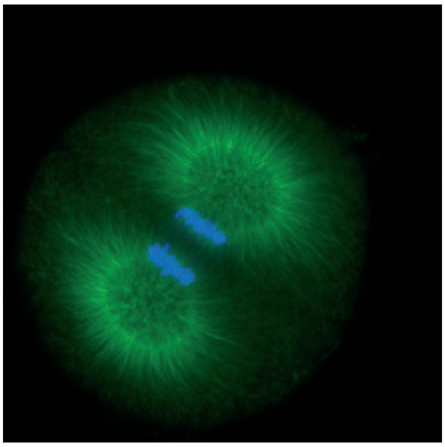
### Medical research

Sequencing the genomes of marine organisms benefits medical research directly. One of the aims of the human genome project is to understand the function of every human gene, which is a long task. The sequencing of many different organisms enables us reconstruction of the history of every human gene, its evolution and its function. The study of marine organisms contributes significantly to this task. This is possible because we are able to manipulate and change genes in "model" organisms which can then be extrapolated to other species. Thus, the academic research aim "if it moves, sequence it" fits into a perspective of understanding basic gene regulatory mechanisms and, in so doing, provides a new means to improve the health and welfare of humans and other animals.

## FORENSICS AND TRACEABILITY

### Barcoding

The use of DNA in human forensics is now commonplace. Similar techniques are used in the conservation and management of endangered species, for identification of animal origin in food products, identification of poaching and illegal trading. These techniques generally involve sequencing a specific fragment of DNA from each species. There are sufficient differences in genes between species, for the sequence of DNA to act as a unique species identifier, commonly called "a DNA barcode". Barcoding offers a simple, rapid and inexpensive means of identifying, not only whole animals, but also animal fragments, even after processing (http://barcoding.si.edu).



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▲ **Microscopic picture of the nuclear division of a sea urchin cell.**

### Conservation issues

The Consortium for the Barcode of Life (http://barcoding.si.edu) plans to generate a DNA barcode database for 20,000 marine and 8,000 freshwater fish species.This will provide government agencies with a powerful tool for use in the enforcement of conservation issues. Quotas and by-catch can be more accurately monitored. In addition, comprehensive analyses of catches will provide more accurate data for understanding fish stocks and their ecological relationships.

## HUMAN HEALTH, PHARMACEUTICALS, NUTRACEUTICALS AND BIOPROSPECTION

### Drugs

The ocean is a largely unexplored treasure chest of pharmaceuticals, nutraceuticals and products for human and animal health. The exploration of the potential of marine biodiversity (thanks to metagenomics in terms of pharmaceutical products of high value) is still at a very early stage and requires the development of co-ordinated infrastructures as well as close collaboration between government, biotech industries and academia. So far, only a fraction of this infrastructure is in place. For example, Thiocoraline, an antitumor drug from marine fungus, is under development by PharmaMar S.A. (Spain), and sulphated polysaccharides are being investigated as antiviral drugs. In addition, the list of interesting biotech products, not necessarily medical, is growing and is discussed in the section below.

### Functional seafood

In the near future, seafood may be viewed as a biotech product for human health as it has been suggested that it will contribute to reduction of the incidence of chronic disease. This will be achieved via the production of "functional seafood" containing high levels of unsaturated fatty acids, fish protein and other health promoting nutrients. Aquacultured fish selected for high levels of specific fatty acids is becoming a reality and this is clearly an area of great potential growth for the aquaculture and fisheries industries. The restricted availability of seafood resources, especially within the confines of aquaculture, requires the maximal use of safety validation in terms, not only of the fish and shellfish themselves, but also of by-products, such as fish meal and oils, or even in non-food applications *(Dosdat et al. 2006)*. Genomics can help with this development.

▼ School of discus and trigger fishes on a coral reef in the Red Sea.

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# The Ocean provides a social and cultural space – a distinctive Europe

## SOCIAL RESPONSIBILITY

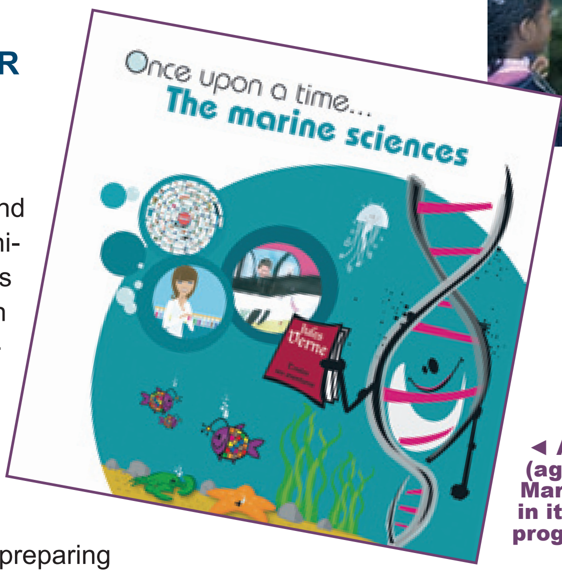
▼ Learning through doing…

The intrinsic health of the ocean is intimately linked to the well being of society. The functioning of coastal and island communities depends on shipping, fishing, aquaculture, and tourism. Rural coastal communities are particularly vulnerable as they enter into direct competition with industrial trawlers and megatourism developments. Rising sea levels encroach gradually but steadily on low lying land. Changing climate patterns directly affect the need for shelter and the opportunities for aquaculture. Twenty percent of animal protein originates from marine sources, and in some areas it is the main dietary source. Any change due to overfishing or climate variation is likely to create challenges. Marine biological sciences, including marine genomics, contribute to the understanding, monitoring, exploitation and management of the ocean.

## TRAINING AND EDUCATION – OUR FUTURE

**Academia, schools and the public**

Training and education in ocean sciences and the DNA blueprint of organisms and communities must be embedded in academia, schools and the public. It is the most crucial factor in educating and convincing people how significant the ocean is for man's life. Teachers, public communicators and NGO personnel trained at academic institutions already relay marine knowledge to the public through teaching pupils in a class setting, during summer camps and after school activities, through preparing news articles, movies, journal texts, and communicating with politicians. Without their effort the ocean would not receive the attention it has. But is there sufficient attention?




◄ A book for children (age 11-14) prepared by Marine Genomics Europe in its outreach programme.

▲ Sampling coastal plankton.

**Marine scientists wanted**

Scientific research, education and management require highly trained personnel at the vocational, technical, Bachelor, Master and PhD level. These people work in labs, at sea, in private companies and government agencies. European institutions specializing in marine sciences are covering all seas and environments. However, these numbers are considered insufficient to tackle global issues of sustainability. *Marine Genomic Europe* bundles a sizeable percentage of the research community involving some 45 laboratories, 118 teams and 600 researchers. Whereas this may seem large, taken with her sister EU marine networks *MarBEF* (www.marbef.org) and *Eur-Oceans* (www.eur-oceans.org), the total is still under 2000 researchers covering all of European ocean sciences.

## ANTHROPOGENIC IMPACT AND COASTAL ZONE MANAGEMENT

**Detecting and monitoring**

Man's impact on the oceans has been increasingly detectable. Effects are measurable at the level of pollution, infections, overfishing and poor returns in aquaculture. The impact of an estimated 40% of the global population living within close range (50 km) of the coast does not go unnoticed any longer. Although long considered the perfect dumpsite, oceanic ecosystems show signs of environmental fatigue through nutrient enrichment, climate modification, hydrocarbon spillage, the inclusion of novel chemicals in the food chain, food chain modification through selective cropping of predatory fishes and the (un)wanted transplantation of organisms (exotic or invasive species). Detecting and monitoring their impact is essential to make political measures realistic for a sustainable blue planet. Most often the initial anthropogenic impact is subtle and hard to detect as a "white" signal among the environmental noise, and hence hard to measure. Marine genomics is presently involved in monitoring of anthropogenic impacts in many ways including:

- Development of microbial systems for oil and waste mitigation
- Pollution monitoring
- Detection and monitoring of alien invasive species
- Overfishing
- Monitoring of the effect of global change on ecosystem functioning
- Harmful algal blooms

**Ocean management**

Coastal zone and open ocean management has become key to the sustainable use and exploitation of the ocean. The UN Convention on the Law of the Sea (UNCLOS) has set a standard among all nations on how to access, exploit and maintain the "commons of the ocean". Slowly a consensus is building on the design of Marine Protected Areas (MPA), despite the numerous scientific knowledge gaps (*Sale et al. 2005*). Unlike on land, MPAs will have to be contiguous and large (in the order of 10 to 30 % of the total surface) if they are to have any effect.

# The Ocean as a natural heritage

## THE ORIGIN OF LIFE

Microbial life originated in the ocean an estimated 3.6 billion years ago, and eukaryotic life some 2.1 to 3.0 billion years ago. A wide diversity of multicellular life appeared some 1.26-0.95 billion years ago. Land became colonized by green plants 0.60 billion years ago and man has joined life on earth a mere 200,000 years ago. The long evolution on Planet Ocean has generated a wealth of biodiversity at the gene, species and ecosystem level. Some aspects have received a disproportionate level of attention with concentration on a top down approach where organisms close to man such as whales, fish and shellfish have been prioritized. In contrast others have been neglected, such as the microbes and viruses. Genomics helps with this.

## GENOMICS AND THE TREE OF LIFE

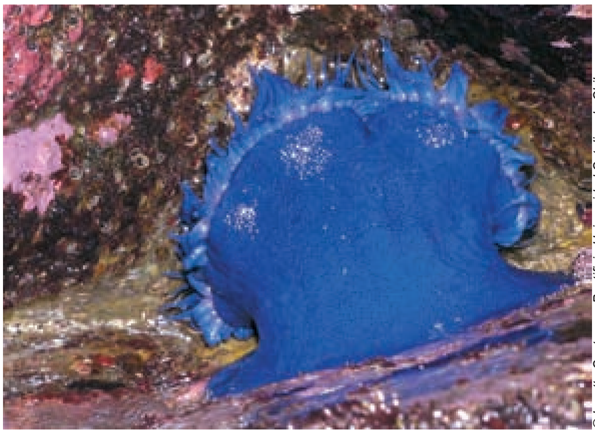
A total of 212,000 species have been identified in the ocean *(Jaume & Duarte 2006)*, but the tally on species diversity is expected to reach millions, possibly even more than on land. However, we know very little about most species identified, let alone those yet to be discovered. Building the ultimate Tree of Life is a huge challenge, and several conditions have to be met.

## LOSS OF BIODIVERSITY

Why do we prepare seemingly endless lists of species of marine organisms? It is foremost an attempt to understand the functioning of the biosphere and hence to help manage the services and goods delivered. Organisms occupy habitats and form an integral part of ecosystems, whose function and dynamics are determined by the variety, abundance and activities of these organisms. The diversity shift is monitored through taxonomic experts and compiled in a global database (Census of Marine Life – CoML - http://www.coml.org). There is growing evidence for the loss of population diversity, where smaller or more delicate (e.g., deep-sea and polar) populations are the first victims *(Reynolds et al. 2005)*.

### The Tree of Life

**The Tree of Life describes the relationships of all living organisms, including bacterial (Eubacteria and Archaea) and eukaryotic organisms on earth in an evolutionary context. Whereas this was initially the task of biologists (taxonomists and systematicists), it has become a joint venture with evolutionary biologists and bioinformaticians. High-throughput DNA sequencing has revolutionised the field. Comparing gene sequences has revealed completely new domains (and phyla), but has also made clear that morphologically similar but genetically different species abound and that the census to date represents serious underestimates.**


© Loretto Contreras, Pontificia Universidad Catolica de Chile

▲ **The sea anemone *Phymactis papillosa* lives in the Southeastern Pacific Ocean.**

> « **Why do we prepare seemingly endless lists of species of marine organisms? It is foremost an attempt to understand the functioning of the biosphere and hence to help manage the services and goods delivered.** »

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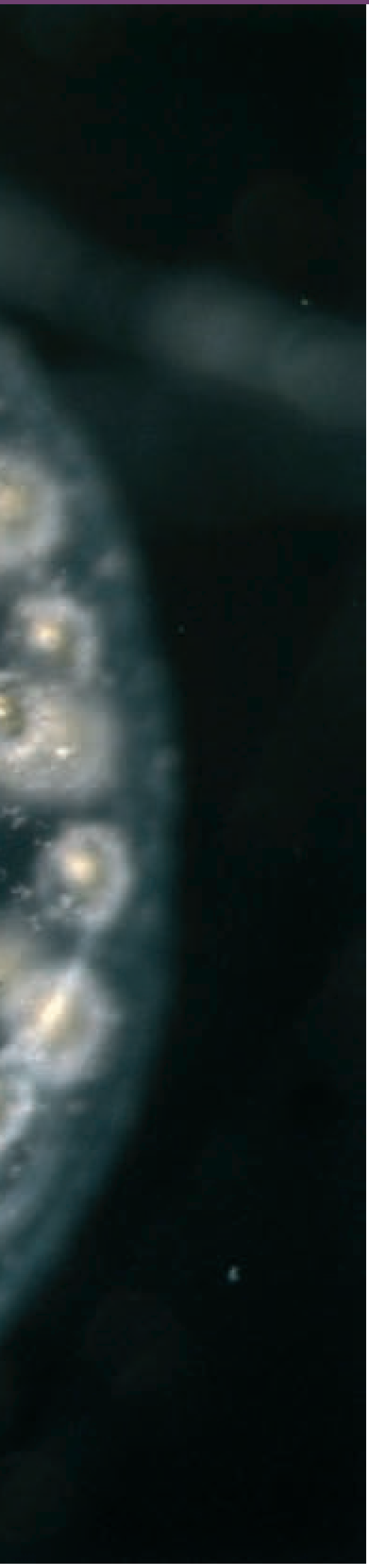
**▲ A millimeter of beauty. The *radiolarian Sphaerozoum* is a nanophytoplankter.**



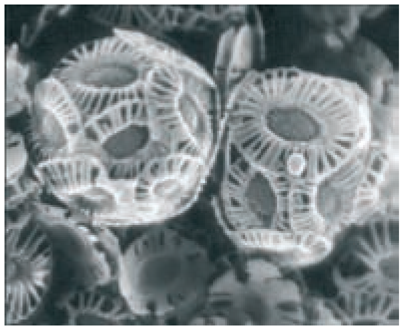
## MICROORGANISMS AND THE GLOBAL BIOLOGICAL PUMP

Genomics has already provided a breakthrough in assessing the diversity, importance and functioning of the smallest creatures in the ocean—the picoplankton, creatures of less than 2 µm. This thriving community is ecologically overwhelming with an estimated contribution to primary productivity of on average 50% to 90% (*Falkowski et al. 1998*); it essentially drives biogeochemical processes. The ocean stores huge amounts of carbon in living creatures and dead organic matter. This process is intimately linked to the cycling of oxygen and the life cycle of living organisms. They shuttle carbon, oxygen and nitrogen between the ocean surface, the abyss and again to the surface. Microorganisms, such as the picoplankton play a crucial role in this system through $CO_2$ sequestration, control of the ocean's acidity, productivity and dynamics. Rapid changes in global climate tend to modify or even offset this balance. The slow down of global ocean currents (the so called conveyer belt) through changes in atmospheric heat distribution, will affect the biochemical and physiological capacities of marine organisms. Such changes can be monitored through metagenomic approaches.

The biological pump described above is of crucial importance for life on earth. Continuous monitoring needs to be provided through permanent off-shore stations with remote sensing to evaluate marine biomass production at all levels and then combined with confirmatory experiments at the laboratory and field scale.

### ■ Metagenomics

**Metagenomics, or the study of DNA recovered from the natural environment focuses on the DNA of many tiny organisms, which cannot be identified and cultured in the laboratory. It has enabled us to start reconstructing the function of microbial communities. The number of novel discoveries through a metagenomic approach is impressive and includes the discovery of a number of novel biochemical pathways** *(e.g., Beja et al. 2001, Peers & Price 2006)* **and novel organisms** *(e.g., Not et al. 2007, Lovejoy et al. 2006)* **with exploitation potential.**



**▲ Virus (approx. 190 nm diameter) attached to a cell of the coccolith *Emiliana huxleyi***

# The Ocean as an economic area

## - a competitive Europe

The ocean provides a wide range of goods and services to man; some of them are directly beneficial to the global economy, others indirectly. A large number of these goods and services are closely linked to genomic technologies.

### FISHERIES AND AQUACULTURE

**Nutrition**

Safe and healthy food is a prime aim of human society. Proteins play a focal role in the human diet and, on average, 20% is of marine origin. This is achieved through both wild capture and aquaculture. However, the former is in decline, with 50% to 90% of the total biomass of top predators having been lost and continuing to be because of unsustainable fishing *(Pauly et al. 2002)*. In particular, open ocean, polar, deep-sea and southern hemisphere shelf stocks have not received the scientific attention they deserve. Because of the poor knowledge and concomitant lack of management and enforcement, these fish stocks are being depleted at an alarming rate.

**Farming the ocean**

The significance of aquaculture as a provider of nutritional protein for a steadily growing world population might equal wild capture fisheries in the near future. Traditional aquaculture has been increasingly supported by technological developments in husbandry, nutrition, disease management and selection. Genomics is playing a significant role in the selective breeding of seaweeds, fish and shellfish via the use of molecular markers associated with characteristics such as stress responses and disease resistance. These types of markers can also be used in paternity testing, pathogen monitoring and have helped fish farmers to control inbreeding and maintain the standard of their brood stocks.

**Certification of origin**

Once fish and shellfish have been landed, customers increasingly demand authenticity whereas govern-

## Tracing fish and fisheries products

**Molecular techniques provide us with the possibility of rapidly identifying any fish species without any prior knowledge of taxonomy. This has a number of uses, one of which is to regulate the misrepresentation of fish stocks i.e. fraudulent sale, to the consumer.**

**A molecular analysis was carried out on fish sold as red snapper (*Lutjanus campechanus*) by nine vendors across eight US states. The results showed that 77% of fish sold as red snapper were in fact other species (*Marko et al. 2004*). With such extensive mislabelling of fish consumers gain the impression that stocks of this particular fish are sustainable, as there is so much of it in the market place. The reality is somewhat different: In 1996, the Gulf of Mexico Fishery Management Council and the United States Department of Commerce declared that the red snapper was grossly overfished and strict quotas were required to ensure stocks returned to sustainable levels. Clearly less desirable fish are being marketed as red snapper and sold at the premium prices commanded for this species. This is consumer fraud.**
**A similar case occurred in the UK where mislabelling was used to circumvent the quota system. The fishing vessel "Zeejager" from the port of Zeebrugge (B) landed in the port of Liverpool (UK) 270 kg of cleaned and filleted flatfish under the name of "cheap and allowed French sole". The suspicious fillets were sampled and sent to a forensic DNA lab for molecular identification. The 270 kg turned out to be sole (*Solea solea*). The ship owner was convicted and fined 15,000 € in the Liverpool Courts (2005).**

▲ At sea with a research vessel.

ments face numerous challenges to enforce the law. Genomic fingerprinting provides the means for correct identification, the source of the population and even the identity of the organism's geographic origin in processed food.

## RED TIDES AND CONTAMINATED FOOD

Phytoplankton blooms are natural phenomena but when these relate to blooms of toxic algae, then the loss of income and damage to fisheries and aquaculture is substantial. For example the cost of red tides (scientifically referred to as Harmful Algal Blooms or HABs) is estimated at US$ 84 million per year for the US alone and at US$ 850 million per year for the EU. An increase of fish and shellfish farming has been observed worldwide and consequently, reports of harmful algae and human illnesses rise as seafood is increasingly consumed. Large shellfish fisheries are closed for harvesting when concentrations of toxic algae reach a level set by the EU for closure. Monitoring for toxic algae is mandatory for all EU countries with a marine border. Monitoring to avoid human and economic loss can be performed by lab based identification in which DNA methods can distinguish between non-toxic and toxic strains. They are the preferred method for the rapid identification of toxic algae. Quantification with molecular methods still needs improvements. So far only New Zealand has permitted monitoring for toxic algae using molecular methods. Validation of these methods for European waters is outstanding but once accepted will be a major step forward in the detection and implementation of mitigation strategies to minimise the effects of HABs.

# The Ocean provides a challenge for innovative technologies and opportunities for industry

## PRODUCTION OF NEW TOOLS

Many recently discovered natural products, which are of biotechnological or medical interest, are produced by bacteria associated with higher organisms like marine invertebrates. These bacteria can usually not be grown in labs, since their growth depends directly on the activity of their hosts. Developing new alternative culture techniques that incorporate an understanding of the special environmental conditions by marine organisms in their natural habitats is an ongoing challenge.
In order to use the rich potential in bioactive compounds from marine microorganisms we need to develop new tools for example, the development of suitable microbial expression systems and fermentation strategies for a sustainable industrial production of bioactive substances is an important challenge.

## MARINE BIOTECHNOLOGY

**Biopolymers**
The list of interesting marine biotech products is growing steadily and includes a range of proteins, carbohydrates and lipids. It comprises, for example, molluscan byssal threads and algal exudates such as biopolymers, adhesives and colloids, exotic or invasive species chemicals, anti-freeze proteins, anticoagulants and immuno-stimulants. Alternative products in the form of, for example, gene probes, upgrade mass industrial processes, micro-conductor chips for analysis of silica metabolism, sulphatases and cazymes (carbohydrate enzymes) capable of converting complex carbohydrates, green fuel and so on.

**Defense reaction in plants**
In this sense, the presence of specific enzymes that can breakdown polysaccharides (sugar), in marine bacteria represent a unique source of enzymes for the production of oligosaccharides of algal origin that are capable of stimulating defense reactions in plants.

**Inhibition of human pathogens**
A promising but virtually untapped new field is the genome analysis of marine viruses called phages. The determination of marine phage genomes may help to establish new strategies for growth inhibition of not only pathogenic marine bacteria but also human pathogens.

**New antibiotics**
The screening for small molecular inhibitors in phages may allow the isolation of chemical compounds that will be a complementary strategy for the identification of new antibiotics to control infectious diseases.

**Diversity**
The remarkable diversity of marine microorganisms offers a promising source for the identification of new catalysts. 90% of the water in the oceans is colder than 5°C. Hence the majority of marine organisms are cold-adapted and produce enzymes characterised by high, specific activities at low and moderate temperatures. This is of great biotechnological relevance. For example the bacteria *Desulfotalea* is able to grow below 0°C in marine sediments and produce cold adapted enzymes. From the biotechnological point of view many cold-adapted enzymes could, in the future, replace their mesophilic counterparts or even help to establish new bioprocesses under low

temperature conditions. In summary these enzymes:

1. save labile or volatile compounds (e.g. in biotransformations or food-processing);
2. prevent the growth of mesophilic contaminants at low temperature (e.g., food processing);
3. could be easily inactivated by moderate temperatures (e.g., molecular biological applications or food processing);
4. could help to save a significant amount of energy (e.g., in washing processes, food processing or bioremediation).

**And more**

The exponentially increasing number of identified genes from marine genomes and metagenomic fragments is only now acquiring full relevance for industrial applications. This include the development of gene probes for biotechnological targets like antibiotics, special enzymes, anesthetics or biosensors, as well as upgrading of mass industrial processes e.g. microconductor chips *(Sheridan, 2005)*. There is the mass production in bioreactors of rare marine products such as growth hormones for aquaculture and pigments.

## BIOINFORMATICS

The use of marine genomic knowledge for bioprospecting requires intelligent screening protocols, which combine knowledge of marine habitats and their organisms with appropriate high-throughput screens, metabolic analyses and molecular targets. Key components in making this happen are the evolving databases and mapservers linking environmental, genomic, functional, biogeographical and metagenomic information (www.MEGX.net, UniProtKB/ENV section, and www.tigr.org/tdb/MBMO). Close collaboration between the biotech industries and academia will favour exploitable results.

▼ **DNA sequencing through capillary electrophoresis.**

# The Ocean as unique laboratory for basic research

Spanning billions of years of evolution and the entire Tree of Life, marine organisms - as individuals, as cells and as biochemichal systems - carry the secrets to understanding how life originated and how it continuously changes.

## CELL BIOLOGY

The cell is the basic unit of all living organisms, which have originated on several occasions during evolution. Almost all fields of cell biology attract interest of marine cell biologists. Post-genomic techniques such as functional genomics, transcriptomics and proteomics have increased our understanding of how cellular components function, interact and are regulated.

## EVOLUTIONARY DEVELOPMENTAL BIOLOGY

**Evolution**

Our view of how the development of multicellular organisms proceeds has changed significantly with the arrival of molecular genetics and more recently genomics. As most higher terrestrial organisms are unique or have ancestral representatives in the ocean, marine evo-devo (evolution/development) is a fully fledged field embedded in marine research. There are tight correlations between sequence identity and conservation of gene order. As an example humans have kept quite a few genes from the the slowly evolving marine worm *Platynereis*.

**Immunology**

Such information may help decipher the relationships between animal phyla, that evolves at the same time some 600 million years ago. The closest relative of the vertebrates remains a contentious issue, with most evidence pointing to a cephalochordate ancestor. Comparative developmental research on the sea urchin *Strongylocentrotus* and the tunicate *Oikopleura* contribute novel insights in immunology, segmentation and genome duplication.

## ECOSYSTEM GENOMICS

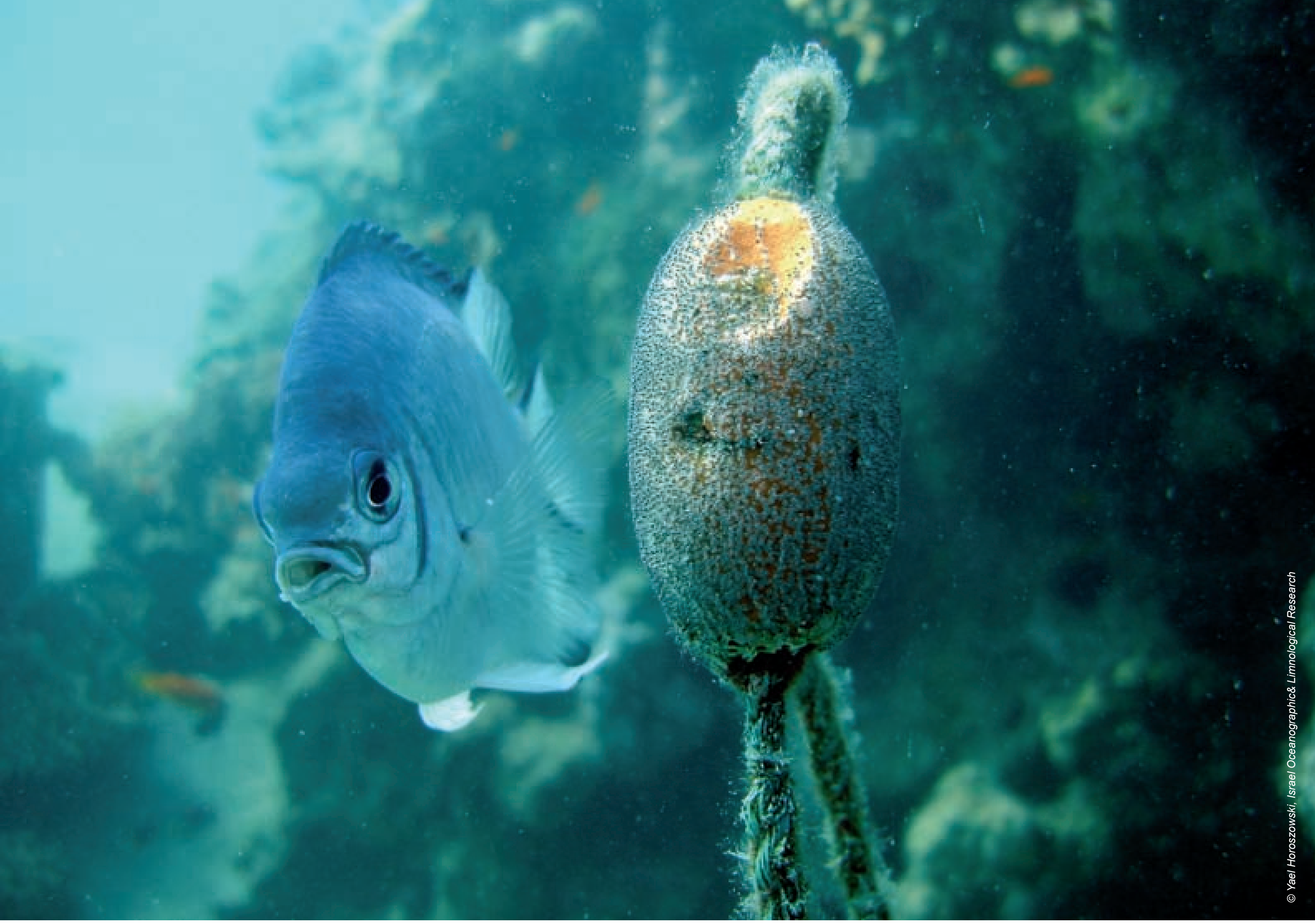
**Population structure**

Despite the large effective population sizes of marine populations and the apparent lack of physical barriers between populations in the ocean, genetic variation between marine populations is huge. As an example, the adaptation of wild Atlantic salmon to salt, brackish and fresh water has been detected at the genetic level. If this adaptating ability is mirrored in more "open" oceanic fish populations, then populations may not interbreed. This has major repercussions for the potential for recolonisation or adaptation to shifting baselines. Natural variation linked to habitat is hard to detect, but clearly progress is being made and this represents a major progress towards understanding evolution and adaptation.

**Evolutionary and Ecological Functional Genomics**

Until recently a major obstacle to gaining a better understanding of how organisms function in an ecosystem, was due to the lack of appropriate DNA data and relevant model organisms. Now however, we have the ability to perform large-scale screening of both species and populations giving rise to: Evolutionary and Ecological Functional Genomics (EEFG – *Feder & Mitchell-Olds 2003)*. EEFG incorporates functional information encoded in DNA to explain evolutionary and ecological observations. Crucial here is the access to key «ecological» models.

This is now being addressed via genomics on species such as the marine microbes: cyanobacteria and coccolithophores, diatoms and multicellular organisms such as tunicates, sea urchins, fish, seagrass, and macroalgae. Processes such as plant-herbivore interactions, host-pathogen interactions, temperature acclimation, life-history traits and behavioural ecology are slowly revealing their secrets. The significance




▲ **Damselfish guarding its eggs (Eilat, Red Sea).**

of such research is exemplified in the documentation of the fast evolution of organisms involved in exotic invasions, recovery from pollution and climate shifts.

**Community genomics: a new discipline**

An ecosystem is more than the sum of its individual components and their environment and there is a growing interest in the integration of genomics in community ecology. This represents a huge challenge, given the complex link between the outward appearance and behaviour of an organism and its interaction with the environment. An example is the modelling of ecosystems and the significance of the biological pump (discussed page 23). Also the impact of invasive species on the native community, for example in the Eastern Mediterranean basin, can be monitored and understood with genomics. Especially those species and populations already at risk due to low population numbers, restricted or patchy habitats, limited climatic ranges, and specific ecosystem services are concerned.

**The impact of overfishing**

Fisheries have reduced fish biomass in many cases by as much as 90%, an effect compounded by the current climate shift. The impact is felt through a loss of species diversity, a decrease of the average food chain length and ecosystem stability. The loss of top predators such as whales, tuna and cod has a measurable effect on smaller sized fishes which become more abundant. Small fishes prey upon zooplankton whose densities decrease, and which in turn reduces cropping of phytoplankton whose biomass increases leading to algal blooms. The effect is monitored at higher trophic levels with a measurable loss of adaptive genetic diversity. In the North Sea cod stocks have experienced massive depletions in numbers with a migration from traditional spawning grounds to colder latitudes. The stocks of the marbled rockcod and the mackerel icefish have yet to recover from collapses that occurred in the 1970s. These may not be European fish species, but European fisheries were involved in their overfishing. In the global economy, we have to take responsibility for world fisheries, not only those stocks on our doorstep.

## GENOMICS OF STRESSED AND EXTREME ENVIRONMENTS

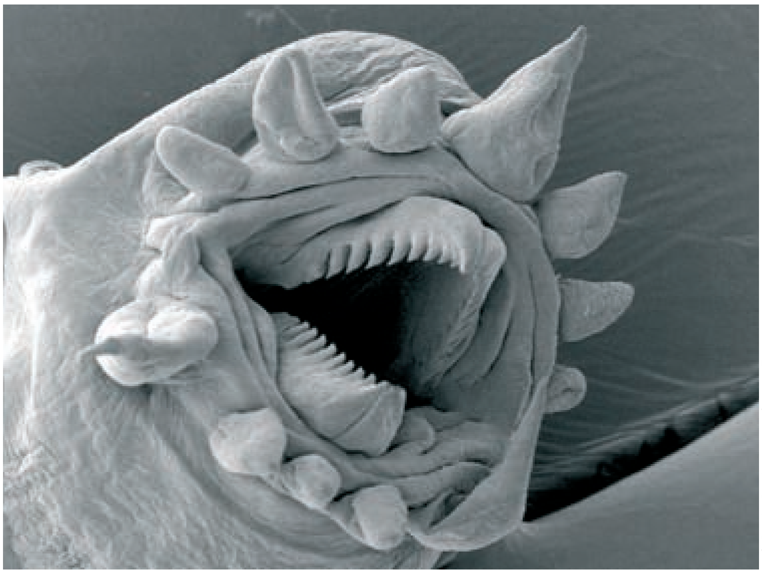
### Hydrothermal vents

Extreme environments abound in the ocean. At great depths there are pressure effects and unique chemical environments found close to warm and cold-water seeps. In coastal region with high levels of evaporation, areas may become hypersaline, and where temperatures soar, oxygen solubility drops. in polar regions the ice traps marine life, and in isolated basins anoxia may rule. It is striking that all levels of marine life have adapted to these circumstances. The discovery of a deep-sea hydrothermal vent in the Galapagos Rift in the Pacific Ocean in 1977 at a depth of 2,600 meters, introduced a paradigm shift in our thinking about physiological processes and evolutionary adaptation. Suddenly, life was possible at the most extreme conditions of pressure, temperature, acidity, ion concentration and oxygen. Previously undocumented symbiotic associations between bacteria and a range of undescribed animals were discovered. Another example is provided by «black smokers». With limited input from solar energy and at temperatures ranging from 360°C to 0°C in the surroundings, black smokers fuel a diverse and productive ecosystem of microorganisms and even some species of worms, mussels and crabs.

### Polar species

At the other extreme of the temperature range, in Antarctica, biodiversity is also very rich. 17% of the world's sea spiders, 12% of polychaete worms, 10% of sea cucumbers and 9-10% of amphipods live in the Southern Ocean. These species are over-represented when considering the area and volume of the ocean, compared to the rest of the planet . Genomic studies on these animals are in their infancy even though these stenothermal species are potential sentinels of climate change, in addition to being sources of biotechnology products, such as antifreezes and cold-adapted proteins.

With improved access to DNA sequencing facilities, we are now able to compare these extremophiles with their better known temperate water relatives and determine what makes them unique and able to survive in such extreme environments. Extremophile biology has become a mature field with novel developments in enzymology, polymer and carbohydrate chemistry.



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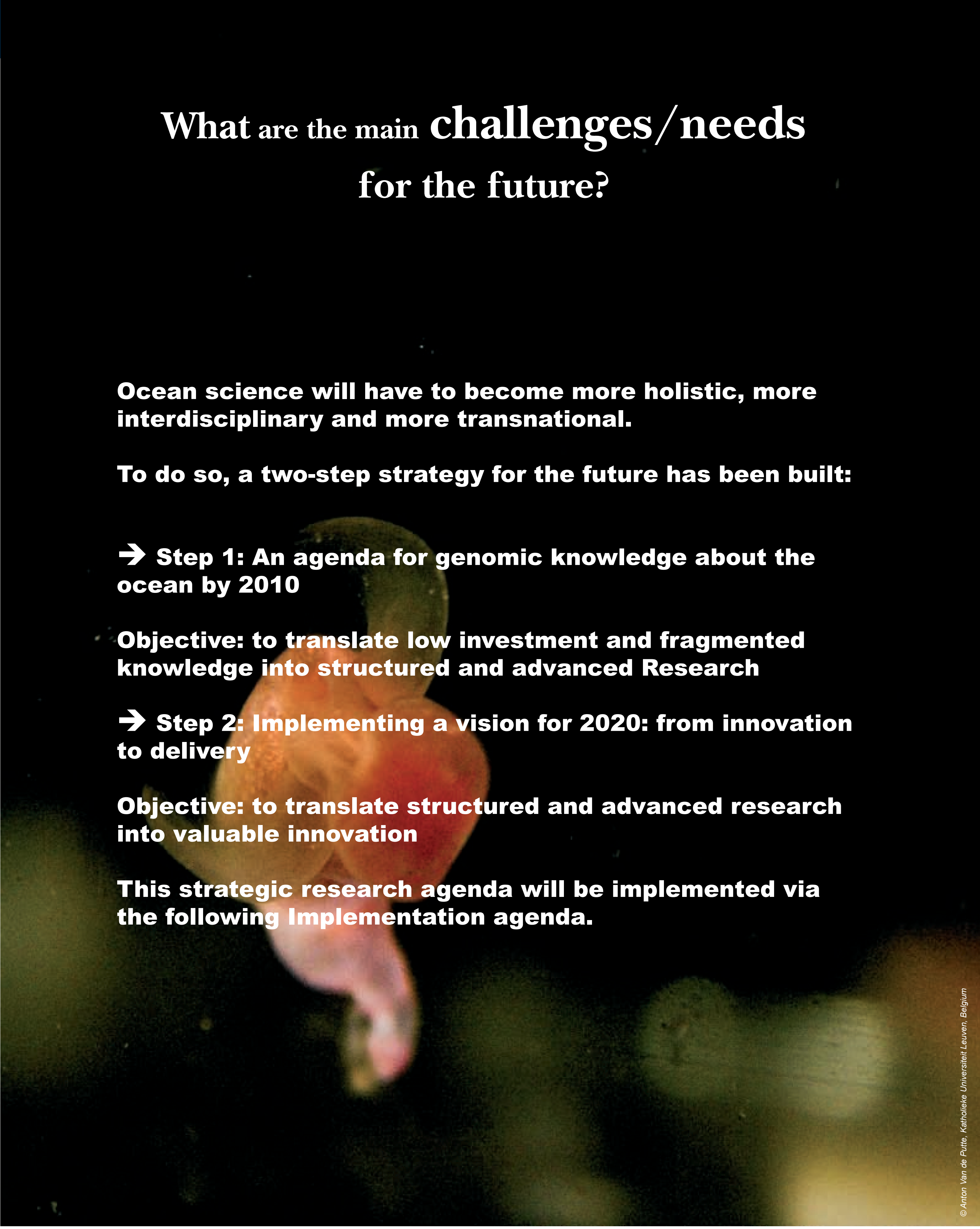
▲ **Head of polychaete worm of the family Polynoidae.**

▲ **Research station of the British Antarctic Survey at Rothera, Antarctic Peninsula.**



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# What are the main challenges/needs for the future?

**Ocean science will have to become more holistic, more interdisciplinary and more transnational.**

**To do so, a two-step strategy for the future has been built:**

**➔ Step 1: An agenda for genomic knowledge about the ocean by 2010**

**Objective: to translate low investment and fragmented knowledge into structured and advanced Research**

**➔ Step 2: Implementing a vision for 2020: from innovation to delivery**

**Objective: to translate structured and advanced research into valuable innovation**

**This strategic research agenda will be implemented via the following Implementation agenda.**

# An agenda for genomic knowledge about the ocean by 2010

Three **major strategic drivers** are used as **cornerstones** for integrating marine science and technology in Europe.

**1. The ocean provides a unique opportunity for basic research.** Major fundamental discoveries are continually being made in all aspects of the ocean system. Better understanding of earth ecosystem functions, physico-chemical interactions, and biological evolution will largely result from basic ocean research.

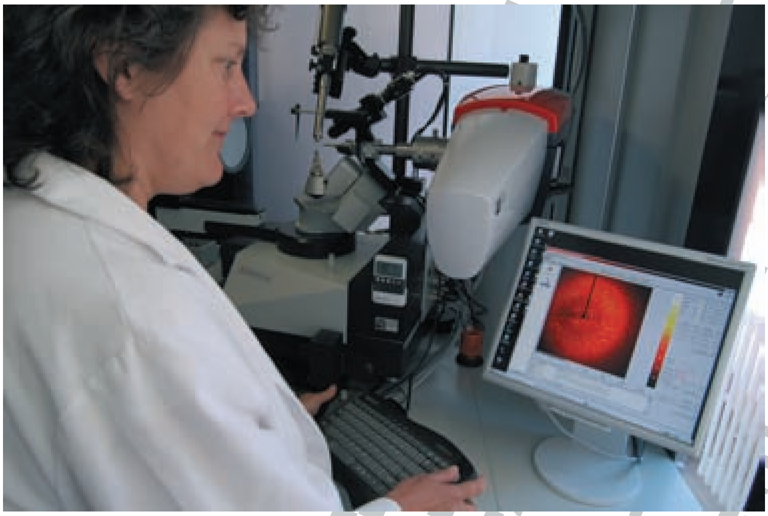
**2. Measuring, monitoring, understanding and being able to predict** the mechanisms of ocean-atmosphere feedbacks in climate change and their impacts on the larger ocean environment are critical to the effective management of ocean and coastal seas.

**3. The management of maritime activities and sustainable exploitation of natural resources** in European seas will be best achieved using a knowledge-based approach.

The real **impact** of marine genomic research on society will be **impressive** but will require the **medium- to long-view in investment return.**

The once **data poor ocean** is rapidly transforming into a **data rich environment.** It is time to "think outside the box". This, however, entails the address of a number of **key issues.**

We have regrouped them in **four major strategic priorities** and **five steps of implementation.**



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▲Inspecting a diffraction pattern of a marine protein cristal.

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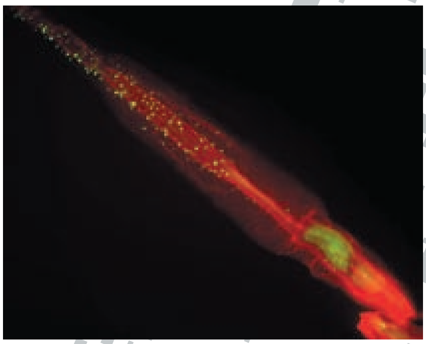
Deep-sea copepod of the genus *Saphirina.* ▶



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Larva of the sea squirt *Ciona intestinalis* (fluorescently stained). ▶

# Four **strategic priorities** require special attention over the next ten years in order to understand **the complexity of marine ecosystems** and to serve the world community.

**1. Changing environments:** the ocean and its biosphere are changing continuously, be it under influence of natural events or the growing impact of man. The latter increasingly brings major concerns in society. Here knowledge is the key to decision and mitigation. Genomics has become a key for understanding biogeochemical processes.

**2. Evolution of biodiversity:** global biodiversity - including marine - is decreasing at an alarming rate. Species disappear or novel species (exotics) are reported in non-normal habitats. The genome is a repository of historical change and hence a source to predict future developments. Ecosystems are composed of species whose interactions affect the innumerable goods and services man gains from the oceans. Genomics is a practical tool to make the many unseen biota visible.

**3. Living resources:** the ocean is a huge source of food. Most crucially, it guarantees a minimum level of health for the poor. Unfortunatly most (shell)fish stocks are overexploited and some are close to collapse. Fisheries management finds a valuable source of knowledge in genetic information.

**4. New biological resources:** biomedical, industrial and societal applications can expect a great deal from blue biotechnology. So far the potential locked in the ocean has not been fully exploited. Genomics provides a novel and unique window into the resources locked up in all organisms from microbes to marine mammals.

## The realisation of these strategic priorities demands a number of steps

**1. Integrated science:** with the growth of molecular sciences, inter- and multi-disciplinary approaches between marine genomics and ecosystem sciences, oceanography, global earth observation and health should be expanded and encouraged on local, regional and global scales. Joint projects, small and large alike, realised through joint funding, are the key to success. Systems biology is increasingly appearing as an integrating science.

**2. Technological support:** progress in (marine) genomics is based on sustained technological support. For example, in the establishment of marine model systems, the exploitation of large metagenomic datasets, postgenomics, bioprospection infrastructures for blue biotechnology and information management.

**3. Development of research capacities:** the increasing data flow from marine life through remote sensing, either from space or from semi-permanent stations in the ocean, offer ocean sciences immense opportunities for a better knowledge of a poorly accessible environment. Automated monitoring, combined with onshore validation, experimentation and data processing will offer the necessary data to understand the significance of microbial remineralisation, ocean-wide primary productivity and the impact of removing top predators through fishing.

**4. Links with society - education and training:** appreciation of the ocean will directly benefit from education and training in ocean sciences and management. Marine scientists promote their science and the environment they work in. As the ocean covers most of the globe, a critical mass of marine researchers is translated in larger numbers of marine scientists and policy makers.

**5. Science mediation:** organisations such as Marine Genomics Europe are perfect mediators between funding agencies, high-throughput technology platforms, specialist communities and the public.

# Implementing a vision for 2020:
# from innovation to delivery

Marine Genomics has enormous potential to improve our lifestyles and prosperity, to enhance the competitiveness of European industry, and to guarantee global sustainability.

In order for this future to be assured, the EU and its member states have to take further action.

With this aim, the EU Network of Excellence (NoE) Marine Genomics Europe is involved in:
- The collection of fundamental knowledge on the functioning of the oceans,
- Knowledge transfer and technology translation between high-throughput genomics, marine biology, oceanographers, industry and society,
- Working with policy makers,
- Transparency and dialogue with society.

We need to focus on **understanding** and **sustainable exploitation** of the ocean in order to:
- Generate knowledge for the sustainability of Planet Ocean,
- Promote marine organisms as models for a variety of problems affecting daily life,
- Promote sustainable exploitation of molecular products,
- Promote the sustainable exploitation of food products,
- Promote marine organisms as models for understanding evolution and the secrets of life.

These goals arise from the ongoing efforts of the three marine Networks of Excellence (NoEs) Marine Genomics Europe, MarBEF and Eur-Oceans.

**Finally …**
Marine organisms represent a rich source **of critical fundamental knowledge** on genomics and biology in general.
Due to its huge potential for exploitation, the demand for marine sciences will strongly increase in the near future. The successful exploitation of these multi-facetted and hitherto untapped resources will demand far greater investment than the current 10% in earth and life sciences.

The real impact of this frontier zone of research on society has already proven to be impressive.


▲ **Although remote sensing provides a tool for the deepsea, direct human access remains indispensable.**

**"A vision is urgently needed for marine related research in Europe leading to a strategy that derives even greater benefits from the Framework Programmes and other sources of funding in Europe, avoids duplication, closes gaps and creates synergies.**
**The strategy should include mechanisms for optimizing coordination, cooperation and dialogue between the Commission and policymakers, industry and scientific communities in Member States and third countries. On the basis of input from the scientific and technical community, it should set out what is necessary to support strong and durable integration of activities among organisations carrying out research relating to the sea and maritime activities in Europe, and to provide for a stronger cross sectoral dialogue between scientific disciplines and technology developers, to provide input for a holistic approach to maritime policy" (EU 2005).**

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▲Upclose and personal with a sponge.

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