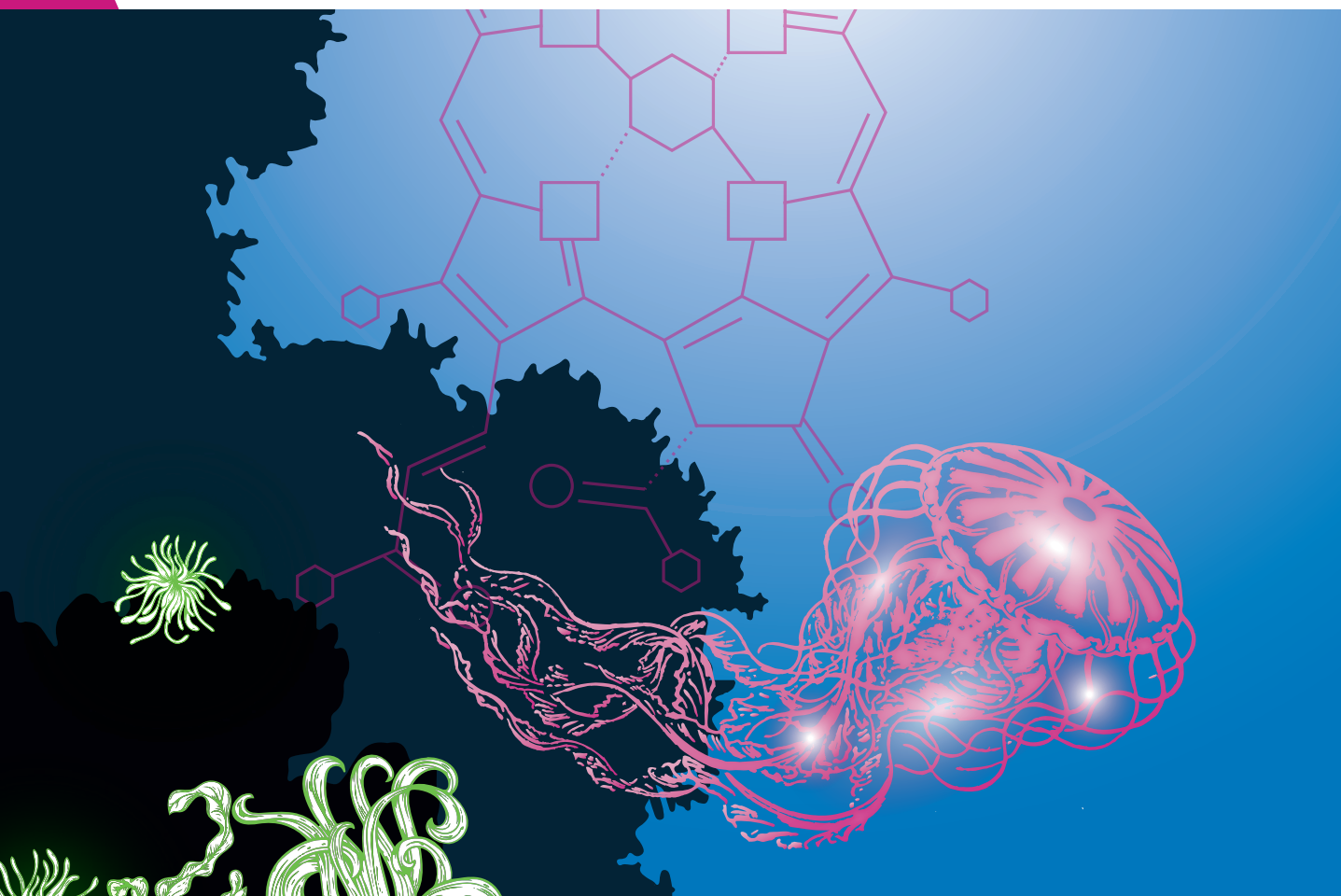


Blue Biotechnology

Commonwealth Blue Economy Series, No. 5



The Commonwealth

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Commonwealth Secretariat



The Commonwealth

Commonwealth Secretariat
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Acronyms and Abbreviations

AD	anaerobic digestion
BRC	biological resource centre
CBD	Convention on Biodiversity
EU	European Union
HEI	higher education institution(s)
OECD	Organisation for Economic Co-operation and Development
R&D	research and development
SIDS	small island developing state(s)
SMEs	small and medium-sized enterprises
SRSL	SAMS Research Services Ltd
UNESCO	United Nations Educational, Scientific and Cultural Organization

Summary

The marine environment provides valuable economic, social and cultural resources, which can contribute to the sustainable economic development of small island developing states (SIDS) and larger coastal states. Traditionally exploited marine resources include living resources, such as numerous species of fish and shellfish, and non-living resources, such as marine aggregates and petroleum, as well as supporting global transport and telecommunication networks. The marine environment also provides human communities with a broad range of essential services that support economic wellbeing and human health. Furthermore, new opportunities have emerged that are gradually being realised, including marine renewable energy and mariculture; currently, there is interest in marine genetic resources with potential pharmaceutical and industrial benefits.

With the growing threats posed by a changing climate, it is increasingly evident that we need to pay more attention to our planet's oceans. The recent concept of the 'blue economy' – which emerged during the 2012 Rio+20 United Nations Conference on Sustainable Development – recognises the need to maximise the enormous economic potential presented by the ocean while preserving it. Over the past three years or so, the 'blue economy' has been embraced by many SIDS as a mechanism for realising sustainable growth around an ocean-based economy. In that time, the idea of the blue economy has emerged as a key component of a new global dialogue about the role of the oceans and seas in sustainable development. For SIDS in particular, the concept of the blue economy presents itself as a promising avenue for economic diversification and growth embedded in fundamental principles of environmental sustainability.

The *Commonwealth Blue Economy Series* aims to support the development of the blue economy in Commonwealth member countries by providing a high-level assessment of the opportunities available for economic diversification and sustainable growth in SIDS.

This fourth volume in the series aims to support the development of the blue economy by providing a high-level assessment of the opportunities available for economic

diversification through the development of a blue biotechnology sector in SIDS and by examining relevant examples from around the world. This is drawn together with a description of the specific enabling conditions that could assist in moving such a blue biotechnology sector towards becoming an economic reality where opportunities exist.

Recommendations focused on ensuring the sustainability of the blue economy by exploring options and opportunities for:

- **Initial sectoral prioritisation:** Focus on niche products, based on local biological resources, developed, produced and marketed worldwide.
- **Scientific exploitation:** Systematically explore existing data to inform and steer any future bioprospecting activity.
- **Biological resource management:** Ensure effective and simple implementation of the Nagoya Protocol's recommendations and establish a local biological resource facility.
- **Development of critical mass:** Develop a government-owned, or locally resourced, public-private independent research company as a focus for activity; build strategic alliances with national and international commercial and academic partners.
- **Financing:** Finance activities through public-led partnerships with the private sector and secure international support.
- **Coherent cross-policy activity:** Use the blue economy framework to assist in the development of clear action plans and rationalise activities under different policy initiatives.
- **Developing indigenous skilled capacity:** Address local capacity as a strategic issue requiring coordination across the blue economy and the economy as a whole, rather than within individual sectors.
- **Developing scientific research capacity:** A national study into capacity for research and current international collaboration is supported, ensuring that, in addition to technical skills, it also considers social science and entrepreneurial aspects relevant to the

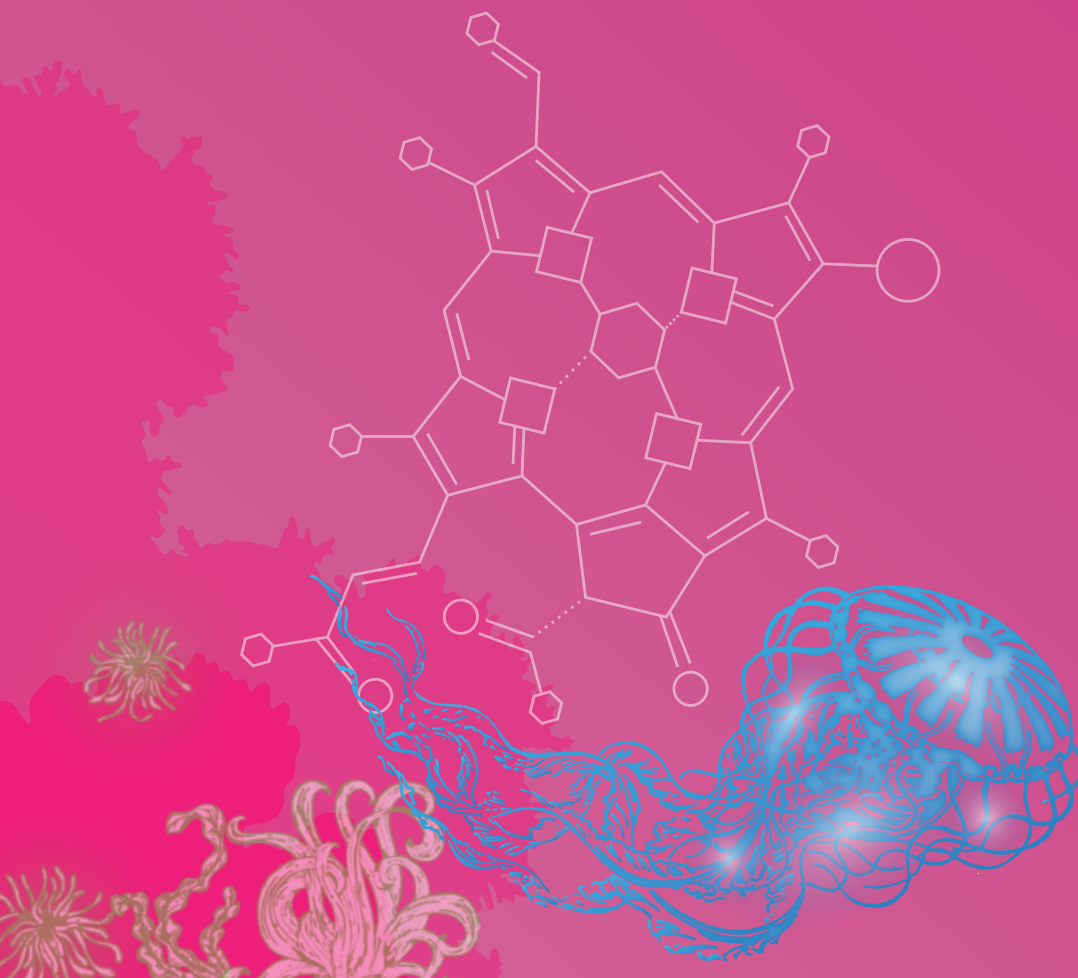
development of and local ownership of blue economy activity.

- **Integrating planning of sectors within the blue economy:** Considering the possibilities of multi-sector development in integrated scenarios will identify overlap in actions (e.g. in relation to research or local infrastructure), address possible conflicts and develop dialogue on the comparative costs and benefits, within the context of sustainable development.

The development of blue biotechnology for food, health products and pharmaceuticals presents novel possibilities, and strategies for developing these possibilities are suggested. Where there are opportunities for rationalisation of activities under different policy initiatives and between sectors to achieve the overarching objectives of the blue economy, this is strongly supported.

Chapter 1

Introduction



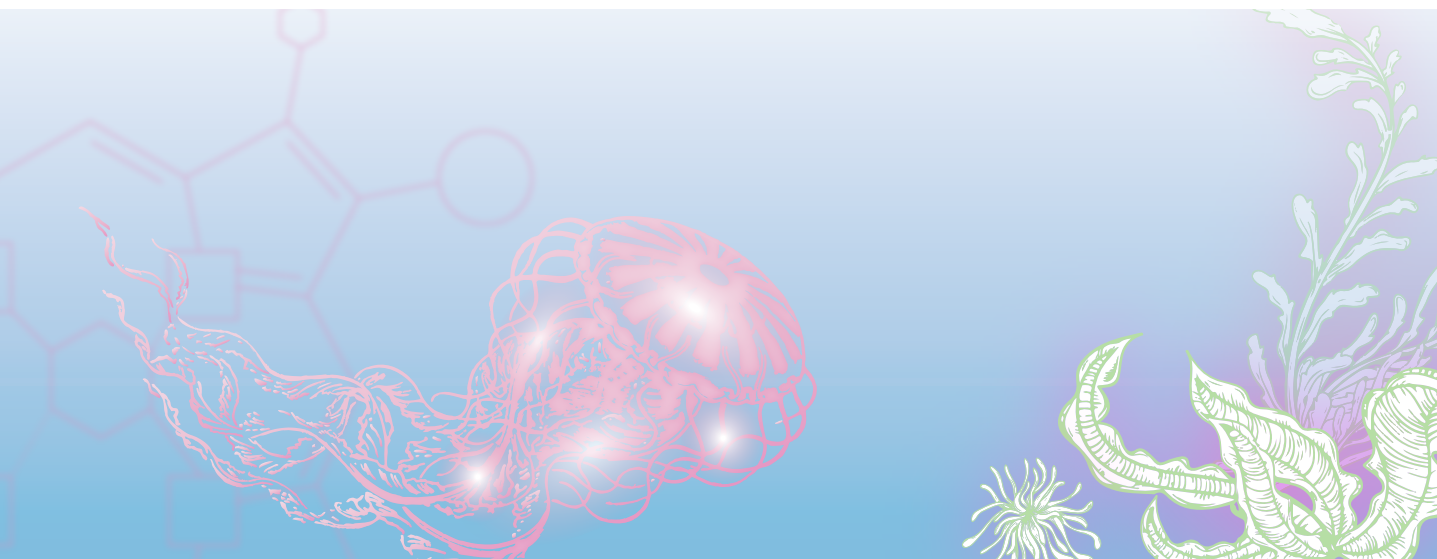
Chapter 1

Introduction

1.1 Developing a blue economy

The concept of an ocean-based, or 'blue' economy has its origins in the 'green economy' concept endorsed at the Rio+20 United Nations Conference on Sustainable Development in 2012. Support for the blue economy at the 2012 conference from small island developing states (SIDS) emphasised the fact that their economies were largely dependent on the health and sustainable use of marine resources.

These low-lying coastal countries have in common similar sustainable development challenges, including small but growing populations, limited resources, remoteness, vulnerability to external shocks, and fragile environments. These challenges are inherent and any effective practical approaches to the development of sustainable economic opportunities from the ocean must take these factors fully on board and be relevant to the SIDS context. Many SIDS also have poorly diversified economies, relying on one or two key sectors to drive the economy. However, they have extensive marine exclusive economic zones and a number of them have been in the vanguard of championing the development of the blue economy as a promising avenue for economic diversification and



growth embedded in fundamental principles of environmental sustainability.

In this regard, the Commonwealth has been at the forefront of promoting the blue economy as a holistic concept that can address sustainable development at multiple levels for a number of years. At their most recent meeting, in Malta in November 2015, Commonwealth Heads of Government recognised that the development of a sustainably managed blue economy offers significant opportunities for economic growth and general development for many Commonwealth states.

The notion of the blue economy refers to those economic activities that directly or indirectly take place in the ocean and in coastal areas and that use outputs from the ocean; it includes goods and services that support ocean activities, as well as the contribution that those activities make to equitable economic growth and social, cultural and environmental wellbeing.

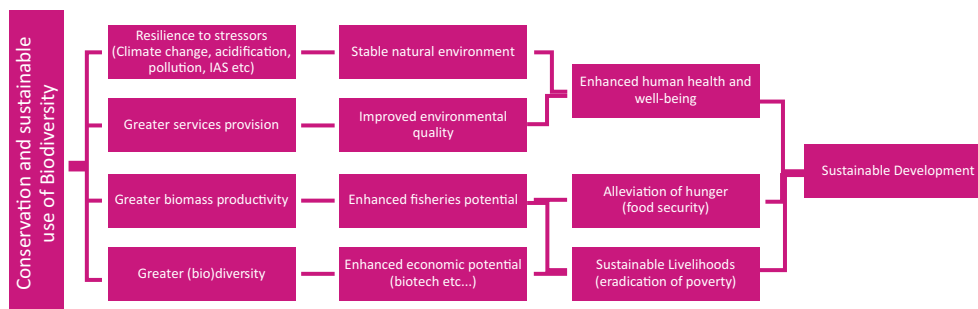
The scope of the blue economy therefore includes activities that:

- explore and develop ocean resources;
- use ocean and coastal space;
- protect the ocean environment;
- use ocean products as a main input;
- provide goods and services to support ocean activities; and
- develop mechanisms to ensure the equitable sharing of national wealth (and benefits) derived from the blue economy.

The blue economy concept also encompasses economic and trade activities that integrate the conservation and sustainable use and management of biodiversity.

The requirement for sustainability necessitates a paradigm shift in both the mindset of those currently exploiting the oceans' resources and the diversity of ways in which the marine environment is used for the benefit of mankind. It is, therefore, inappropriate to continue with 'business as usual' and to simply re-badge the current uses of marine resources as 'blue'. By conceptualising the ocean as a development space where spatial planning integrates conservation, sustainable use, resource extraction, sustainable energy production and transport, the

Figure 1.1 The blue economy



Source: UNCSD, 2014.

blue economy offers an alternative economic approach that is guided by environmental principles. It challenges the status quo, whereby oceans have been viewed as a free resource and an unlimited sink for the disposal of waste; instead, it shifts the focus so that ocean values services are included in decision-making and benefits are shared more equitably. The successful implementation of the blue economy model (Figure 1.1), nationally, regionally or globally, will require a more integrated and holistic approach to assessing development scenarios, and their implications for society.

The blue economy will incorporate ocean values and services into economic modelling and decision-making processes, thereby helping SIDS and other maritime developing countries address equity in access to, development of and the sharing of benefits from marine resources. Optimising the benefits received from the development of marine environments in SIDS – including mariculture, marine biotechnology and marine renewable energy, as well as ongoing initiatives relating to fishery agreements, oil and mineral extraction – will require significant political, financial, logistical and scientific resource. However, the outcomes from such a strategy, including diversifying economic development, increasing export income, generation of high-value employment and enhancing international recognition, will bring real and tangible benefits.

1.2 Blue biotechnology

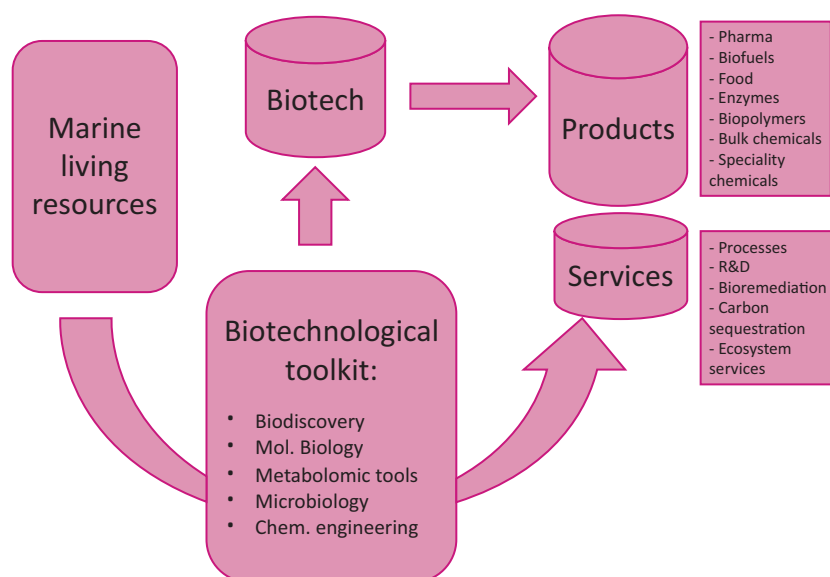
The oceans make up about 70 per cent of the surface of our planet but over 99 per cent of the biosphere (since organisms are found throughout the water column), and they represent

the greatest extremes of temperature, light, and pressure encountered by life. Adaptation to these harsh environments has led to rich marine biodiversity and genetic diversity with potential biotechnological applications related to drug discovery, environmental remediation, increasing seafood supply and safety, and developing new resources and industrial processes.

The term biotechnology is widely employed and has different connotations and meanings for different individuals; however, a useful and all-encompassing definition by the Organisation for Economic Co-operation and Development (OECD) is: ‘The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services’ (OECD, 2005). In blue biotechnology, or blue biotech, the biological materials originate from the aquatic environment, freshwater and marine, and this has in recent years become synonymous with marine biotechnology. With the ongoing revolution in methodological development, the toolkit for developing commercially viable products and processes has expanded (Figure 1.2).

Furthermore, major, primarily public sector, research and development (R&D) investment in Europe, North America and the Far East has provided the tools and building blocks for new generations of start-up small and medium-sized enterprises

Figure 1.2 Blue biotech workflow: from bio-resource to wealth creation

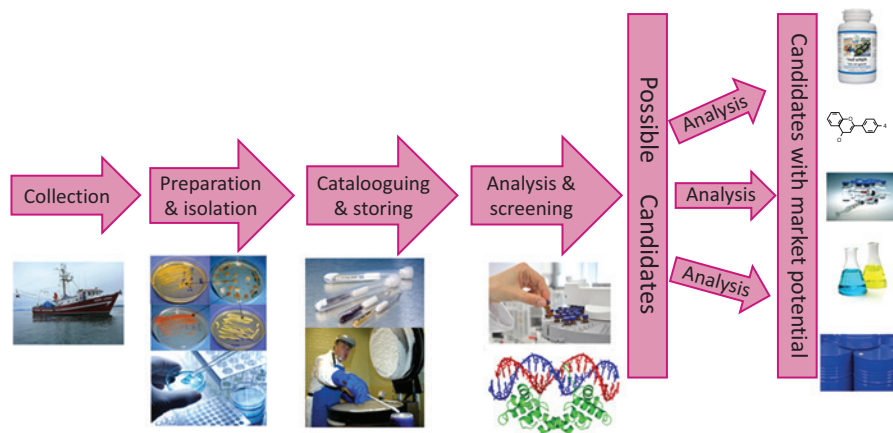


(SMEs), as well as resulting in a change in emphasis in some of the major pharmaceutical companies. Blue biotechnology is increasingly seen as a technical and commercially realistic direction of development and is a major sector of interest in North America and the European Union (EU) in particular. The global market for marine biotechnology products and processes was estimated at €2.8 billion in 2010 (Børresen et al. 2010), with a cumulative annual growth rate of 5–10 per cent. This may be an underestimation, as Lloyd-Evans (2013) has suggested; if one includes antioxidants and other functional ingredients that can be derived from marine sources, the market may be in the range of US\$6.7–29 billion. The potential of the sector as a whole is huge, and the contextual relevance to SIDS and some of the realistic opportunities available are explored in more detail in the following chapters.

The key to future biotechnology is bioprospecting, which can be described as a systematic search in marine organisms from the sea, along the coast, the seabed or beneath the seabed. This may include all kinds of organisms: micro-organisms (micro-algae, bacteria, fungi and viruses) and larger organisms such as sea plants, shellfish and fish. Indeed for many potential products and applications it may be the interactions, or synergies, between different organisms that result in the activity or product of commercial value. The purpose of marine bioprospecting from a business perspective is to find components, compounds or genes that may be included as components in products or processes. There is an extensive range of uses and applications that extend well beyond the pharma sector, and these include nutraceuticals, functional foods, cosmeceuticals, human food, animal and fish feed, and biofuels.

The technological journey involved in bioprospecting, from finding an organism with biotechnological potential to having a product that is marketable, can be a complex, time-consuming and expensive procedure (Figure 1.3). In the case of bioprospecting for molecules with pharmacological activity, a minimum of 10–15 years and hundreds of millions of dollars may be required to take a product to market. However, for other, non-pharma, products the development pipeline may be much shorter, and, particularly for those products that can be manufactured using proven technologies and where there is a strong market demand, the period time from discovery to income generation may be as short as 2–5 years.

Figure 1.3 Technical stages of development in marine bioprospecting



Marine organisms present a better opportunity for encountering successful candidates than terrestrial plants, animals or microbes because of their biodiversity, our limited knowledge of them compared with our knowledge of terrestrial organisms and the range of extreme ecological environments in which they are found (Kijjoa and Sawangwong, 2004). This opportunity has been a driver in Europe in particular for exploring the potential of marine biotechnology to form a significant economic sector (Børresen et al. 2010). Furthermore, there are currently economically successful marine-derived natural products to reinforce the academic, commercial and political interest in this potential (see Boxes 1.1 and 1.2 for examples). The potential and opportunities available to SIDS are discussed in more detail in Chapter 3.

Box 1.1 Health and beauty (cosmeceuticals)

The major cosmetics company Estée Lauder uses pseudopterosin, an anti-inflammatory extracted from the sea fan *Pseudopterogorgia elisabethae*, in skin lotions marketed under the trademark 'Resilience'. The French cosmetics company Clarins uses extracts of the algae *Durvillea antarctica* in its best-selling Extra Firming Day Cream, which it markets for the treatment of mature skin. A third French company, Sederma, sells Venuceane™, a skin protection product that includes a radical-scavenging enzyme originally discovered in the extremophile bacterium *Thermus thermophilus*.

Box 1.2 Pharmaceuticals

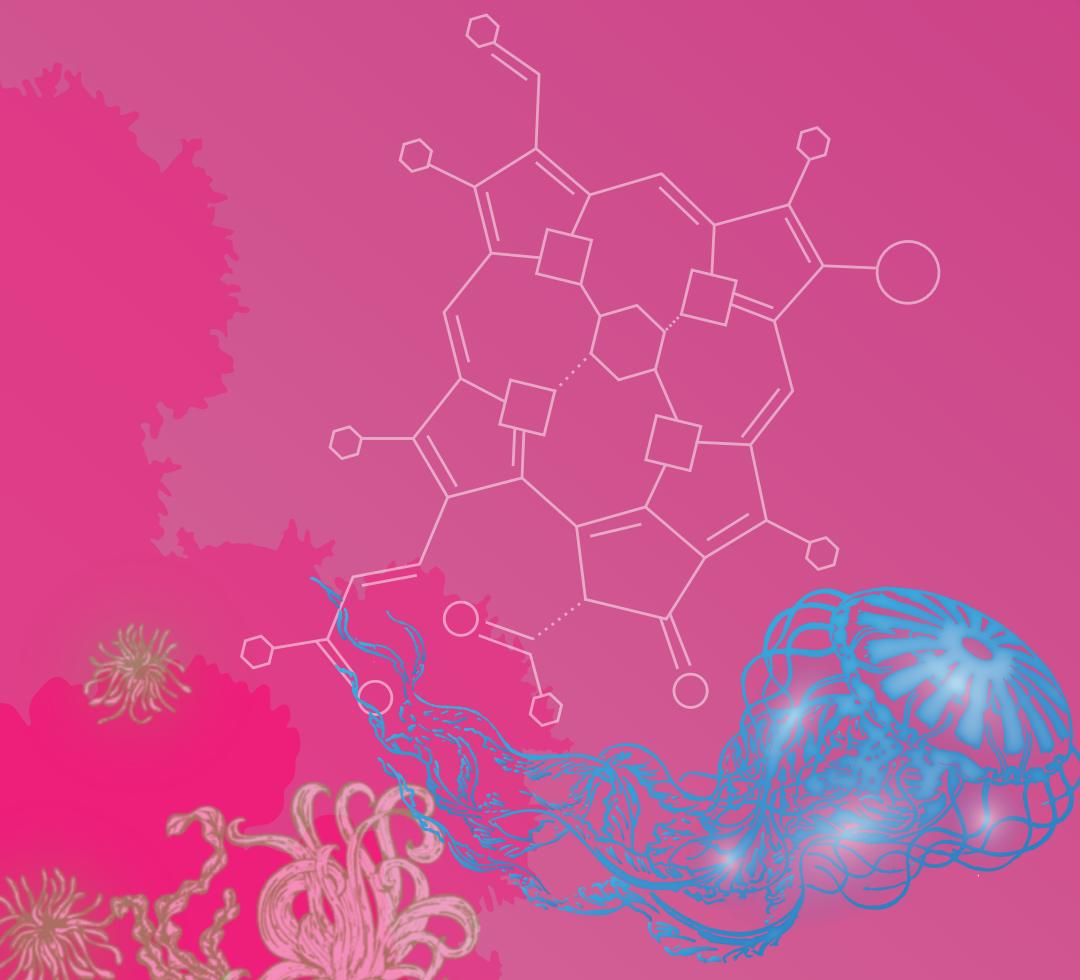
The cone snail *Conus magus* incapacitates its prey by injecting a peptide neurotoxin. A synthetic version of this peptide (Ziconotide) was developed by the Élan Corporation plc (Ireland) into a synthetic drug for the treatment of patients suffering from chronic neuropathic pain. This was approved for sale under the name Prialt® by the US Food and Drug Administration in December 2004 and by the EU in February 2005. A further example is the marine tunicate *Ecteinascidia turbinata*, which is the basis of a commercially available anti-cancer agent, Yondelis®. The Spanish company Pharmamar received approval to market Yondelis® in Europe in September 2007 for the treatment of soft tissue sarcoma, and this was the first drug to be approved for this condition for more than 25 years, with sales of US\$30 million in 2008, which rose to \$45 million in 2009. This drug was subsequently approved for use in 57 countries worldwide, of which 26 are outside Europe. After it had received approval for the treatment of ovarian cancer, sales increased to \$17 million in the first quarter of 2010 (Børresen et al. 2010).

References

- Børresen, T, C Boyen, A Dobson, M Höfle, A Ianora, M Jaspars, A Kijjoo, J Olafsen, G Rigos and RH Wijffels (2010), *Marine Biotechnology: A New Vision and Strategy for Europe*, Marine Board-ESF Position Paper 15, 1–93.
- Kijjoo, A and P Sawangwong (2004), 'Drugs and cosmetics from the sea', *Marine Drugs*, Vol. 2, 73–82.
- Lloyd-Evans, M (2013), *CSA Marine Biotech: Final Public Project Report*. Available at: <http://www.marinebiotech.eu/sites/marinebiotech.eu/files/public/library/CSA%20project%20reports/CSA%20MARINEBIOTECH%20Final%20report.pdf>. Accessed 4 April 2016.
- OECD (2005), 'Statistical definition of biotechnology'. Available at: www.oecd.org/sti/biotech/statisticaldefinitionofbiotechnology.htm. Accessed 4 April 2016.
- UNCSD (2014), 'Blue economy concept paper'. Available at: [//sustainabledevelopment.un.org/content/documents/2978BEconcept.pdf](http://sustainabledevelopment.un.org/content/documents/2978BEconcept.pdf). (accessed 4 April 2016).

Chapter 2

Blue Biotechnology: A Rapidly Developing and Evolving Sector of the Blue Economy

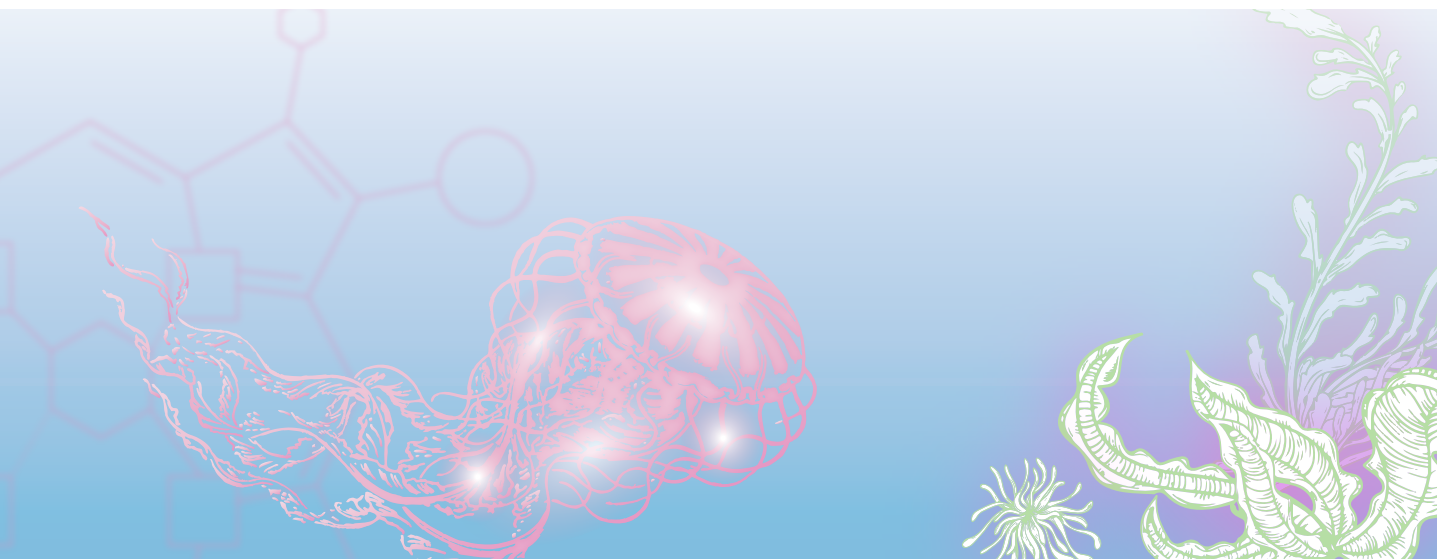


Chapter 2

Blue Biotechnology: A Rapidly Developing and Evolving Sector of the Blue Economy

2.1 Blue biotechnology assets

Most bioprospecting-orientated R&D looking for new pharmaceutically active compounds has historically focused on the terrestrial environment; however, there is a strong rationale for a more systematic exploration of the marine environment. Life in the oceans differs significantly from land-based ecosystems, and it is widely considered that at higher taxonomic levels – that is, above genus and species level – there is a greater range of biodiversity in the marine environment. It is this genetic diversity and its associated functional diversity that has stimulated the current tranche of EU-funded bioprospecting projects, such as SeaBioTech,¹ BlueGenics² and PharmaSea.³ Today, seas and oceans, with their largely unexplored biodiversity, offer significant potential for innovation on two different fronts: a better understanding of marine and maritime resources and their biodiversity, and a more efficient exploitation of the economic and scientific potential of those resources. Blue biotech can provide the tools that will allow this potential to be translated into real products and knowledge.



2.2 Bioprospecting and blue biotechnology beyond pharma

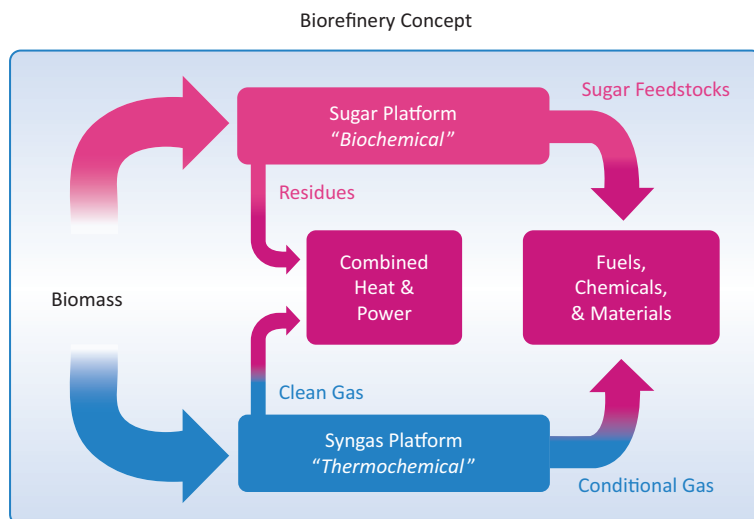
The drivers that stimulate interest in blue biotechnology and influence the goals of bioprospecting projects are directly comparable to those that affect economies worldwide namely:

- the issues of food security and water availability;
- energy security needs;
- demand for transport fuels;
- an ageing population in developed economies;
- increased affluence and aspirations in developing economies;
- increasing carbon dioxide levels and climate change.

Marine-derived products and services have the potential to provide solutions that could help to address these major issues. For example, marine micro-algae can, using sunlight as their energy source and carbon dioxide as their carbon source, produce a range of products (oils, protein, antioxidants, etc.) without compromising potable water supplies, as they grow on seawater. It is easy to focus too directly on the potential huge rewards that new pharmaceuticals can generate, but the investment needed to take a new product to market is in excess of US\$2.5 billion (Mullin, 2014). However, there is commercial value at each stage of the process (biological material to drug), and opportunities for realising this value are discussed below.

Integral to the development of blue biotechnology and the exploitation of marine resources is the concept behind the circular economy, namely a departure from the 'take, make and dispose' approach that underlies much of modern manufacturing etc. Instead, in the circular economy model, consumer goods and other products are designed so that they can be repaired and/or easily recycled rather than replaced. Biological materials would be managed so that they could be returned to the biosphere without contamination. In biotechnology, this is most commonly discussed in the context of developing an integrated biorefinery, that is, a facility that integrates biomass conversion processes and equipment to produce fuels, power and chemicals from biomass (Figure 2.1). The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from a

Figure 2.1 The US National Renewable Energy Laboratory biorefinery concept



Source: www.nrel.gov/biomass/biorefinery.html

single feedstock (crude oil). Industrial biorefineries have been identified as the most promising route to the creation of a new domestic bio-based industry. Although they may not always be applicable in the context of blue biotechnology conceptually they provide the holistic solution to resource exploitation, maximising potential, dealing with waste materials and extracting value at every stage of a process.

Endnotes

- 1 <http://spider.science.strath.ac.uk/seabiotech/>
- 2 <http://www.bluegenics.eu/cms/>
- 3 <http://www.pharma-sea.eu/>

Reference

- Mullin, R (2014), 'Cost to develop a new pharmaceutical drug now exceeds \$2.5B', *Chemical Engineering News*, 20 November 2014.

Chapter 3

Options and Technologies for Blue Biotechnology



Chapter 3

Options and Technologies for Blue Biotechnology

3.1 Blue biotechnology: opportunities across the value pyramid

Marine biotechnology encompasses a wide range of activities and, as discussed above, can include everything from bioprocessing of harvested materials (fish, algae, etc.) to cultivating marine microbes or developing an innovative buoy system for monitoring ocean pollution. Figure 3.1 shows a range of different products and services that can be generated from marine resources, categorising them on the basis of their commercial value, from top-end pharmaceutical compounds to low-value bioenergy produced from organic waste. It is worth noting that special applications products are usually described as low volume, high value and, at the other end of the scale, base commodities are invariably high volume, low value. In the following sections, products and processes representing each level of the value pyramid are outlined. There is potential for individual SIDS, or SIDS collaborating closely, to produce compounds and products at certain levels in this value pyramid, but, given the costs involved in developing special applications, collaboration at an international level is likely to be required.

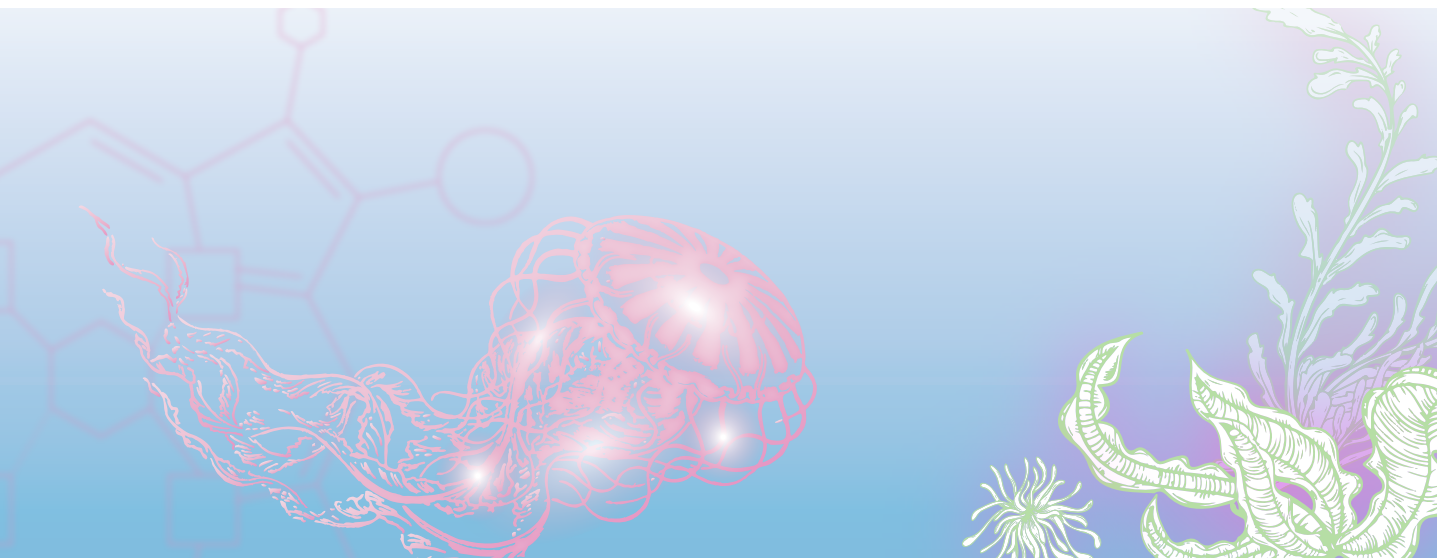
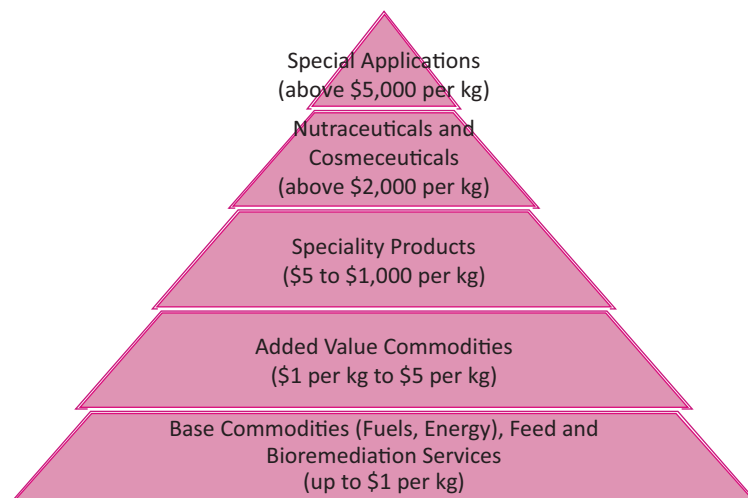


Figure 3.1 Value pyramid of products obtained from the marine environment



3.1.1 Speciality applications

Drug discovery through bioprospecting represents one of the most promising and highly visible outcomes of marine biotechnology research. Compounds from marine invertebrates, algae and bacteria are very different from those from related terrestrial organisms and have the potential to result in new classes of medicines. The drugs cytarabine (ara-C) and vidarabine (ara-A) were developed from sponges in the early 1950s and are used to treat leukaemia and the herpes simplex virus, respectively; these proved to be commercial success stories with an estimated annual worth of US\$50–100 million (Greer and Harvey, 2004). In total, anti-cancer agents from marine organisms have an estimated value of US\$1 billion a year (Greer and Harvey, 2004). However, of those compounds that do enter the clinical development pipeline, a large number are eventually discarded, because their efficacy is not as good as anticipated or they prove to be economically unviable. Furthermore, the financial investment in bioprospecting required to discover a successful product is large. For example, the United Nations Atlas of the Oceans reports that Japan alone spends nearly US\$1 billion a year on marine bioprospecting, with 80 per cent of this funded through the private sector.

It is worth noting that only 1 out of 10,000–20,000 molecules extracted from terrestrial micro-organisms, plants or animals will reach the market and a similar ratio can be expected from

marine-derived materials. Furthermore, it may take 10–15 years and the costs of bringing a new pharmaceutical to market have reportedly risen from US\$800 million in 2003 to \$2.87 billion in 2014, if you count post-marketing R&D (Tufts Center for the Study of Drug Development, 2014). However, as discussed above, successful, commercially rewarding pharma products have been developed from marine resources; furthermore, there are also some non-pharma products in this sector, including the cyanobacterial pigment allophycocyanin, which commands a price of up to US\$50/mg for use as an ultra-sensitive fluorescent tracer in protein labelling.

3.1.2 Nutraceuticals, cosmeceuticals and speciality products

The ‘ceuticals’ market includes a very diverse range of natural products used in small volumes but commanding very high market values. Spending on personal care and cosmetic products is growing steadily globally, with a 2 per cent share of global personal care product sales for natural and organic products. Rising average life expectancy in developed countries has led to an increase in the popularity of anti-ageing products. Furthermore, exotic natural ingredients have strong marketing power and can command a premium price. Research is being conducted into novel functional ingredients from a range of sources and this includes compounds such as mycosporine-like amino acids, terpenes and carotenoids, tocopherols and pyrenoin. All of these compounds are being investigated for photoprotective effects – in other words as sunscreen ingredients – or as antioxidants.

There are three main routes by which products to enter the cosmetics market: as raw materials; as bulk extracts for formulation; and as specialised functional ingredients. Each of these is associated with a different size of industry. Small businesses with innovative products based on raw materials (e.g. seaweed soaps) may provide local employment and there may be potential for acquisition by larger entities if the product is promising. Cosmetic ingredient suppliers are increasingly interested in non-petrochemical-derived surfactants, so that products can be labelled ‘natural’.

Neutraceutical and cosmeceutical products cover a wide product range and application area, which can include everything

Table 3.1 Examples of current nutraceuticals, cosmeceuticals and speciality products of marine origin

Product	Source/origin	Target market sector	Market size
Hydrocolloids: agar > €150 M, carrageenan & agarose	Macro-algae	Food, cosmetics, pharma & research products	ca \$2 bn ^[1] ; ca \$4.5 bn ^[2]
Carotenoids : astaxanthin (ca \$260 m); β - carotene (ca \$250 m); lutein (ca \$190 m); canthaxanthin (ca \$150 m)- <i>majority synthetic</i>	Micro-algae	Nutraceuticals & foods	\$1 bn ^[1]
Essential fatty acids and oils ('omega-3') fish oil products 75%	Micro-algae & fish	Nutraceuticals & foods	\$1-1.5 bn ^[2]
Chitosan, glucosamine supplements	Crustacea	Nutraceuticals	\$2 bn ^[3]
Anti-oxidants and other functional ingredients	Micro-algae, Macro- algae	Cosmetics & personal care	>\$700 m ^[1] ; >\$20 bn ^[2]

[1] = ingredients; [2] = direct use for food; [3] = products containing these ingredients; data from a wide range of sources.
Source: modified from Lloyd-Evans (2010)

from antioxidants and flavour ingredients to ingredients in cosmetics, personal care products and food ingredients (Table 3.1). These types of products are sold on the basis of their effect during use, and their value can depend on the application area. Some types of animal feed ingredients will also fall into this category, particularly where the ingredient has a direct impact on the end product and its markets. For example, the pigment astaxanthin is included in salmon feed to give the flesh its pink colouration. Products in this category have a price of US\$5/kg to \$1,000/kg, with market volumes ranging from 1,000 tonnes to 100,000 tonnes. Naturally derived products may carry a premium over synthetic alternatives, especially where there are tangible or even just perceived performance benefits. At the high-value end of the scale, both large multinationals and SMEs invest heavily in R&D, products and biotechnological approaches to the transformation and/or recovery of 'value-added' speciality products; for example, fish protein may be treated with particular proteinases to produce specific emulsifiers, surfactants, flavourings and pharmaceuticals (Haard et al. 1994).

There is an expanding market for macro- and micro-algal products for use in personal care, and there is potential for adding value, especially if locally produced ranges include regionally sourced/grown material feeding into the organic, natural and 'free from' markets. Products can range from simple dried seaweeds for home baths to high-value spa and cosmetics ranges such as the Blue Lagoon products from Iceland.¹ Much of the evidence for the efficacy of these types of products is anecdotal and many are marketed on the basis of traditional uses. This has led the market leaders to invest substantially in R&D to substantiate efficacy. This in turn justifies the image these products have as high-value products.

3.1.3 Added-value commodities

Added-value commodities sit in a middle ground. They can sell at a premium over energy and feed products and can include commodity chemicals – such as lactic acid, a precursor for a variety of products including bioplastics and de-scaling soap scum; polyhydroxyalkanoates, a form of bioplastic produced naturally by certain bacteria; and butanol, a biofuel that also has solvent properties – with prices ranging from US\$1,000 to \$5,000 per tonne. They must compete on terms of price within an open market with multiple producers and with their fossil counterparts. This means that their selling price is critical; there may be a small premium for an environmentally friendly bio-based product, but this will depend on the product's end market. In addition, market volumes need to be taken into consideration and these can range from hundreds of thousands of tonnes to tens of millions of tonnes.

3.1.4 Base commodities

These include energy and animal feed products with prices in the range of US\$1/kg. Energy products include liquid biofuels, such as fatty acid methyl ester (biodiesel), ethanol and jet fuel, and biogas from anaerobic digestion (AD). AD is a biological process and involves a set of bacteria breaking down waste organic material to produce methane gas and also potentially a liquid fertiliser. The current bioethanol price is around US\$670/tonne and the base price of biogas is equivalent to that of natural gas (1.5–5 p/kWh over the past two years). Prices for animal feed are between US\$70/tonne and \$1,600/tonne, on a

dry weight basis, with pricing dependent on nutritional value. In addition to saleable products, this part of the value pyramid includes the bioremediation of wastes, most notably carbon dioxide, organic waste and wastewater. Marine organisms also have the capacity to degrade organic pollutants and produce biopolymers and surfactants for use in environmental waste management.

3.2 Fucodian: An example of commercial potential

Fucoidan is a sulphated polysaccharide found mainly in various species of brown micro-algae and brown seaweeds. It has been reported to have potentially beneficial bioactive and anti-cancer functions for humans (Aisa et al. 2005). However, these capabilities may take many years to develop commercially because of the need to undertake comprehensive scientific research to prove its efficacy and fulfil all the regulatory requirements that must be met before new pharmaceuticals can be launched. More readily commercialisable is the use of the material as an ingredient for personal care products (Table 3.2). Fucoidan has been associated with inflammation modulation and immune system stimulation, as well as greater cardiovascular health, and it has a current market value of US\$1,200/kg. One company currently marketing this material as a component of their product range is UNA skincare.² These

Table 3.2 Commercial opportunities to exploit fucoidan versus investment level and complexity of development

Market opportunity	Complexity/regulatory issues	Estimated investment*	Time from concept to market*
Soaps & non specialist personal products	Low/minimal	\$10 ks	<1 Year
Mid range personal care products	Medium/H&S data required	\$10 ks–\$1 M	1–2 Years
Speciality personal care products	Medium-high/Both safety data & efficacy data needed	\$500 k–\$ Ms	2–5 Years
Cosmeceutical/ pharmaceutical interface products	High/Need to adhere to regulatory framework	\$1 M–\$ Ms	2–30 Years

*These figures are estimates based on the authors' experience, not published data.

products were derived from the original scientific research undertaken by the Icelandic R&D company Matis, with the subsequent product and process development being undertaken by a spin-out company, Marinox. This has led to collaboration with an Irish company, Marigot Ltd, and the creation of 15 new jobs in the small town of Stykkishólmur in north-west Iceland, where the algae from which the products are derived are grown, harvested and processed. As can be seen from this example, the route from concept to marketed product may be complex, involving a wide range of actors, specialist knowledge and international collaboration.

Endnotes

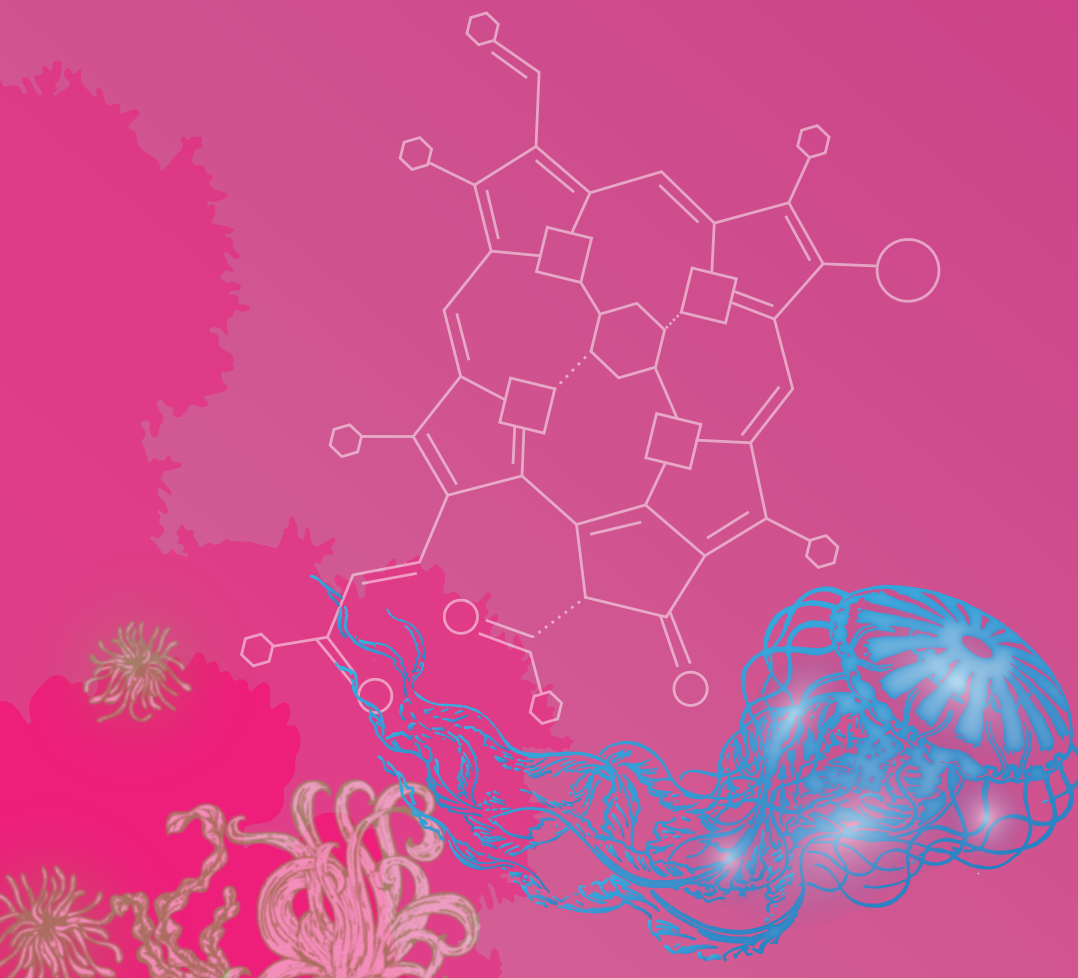
- 1 www.bluelagoon.com/shop/
- 2 www.unaskincare.com/en/

References

- Aisa, Y, Y Miyakawa, T Nakazato, H Shibata, K Saito, Y Ikeda and M Kizaki (2005), 'Fucoidan induces apoptosis of human HS-sultan cells accompanied by activation of caspase-3 and down-regulation of ERK pathways', *American Journal of Hematology* Vol. 78, 7–14.
- Greer, D and BJ Harvey (2004), *Blue Genes: Sharing and Conserving the World's Aquatic Biodiversity*. (Earthscan and the International Development Research Centre, London and Ottawa, 2004). 246 pp.
- Haard, NF, BK Simpson and ZE Sikorski (1994), 'Biotechnological applications of seafood proteins and other nitrogenous compounds', in Sikorski, ZE, BS Pan and F Shahidi (eds) *Seafood Proteins*, Chapman & Hall, New York, 194–216.
- Lloyd-Evans, M (2010), 'Out of the blue', *Chemistry & Industry*, Issue 2. Available at: www.soci.org/chemistry-and-industry/cni-data/2010/2/out-of-the-blue. Accessed 4 April 2016.
- Tufts Center for the Study of Drug Development (2014), 'Cost to develop and win marketing approval for a new drug is \$2.6 billion', news release. Available at: http://csdd.tufts.edu/news/complete_story/pr_tufts_csdd_2014_cost_study. Accessed 4 April 2016.

Chapter 4

Enabling Conditions



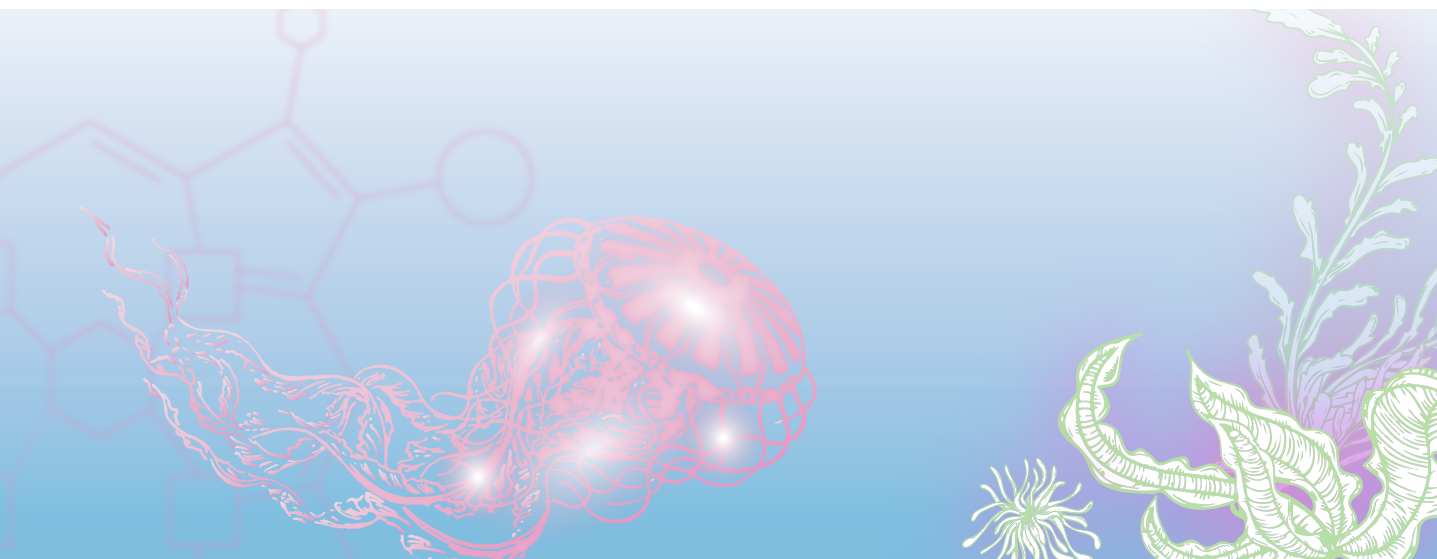
Chapter 4

Enabling Conditions

The following section cannot in itself provide a template with which a future sustainable, high-value biotech sector can be built; however, it aims to raise a number of points that are important to ensure that value is obtained from the resources available. In addition, a number of models are suggested, based on the authors' perception of international best practice, that could apply to developing and sustaining biotech activity in any given SIDS.

4.1 Ownership of biological resources

The Nagoya Protocol applies to genetic resources that are covered by the Convention on Biological Diversity (CBD) and to the benefits arising from their utilisation. Furthermore, the Nagoya Protocol also covers traditional knowledge associated with genetic resources that are covered by the CBD and the benefits arising from their utilisation. This is enshrined in international law, but it is the tools and mechanisms to assist in implementation that are key to ensuring that value accrues to the economies of individual SIDS. Some developing countries, such as Kenya, have comprehensive mechanisms that manage the process (in Kenya's case, the National Environment Management Authority). However, the relatively high costs, lack



of clarity and complexity of the procedures have the potential to result in non-compliance, and it has been suggested that ‘in its current state, Kenyan ABS (Access and Benefit Sharing) legislation creates hurdles to access rather than facilitating it’ (Kamau, 2009). In addition, high-profile disagreements – such as the Kenyan Wildlife Service threatening to launch a claim against Genencor, alleging that the enzymes IndiAge Neutra® and Puradax®, which are used to stonewash denim, were illegally obtained from the Kenyan soda lakes (Barnett, 2004; Sheridan, 2004) – may reduce interest in bioprospecting and damage relationships that could be mutually beneficial. Most SIDS have the advantage of a smaller, tighter and politically better-connected group of people who will have responsibility for the development of the blue economy. The Nagoya Protocol’s success in the context of any individual SIDS will depend on effective implementation at the domestic level. A range of tools and mechanisms provided by the Nagoya Protocol will assist in this process, including establishing a national focal point and a competent national authority to serve as contact points for information, grant access and cooperate on issues of compliance. In addition, structures and expertise will need to be developed with respect to access and benefit-sharing to facilitate equitable sharing of any income that may be derived from materials exploited. Concerns about bio-piracy should not be allowed to prevent the development of the sector, and it is strongly advised that a clear and simple process, as well as managing the expectations of end users of the potential for accruable benefits, will be key to the success of the exercise.

4.2 Bioprospecting options

Although the focus of many is at the high risk, high return end of the scale (i.e. interest in novel pharmaceuticals), the suggestions below could equally be applied in the context of exploring materials for cosmeceuticals, nutraceuticals or other naturally derived materials. The objective must be to add as much value as possible to the process by moving the biological resource along the development pipeline (see Figures 1.2 and 1.3) in order to increase any financial return from products developed. It is not practicable or feasible for any SIDS to develop a large-scale pharma sector alone. However, this is achievable by building strategic alliances and working with international partners (academic institutions, SMEs and/or

big pharma) to feed materials into a biodiscovery pipeline. An interesting relevant model is the approach developed for bioprospecting in the High Arctic in Canada between Nunavut Tunngavik Inc., owned by the indigenous Inuit people, and the University of Prince Edward Island, with its commercial partners Nautilus Biosciences Canada and Croda International. Under this agreement, laboratory facilities were established in the High Arctic and staff employed and trained to undertake fieldwork, collect samples, isolate and cultivate target organisms and feed samples into the biodiscovery pipeline. Furthermore, a precedent-setting agreement has been developed to share any profits from bioprospecting finds in Frobisher Bay.

At the upper end of the range of objectives of this type of bioprospecting is finding a cancer drug that can generate billions of dollars; this is, realistically, a 'long shot'. However, finding an organism that could be used in cosmetics is more likely, and this could generate tens of thousands of dollars. Clearly, the statistical likelihood of an individual organism having economic potential is low, so intelligent and informed screening approaches that target the product of interest should be employed. This type of work could be undertaken in any SIDS by appropriately trained local support scientists. This upskilling would hopefully be the first stage in providing a pool of skilled workers who could sustain and ultimately drive the development of locally owned biotech SMEs.

4.3 Facilitation of research and entrepreneurship

The vision of blue economy biotech activity is inextricably linked with the development of a local, entrepreneurially active biotech community. A variety of tax incentives, training initiatives and infrastructural investments, etc., could help to facilitate this, but a key aspect is the development of a focus for relevant scientific activity. There are a variety of options that could be explored, including university, research institute or science park models, but all have at their core public sector investment. A way forward has been successfully developed in Iceland. This is the government-owned, independent research company Matís. This company was founded in 2007 following the merger of three former public research institutes; it pursues R&D aligned with the food and biotechnology industries as well as providing Iceland's leading analytical testing service for public and private

authorities. In addition, Matís hosts a variety of micro-companies that use the scientific, lab and administrative facilities of the host, which is often a shareholder in the micro-business. This model allows individual scientists and technicians to work within the laboratory for more than one company, thus maximising the benefits of expertise and experience within the small biotech community. It also provides critical mass and allows the company to work globally with academia and others in the commercial sector. Although an organisation the size of Matís (which currently has a staff of around a hundred) may not be achievable in the smaller SIDS, this model, potentially in association with a centralised biological resource centre (BRC) (see section 4.4), could, with 10–20 staff, create the critical mass to provide the momentum needed to establish a sustainable biotech sector. An extension of this concept is the development of a biotech incubator on the campus of a local university or higher education institution (HEI), where facilities and expertise could be shared and international links exploited.

4.4 Developing a centralised biological resource centre

The focus of this section is specifically on micro-organisms; however, the underlying issues may be relevant to other marine and terrestrial materials. Irrespective of the product and/or process that may be developed, the security of the biological resource from which they have been developed is of key importance. Any biodiscovery pipeline or other biotech applications that will be developed have as the key component of their function living material. To isolate and purify these organisms will have had significant financial implications and, for sustainable use and/or study, they need to be conserved. Re-isolation of the biotechnologically exploitable organism from the environment is technically problematic, as well as adding unnecessary cost, and trusting to unregulated maintenance of the organisms beyond local control cannot guarantee biological or contractual security. The establishment of a local collection facility would provide a resource that could be exploited nationally or internationally and could form a foundation for future biotechnological exploitation. The establishment of a BRC has significant long-term financial implications; however, the benefits could be significant should potential be realised from the organisms held. A valid and potentially beneficial way

forward would be for SIDS to develop this type of facility on a regional basis in association with other SIDS.

4.5 The SIDS' brand

Biotechnological exploitation, high-tech or low-tech, ultimately depends on there being a market for the product or process and its being commercially viable. A SIDS' 'brand' may be able to contribute to the commercial viability of a product by communicating values such as prestige, high quality, natural, pure, unspoiled. Whereas the production of some biotech products, such as bulk chemicals and pharmaceuticals, may not be practicable, because of lack of land availability, investment or infrastructure, the production of niche products such as cosmeceuticals and nutraceuticals could be commercially viable. These would benefit from exploiting the local SIDS' brand to connect to international markets. This approach has been successful in Iceland (Box 4.1), where cosmetics (skincare products and treatments) based on Icelandic algae grown in photo-bioreactors are marketed with reference to the 'natural purity' and 'healing power' of the Blue Lagoon. Niche products, based on biological resources from an individual SIDS, developed, produced and marketed worldwide, provide a realistic opportunity to generate high-value jobs and diversify the economy of the country.

Box 4.1 The Icelandic model – realising the potential of extremophiles

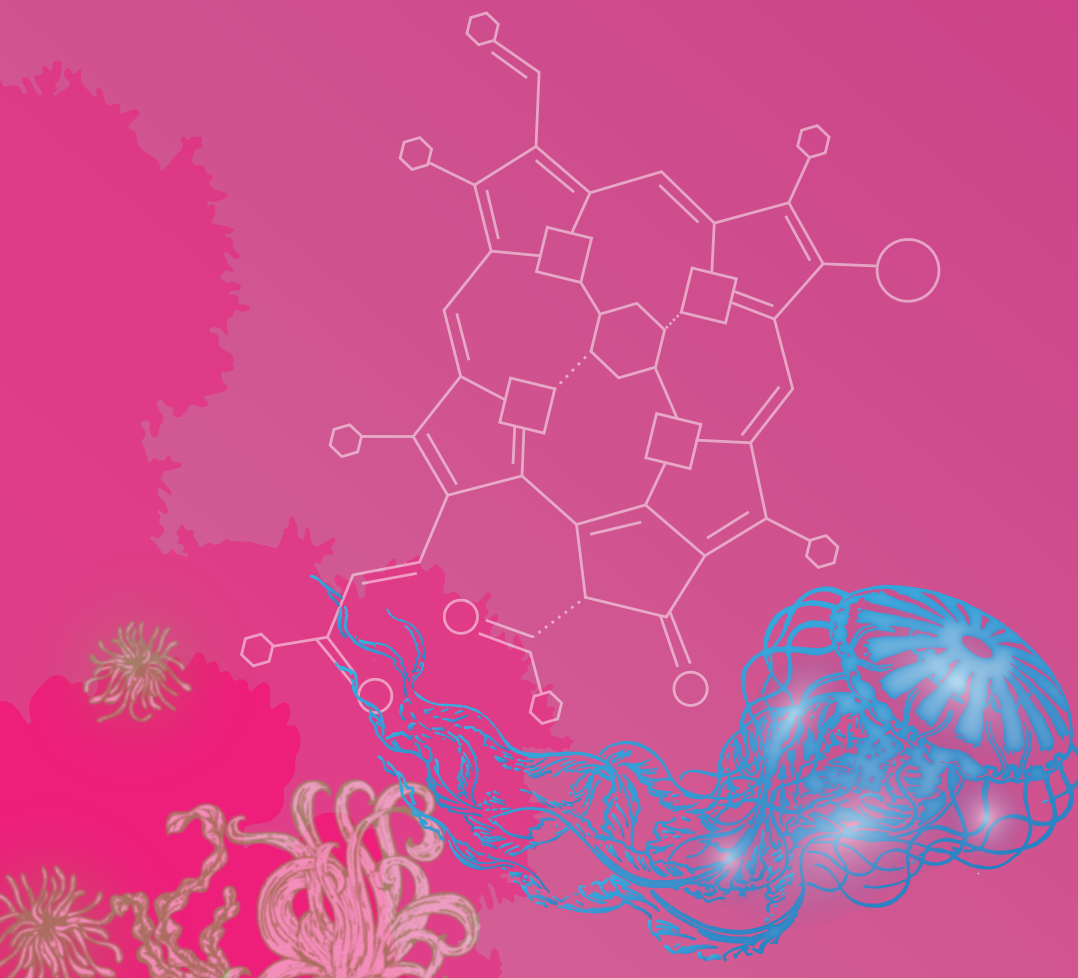
Iceland, with a population of approximately 330,000, has many parallels to SIDS; however, it has carved out a world-class biotechnological niche in the exploitation of microbes from extreme environments including marine and terrestrial geothermally heated water bodies. How has this been achieved? As in SIDS, the nature of the environment in Iceland has historically fostered a tendency to be entrepreneurial and make the best use of the resources available. This mindset, the existence of extreme environments and investment in academic research were the starting points for the process. Subsequently, public funding – facilitating the development through an innovative model combining academic and business of core facilities – has established critical mass and a platform for the creation of further SMEs and micro-businesses. Critically, international academic and commercial collaborations have played important roles in fundamental research and in process and product development. The combination of the abovementioned developments with the availability of a skilled workforce, as well as an international outlook with respect to research, development and marketing, lie at the core of the success of the Icelandic model.

References

- Barnett, A (2004), 'Multi-million bio-piracy lawsuit over faded jeans and African lakes', *The Observer*, 5 September 2004.
- Kamau, EC (2009), 'Facilitating or restraining access to genetic resources? Procedural dimensions in Kenya', *Law, Environment and Development Journal*, Vol. 5, 152. Available at: www.lead-journal.org/content/09152.pdf. Accessed 4 April 2016.
- Sheridan, C (2004), 'Kenyan dispute illuminates bioprospecting difficulties', *Nature Biotechnology*, Vol. 22, 1337.

Chapter 5

Conclusion and Recommendations



Chapter 5

Conclusion and Recommendations

5.1 Conclusions

There are numerous opportunities for SIDS to explore and eventually recover economic value from the biotechnological potential of their marine resources. The model adopted by any individual SIDS will depend on investment, available skills and infrastructure, as well as political leadership. All of these factors and ownership/‘buy-in’ by local stakeholders are critical to a successful transition from ‘business as usual’ to a truly blue economy (Figure 5.1). There are technological hurdles that need to be overcome, but international collaboration with subsequent local capacity development could result in both wealth creation and diversification of the economy, for some SIDS this will necessitate a bottom up building of the biotech sector, for others it may involve the tactical expansion and linking of existing academic, SME and intra-structural actors and organisations.

5.2 Recommendations for fostering the development of blue biotechnology

Listed below are a variety of strategic-level recommendations that could assist in the development of blue biotechnology in an individual SIDS:

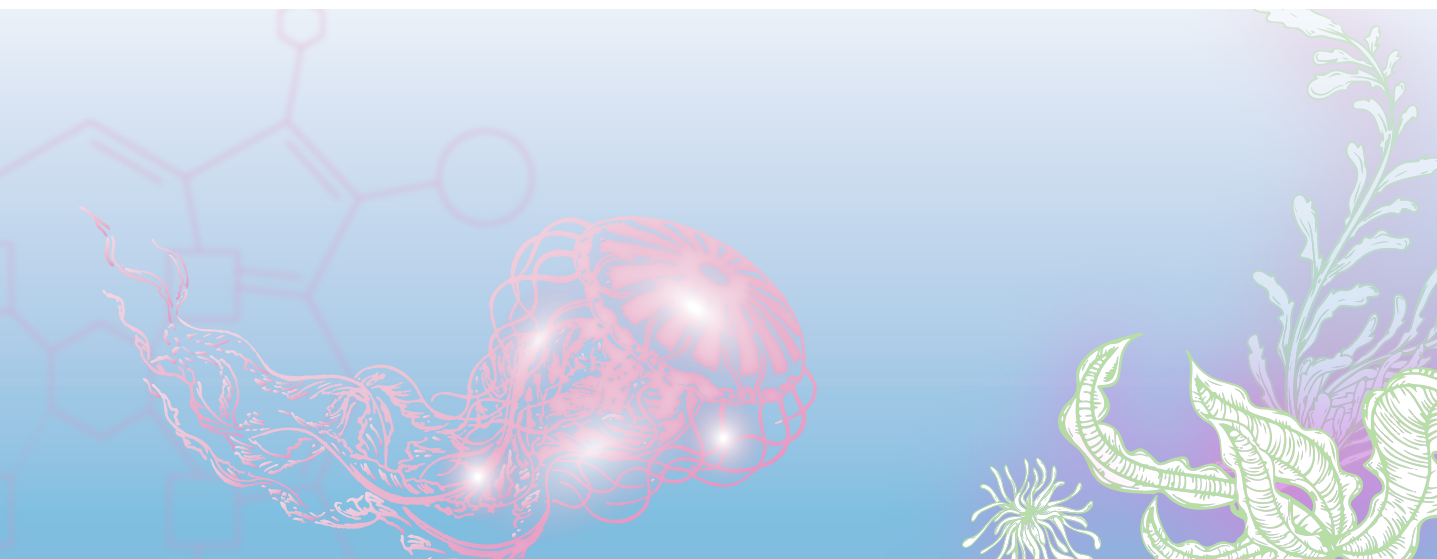
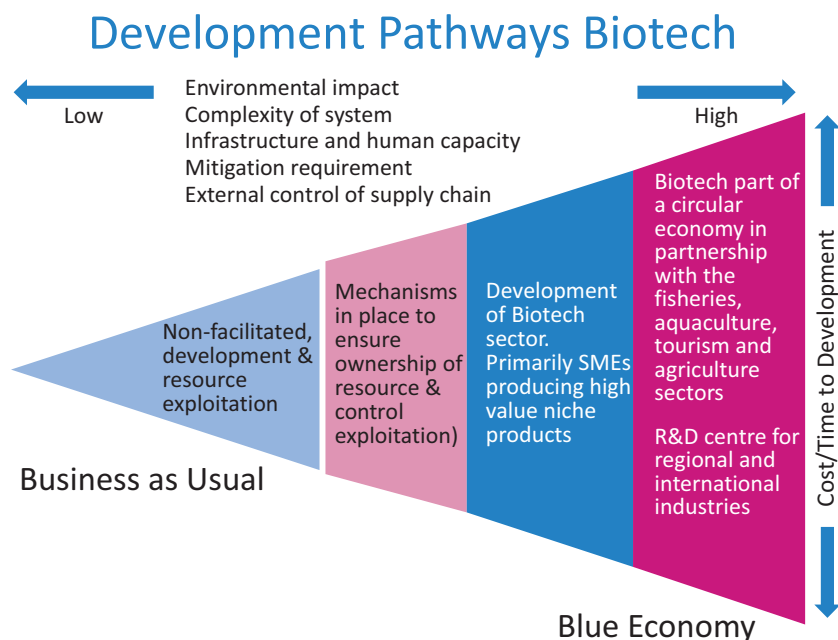


Figure 5.1 Transition from economic 'business as usual' to a blue economy



- **Initial sectoral prioritisation:** Focus on niche products, based on local biological resources, developed, produced and marketed worldwide. Although bioprospecting for pharmaceuticals is a possible option with the involvement of external partners, niche products, based on biological resources, developed, produced and marketed worldwide from any SIDS, provide a more realistic opportunity to generate high-value jobs and diversify the economy of the country.
- **Scientific exploitation:** Existing data should be systematically explored to inform and steer any future bioprospecting activity,
- **Biological resource management:** Ensure effective and simple implementation of the Nagoya Protocol's recommendations and establish a local biological resource facility. The establishment of a local collection facility will provide a resource that can be exploited nationally or internationally and form a foundation for future biotechnological exploitation.
- **Development of critical mass:** Develop a government-owned, or locally resourced, public-

private independent research company as a focus for activity; build strategic alliances with national and international commercial and academic partners.

Blue growth is the only long-term strategy capable of supporting sustainable growth in the marine and maritime sectors as a whole and, although blue biotechnology is an important component of this, it is inextricably linked to other economic activities in the marine space, including mariculture, tourism, conventional fisheries, etc. Therefore, there is a need to holistically facilitate the development of the blue economy concept as a whole, and the overarching recommendations below (section 5.3) complement and reinforce the sector-specific recommendations outlined above.

5.3 Blue economy implementation

Practically, the blue economy model cannot be implemented in SIDS under a ‘business as usual’ scenario. There need to be fundamental changes to facilitate the development of new economic sectors and to ensure their sustainability. Inevitably, this will be an evolving process requiring collective dialogue on the merits and economic and social benefits, as well as the potential negative effects, of implementation at the local scale. Listed below are additional recommendations that address the full range of factors that need to be in place to implement a robust, successful blue economy.

5.3.1 Financing

Public-led partnerships with the private sector are essential to provide initial capital for novel project development, with longer-term risk-sharing mechanisms to maintain investor interest. Economic modelling could be used to understand the likely costs and feasibility of diversification options before investing resources. Locally generated or internationally awarded funds could be allocated to specific projects through a specific fund for blue economy activities.

5.3.2 Policy landscape

Use blue economy initiatives to rationalise a complex policy landscape and develop clear action plans.

5.3.3 Indigenous skilled capacity

In some SIDS, the lack of indigenous skilled workers has been highlighted as a problem for developing new and expanding existing sectors. This is a strategic issue that must be rationalised across the blue economy, rather than within individual sectors, with prioritisation according to the most desirable and feasible applications.

5.3.4 Scientific research capacity

It is internationally agreed that key components of the successful implementation and development of the blue economy are research and international collaboration. If the information is not currently available, a national study into capacity for research and international collaboration should be undertaken, ensuring that, in addition to technical skills, it also considers social science and entrepreneurial aspects relevant to the development of and local ownership of blue economy activity.

5.3.5 Scientific research strategy

A coordinated research and development strategy is needed to address specific sector requirements and the broader implementation of the blue economy. This should involve local HEIs and non-governmental organisations, as it is vital that local knowledge capacity is increased in parallel with ownership of development of the blue economy. With regard to research, the science needed to support transitions to sustainability is necessarily trans-disciplinary, engaging social scientists alongside technical science, particularly to understand and increase the role of the civil society. The momentum of the United Nations Educational, Scientific and Cultural Organization (UNESCO), and in particular its strategy for enhancing island resilience through quality education, education for sustainable development, human resource development and institutional capacity-building (UNESCO, 2014), provides an excellent basis for establishing actions to enable SIDS to proactively transition to sustainable development.

5.3.6 Mobilising critical mass

Capacity-building, effective international networking and collaboration, and skills transfer from foreign academic

organisations and technology providers, in addition to regional cooperation, are crucial because of limited in-country resources. To be sustainable, the sectors that are developed need critical mass. This can result in local synergies, sharing of resources and enhanced capacity to add value. Moreover, international interaction will invariably be easier and more equitable. A standard approach, used internationally to facilitate the creation of such a critical mass, is the development of technology incubators, science parks, etc.

5.3.7 Investing in, and expanding, the SIDS' brand

There are significant marketing advantages in using a SIDS' existing positive brand image, linking this to the blue economy and ecological sustainability. Before products reach market, this approach could be used to enhance product desirability to customers and thus the market value and economic return generated.

Reference

UNESCO (2014), *Islands of the Future: Building Resilience in a Changing World*.
Available at: <http://unesdoc.unesco.org/images/0022/002245/224512e.pdf>.
Accessed 4 April 2016.

Glossary

Allophycocyanin is an intensely bright pigment with commercial applications that is isolated from red algae and cyanobacteria.

Amino acids are organic compounds that serve as building blocks for proteins.

Anaerobic digestion is a biological process that involves a set of bacteria breaking down waste organic material to produce methane gas and also potentially a liquid fertiliser.

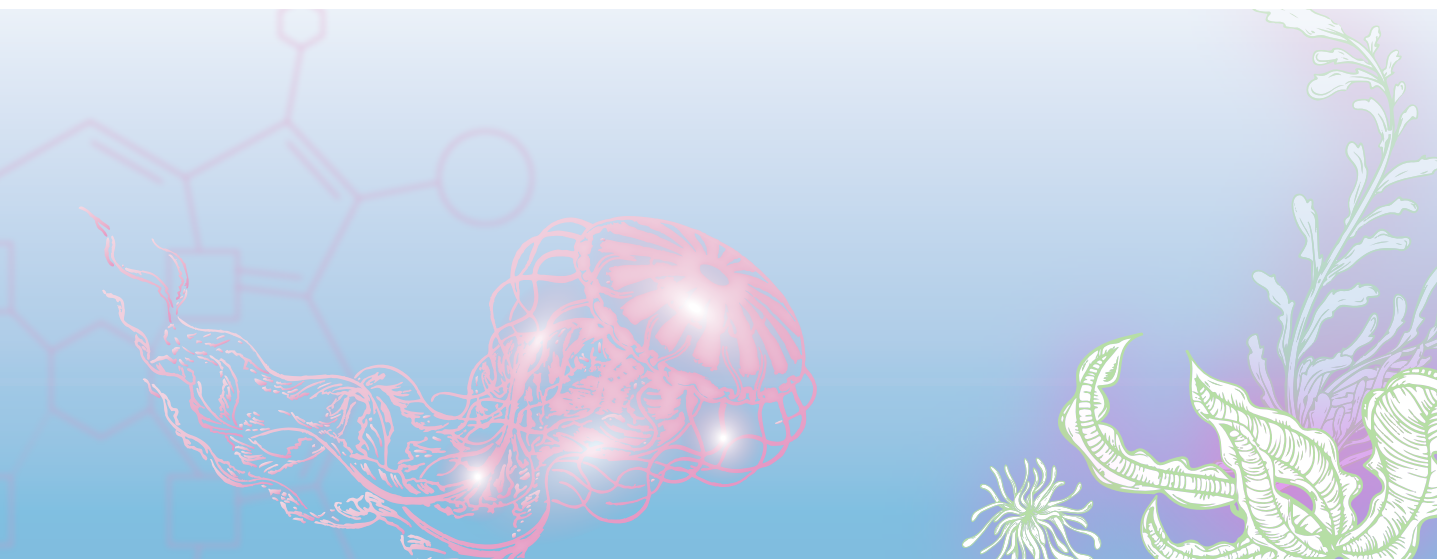
Aquaculture is the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants including algae.

Bioprospecting can be described as a systematic search in marine organisms from the sea, along the coast, the seabed or beneath the seabed.

A **biorefinery** is a facility that integrates biomass conversion processes and equipment to produce fuels, power and chemicals from biomass.

The **biosphere** is the global sum of all ecosystems.

Carotenoids are organic pigments that are found in the chloroplasts and chromoplasts of plants and some other photosynthetic organisms, widely used as colourants and antioxidants.



Cosmeceuticals are cosmetic products with biologically active ingredients purporting to have medical or drug-like benefits.

Cyanobacteria are bacteria that obtain their energy through photosynthesis. They have commonly been considered to be algae and were historically called 'blue-green algae' because of their distinctive colour.

Extremophiles are organisms, generally micro-organisms, that can thrive in extreme conditions of temperature, pressure or chemical concentration, such as in very hot, salty environments, that are unsuitable for, or may be lethal for, the vast majority of organisms.

Functional foods are foods with health benefits that go beyond their basic nutritional value.

Genencor is a biotechnology company based in Palo Alto, California, and a subsidiary of DuPont. Genencor is a leading producer of industrial enzymes and low-priced bulk protein.

Mariculture is a specialised branch of aquaculture involving the cultivation of marine organisms for food and other products in the open ocean, in an enclosed section of the ocean, or in tanks, ponds or raceways that are filled with seawater.

Metabolites are the intermediates and products of metabolism. The term **metabolite** is usually restricted to small molecules.

Mycosporine-like amino acids are small secondary metabolites produced by organisms that live in environments with high volumes of sunlight, with potential applications as sun-screening agents.

Nutraceuticals are products that range from isolated nutrients, dietary supplements and herbal products to foods for specific diets and processed foods such as cereals, soups and beverages.

A **peptide** is a molecule consisting of two or more amino acids. Peptides are smaller than proteins, which are also chains of amino acids.

Photo-bioreactors are bioreactors (i.e. specialised culturing systems) that utilise a light source to grow algae.

Polyhydroxyalkanoates are linear polyesters produced in nature by bacterial fermentation of sugar or lipids.

Pyrenoine is a cosmetic agent from the brown algae *Fucus*, with antioxidative properties suitable for anti-ageing and skin-protection products.

Terpenes are a class of hydrocarbons occurring widely in plants and animals, with wide-ranging activities.

Tocopherols are a family of vitamin E compounds naturally found in plants.

