Chapter 6

Conclusions: Delivering on the promise of marine biotechnology

This chapter presents conclusions, identifies the policy areas of greatest potential impact for enabling the sustainable development of marine biotechnology and highlights the challenges of supporting both productivity and ocean sustainability. It provides a foundation for future work to overcome the challenges and realise the potential of marine biotechnology.

Marine biotechnology in the 21st century

Advances in genome science and related technologies have led many countries to focus attention on marine biotechnology. Marine organisms, once difficult to access and study, can now be examined more quickly and in greater detail than ever before. Genomic and metagenomic analyses of marine organisms and the marine environment are revealing the complexity and biodiversity of marine ecosystems. By all estimates, the ocean's biodiversity far exceeds that of terrestrial environments but is largely unknown. Yet marine bioresources may be a significant source of new biological and chemical processes and principles from which new bioactive compounds can be isolated, modelled or created. Marine biotechnology is increasingly recognised as a potential source of innovation.

Addressing global challenges

Advances in genomics and computer science have transformed earlier views of the ocean. It is no longer simply a source of food and a way to transport goods but a vast reservoir of genetic potential and a means of achieving a wide range of socioeconomic benefits. The application of marine biotechnology in a number of sectors suggests that it may help to meet the global challenges of population health, food and fuel security and greener industrial processes:

- *Human health and well-being*: The ocean is recognised as a source of drugs and natural products with various functionalities. As of 2012, seven marine-derived drugs had received FDA approval, eleven were in clinical trials and 1 458 were in the pre-clinical pipeline. Marine microbes are of particular interest as new sources of antibiotics for treating drug-resistant bacterial infections.
- *Industrial biotechnology*: Novel catalysts from marine organisms are used in a number of industrial applications and the potential of algae as a sustainable biofuel and a source of refined high-value chemicals is being explored.
- *Food supply*: More sustainable food production is being achieved through new fish breeding and rearing technologies, the development of novel feeds, the understanding of health issues and new opportunities for the use of wastes.
- *Environment sustainability*: Tools and processes are being developed to monitor and address potentially negative environmental impacts.

A new source of economic growth

The economic potential of marine biotechnology appears to be significant and growing: in 2010 the market was estimated at EUR 2.8 billion with annual growth of 4-12%, depending on the model used. Growth in marine biotechnology is expected to create new jobs along the value chain from academia to industry in the marine sector and to sectors such as pharmaceuticals, food, industrial processing and nutraceuticals.

This is spurring renewed interest in marine bioresources and marine biotechnology as a source of innovation and economic growth. Many governments and regions are investing in marine biotechnology and developing frameworks to support the field. Some countries have incorporated marine biotechnology in their national "bioeconomy" strategies and blueprints.[1]

Challenges to development

This report has considered the potential of this burgeoning field as well as issues that may impede its development. In order to ensure its relevance to policy for marine biotechnology, it has focused on issues that are unique to this field. Because marine biotechnology is inextricably associated with the marine environment, particular attention must be paid to the vast physical and geographic distribution of bioresources, the diversity of these bioresources and the complexity of the marine ecosystems.

Governance of distributed bioresources

The distributed, and often dynamic, nature of bioresources means that they are often found beyond the jurisdiction of any one nation. For most purposes, they can therefore be considered shared resources. This is particularly the case for organisms in the deep ocean or open seas outside exclusive economic zones (EEZ) and for motile or current-based organisms with a wide geographic range. The Convention on Biological Diversity and the Nagoya Protocol provide a broad framework governing access to and sharing the benefits of resources within EEZ. However, this framework is less relevant and effective for organisms beyond these areas. This raises questions about ownership, access to these bioresources and the sharing of the benefits to be obtained.

Similar questions are raised concerning the protection of these shared resources. This report has discussed the utility of marine protected areas and various approaches to their governance and protection. The complexity of marine ecosystems and the comparative lack of knowledge regarding the functioning of and interaction of organisms and between them and their environment complicate efforts to protect or develop marine resources. How does the ecosystem respond to varying levels of an organism and how can a single organism or functionality be singled out? This raises two development-related challenges: the infrastructure needed to develop marine bioresources and the sustainable use of those resources and their ecosystem services.

Developing infrastructure

To protect the marine environment and to derive social and economic benefits from marine biotechnology will require in-depth knowledge of marine bioresources and their ecosystems. It will also require an appropriate R&D infrastructure to enable the generation, analysis, sharing and dissemination of knowledge about marine bioresources. Marine biotechnology has benefited significantly from prior life-science investment in R&D, particularly for human genomics. Genome sequencing is no longer the barrier it was a decade ago and our understanding of marine bioresources has improved significantly. Metagenomic analysis is providing a means to access and study the complexity of the marine environment but it also reveals deficiencies in marine biotechnology R&D, which are compounded by our limited understanding of ocean bioresources. Access to these, especially in the deep ocean, remains a challenge, and the complexity and novelty of marine bioresources makes annotation of data difficult. New infrastructures are needed, with new models, new culture systems and new bioinformatics-based tools to visualise and analyse genomics and other types of data.

Economic monitoring tools

As governments seek to incorporate marine biotechnology into innovation strategies, it is becoming clear that they lack the tools needed to measure the success of these strategies. This is due to the lack of appropriate indicators, the difficulty of tracking outputs of marine biotechnology across a wide range of sectors, and the difficulty of separating the contribution of marine biotechnology to the innovation process from the resultant products. The field differs from biomedical or industrial biotechnology in that marine biotechnology is still defined in terms of its source (or target) material, rather than the market it serves.

As governments and other stakeholders continue to invest in marine biotechnology, there will be a need for new measures and indicators to track investment and outcomes. These will need to go beyond existing measures of investment to find ways to measure outputs in different sectors. It will also be necessary to measure the non-market contribution of the ocean and marine biotechnology as the promise of marine biotechnology, both economic and otherwise, owes much to the health of the marine environment.

Strategic partnerships to enable innovation

The wide range of applications of marine biotechnology creates special challenges. There is a need, as in other fields, to form strategic partnerships for knowledge co-creation, transformation, mobilisation and diffusion from basic R&D through to diffusion of innovations in the market place. There is also a need for dialogue among all stakeholders regarding access, development and exploitation of bioresources from the marine environment. However, given the variety of sectors concerned, it is unlikely that a one-size-fits-all approach to marine biotechnology partnerships will be effective.

It is also clear that policies to support marine biotechnology applications in one sector might be quite different in others. These differences relate to differences in markets and in the knowledge or capacities of stakeholders in different sectors. It will be important to consider many different approaches to knowledge creation and sharing and the commercialisation of innovations in different sectors.

Addressing hurdles to marine biotechnology development

Throughout previous chapters, two recurrent themes have appeared important for the sustainable development of marine biotechnology: the need for communication among stakeholders and the need for internationally co-ordinated action. While these themes are not unique to the field, their emergence from this study's focus on the distinctive features of marine biotechnology makes them especially noteworthy and in need of attention in future policy work.

International collaboration and co-ordinated action

The sheer size of the ocean, which is far larger than the terrestrial surface of the planet, has long served as a call for internationally co-ordinated development of resources. This report has shown that the ocean is home to vast bioresources which are widely distributed and rarely confined to any nation's exclusive economic zone. Most are motile, self-propelled or moved by ocean currents, and present across vast geographic regions; others lie in more restricted habitats of the deep ocean and other areas beyond national jurisdiction. No single nation owns these highly distributed resources and their conservation will require internationally co-ordinated agreements and actions.

International co-operation has resulted in a framework for the conservation of biodiversity, but further co-operation is needed. Chapter 5 detailed the need to develop a framework for access to marine genetic resources in areas beyond national jurisdiction. It also highlighted the potential value of a framework for enforcing actions related to the sharing of benefits from these resources. These challenges are heightened in the absence of a single governing authority, especially as the focus turns from protecting marine resources to their exploitation and as different stakeholders engage in different ocean-related activities.

Development of the R&D infrastructure for improving understanding of marine bioresources and supporting their sustainable development can also profit from international co-operation. International megaprojects, such as the human genome project described in Chapter 4, have successfully focused considerable resources on the development of specific infrastructure. For marine biotechnology, however, next-generation sequencing has revealed gaps in the infrastructure for analysing genomic information and underscored how little is known about the complexity of life in the ocean. For marine biotechnology, the challenge will be to create infrastructure to help understand the complexity of marine organisms and related marine ecosystems. Given the type and volume of information required to enable the field and the type of research infrastructure required to obtain this information, development of the infrastructure may best be accomplished though international collaboration.

As discussed in Chapter 3, there are many opportunities for international co-ordination on the development of indicators and measures for marine biotechnology. The development of standards or measures of ocean health may best be accomplished through international collaboration as they will be most useful if universally accepted.

The development of economic statistics and indicators may need to be modelled on established national metrics. However, it would be useful to have international agreement on the definition of marine biotechnology, especially as it relates to biodiversity and to other forms of biotechnology. This may affect the development of relevant economic indicators and measures, especially those for measuring the health of the ocean.

Improved dialogue or communication

Focused and effective international dialogue will be needed to address hurdles such as development of indicators, R&D infrastructure and sustainable development of marine resources. Dialogue at national and regional level among end users, regulators, the private sector and researchers will also be important for innovation in marine biotechnology and its applications (see Chapter 5).

Consultation with civil society regarding the development of marine bioresources can help to ensure sustainable development and optimal diffusion of the technology. Early dialogue can help to secure public support for innovation in the marketplace (social acceptance) and, in cases of local custodians of marine-based genetic resources, it can expedite access to marine bioresources and downstream knowledge co-creation. The Nagoya Protocol provides a framework for discussions of access to marine genetic resources and traditional knowledge for the development of resources, but there is scope for earlier dialogue and stakeholder engagement.

The challenges associated with the scaling up of laboratory-based proof of concept to industrial level are great but may be mitigated in part through earlier collaboration between industry and academic or other researchers, including through strategic partnerships. This opportunity has been recognised and many government and other initiatives encourage industry-academic partnerships early in the process to support co-development of knowledge and platforms. However, different types of marine biotechnology applications and different industries will require different types of dialogue and will benefit from different strategic partnerships.

Finally, there may be a need, as evidenced by the emergence of marine biotechnology in national bioeconomy strategies, for a communication strategy around marine biotechnology, perhaps with a focus on environmental issues and sustainability more broadly. A communication strategy might explain what biotechnology is and how applications of marine biotechnology can affect the production of food, biofuels and other economically and socially important activities. It might be carried out in part by a neutral, apolitical, "ocean ambassador" who would participate in national and international events to represent and safeguard the interests of the ocean. This might help to galvanise support for marine biotechnology.

Areas for future work

Governments and private-sector organisations around the world have begun to focus on the marine environment and are working to harness its potential, utilising the methodology and knowledge of marine biotechnology. Several features of marine bioresources may nonetheless require new policy work to ensure the translation of new scientific and technological advances into commercially viable products in an environmentally sustainable manner.

The OECD Working Party on Biotechnology has identified three areas of focus for future policy work: governance of marine bioresources and eco-systems, measures and indicators for marine biotechnology, and development of new R&D infrastructure. International collaboration and co-ordination and stakeholder dialogue are expected to feature prominently in this work.

Governance of marine bioresources and ecosystems

Marine biotechnology is predicated on access to marine resources distributed throughout a vast and complex shared ecosystem. An appropriate framework is needed to ensure access to these resources in an environmentally and socially sustainable manner if the potential of marine biotechnology is to be realised.

Measures and indicators for marine biotechnology

Marine biotechnology is poised to make a significant contribution to the bioeconomy. Many countries have included it in national strategies to bring economic and social benefits to their citizens. To measure the contribution of marine biotechnology to the bioeconomy and the return on investment and impact of government policies will require indicators and statistics that are appropriate for marine biotechnology.

Recognising the ecosystem services that marine biotechnology provides (including its non-market value) and the need for the sustainable development of marine bioresources, tools and metrics will also be needed to serve as indicators of "healthy ecosystems" and ensure the fitness of marine bioresources for future generations.

Development of new research and development infrastructure

Marine biotechnology requires a comprehensive understanding of marine bioresources and marine ecosystems. Given the complex nature of the marine environment, it will be necessary to develop new infrastructures for characterising and understanding the potential of ocean bioresources.

Note

1. See Chapter 3, www.sitra.fi/en/natural-resources-strategy, www.pmg.org.za/report/20120222-department-science-technology-grand-challenges-bioeconomy-committee-d, and www.whitehouse.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf, accessed August 2012.

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