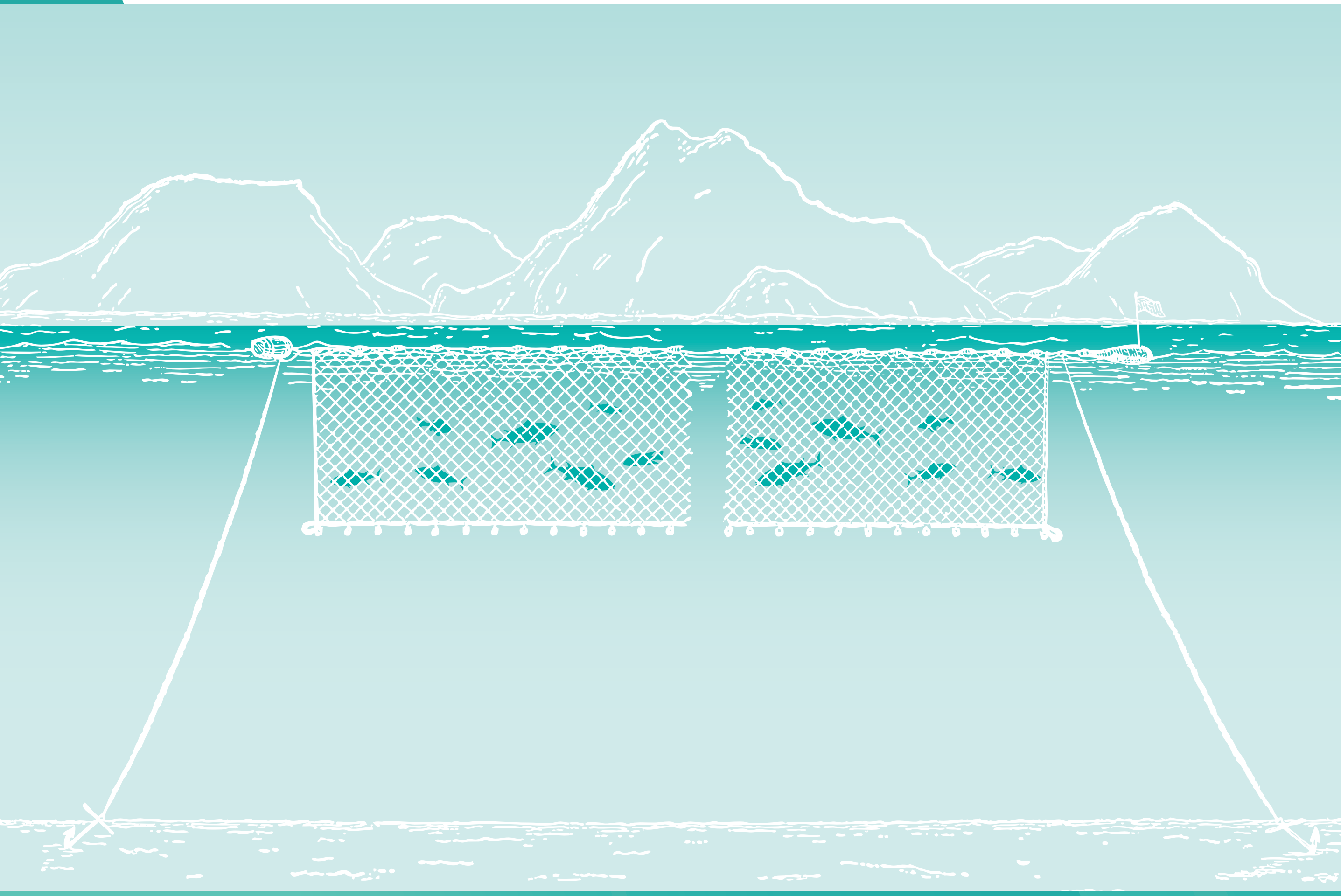
Aquaculture

Commonwealth Blue Economy Series, No. 2



The Commonwealth

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Commonwealth Secretariat

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Contents

Acronyms and Abbreviations

CBA	community-based aquaculture
DPSIR	Driving forces – Pressures – State – Impact – Responses
EAA	ecosystem approach to aquaculture
EEA	European Environment Agency
FAO	Food and Agriculture Organization of the United Nations
IMTA	integrated multi-trophic aquaculture
MSI	Mariculture Sustainability Index
SIDS	small island developing state(s)
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. Since 2012, 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 second volume in the series explores the potential for the development of a blue economy mariculture industry, as well as specific enabling conditions that could assist in moving towards economic reality where opportunities exist.

Recommendations focus on ensuring sustainability of a mariculture industry by exploring options and opportunities for:

- **Using existing frameworks for sustainable mariculture development**
  Any aquaculture development should use the ecosystem approach to the development of an aquaculture framework.
- **Developing a stepwise approach to capacity development**
  Especially for those SIDS without an existing aquaculture industry, it would be beneficial to start at the low-complexity end of the spectrum of development and to allow the aquaculture industry to grow organically (supported by government investment) and to move up the complexity spectrum as local capacity and infrastructure develop.
- **Coherent cross-policy activity**
  The blue economy framework should be used to assist in the development of clear action plans and activities should be rationalised under different policy initiatives.
- **Developing indigenous skilled capacity**
  Local capacity should be addressed as a strategic issue requiring co-ordination 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 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.

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 for a number of years at the forefront of promoting the blue economy as a holistic concept that can address sustainable development at multiple levels. 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 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.

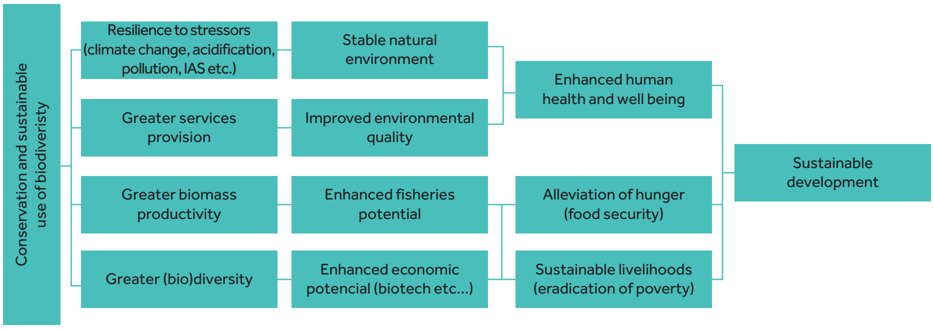
The scope of the blue economy therefore includes activities that:

- 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 (or the benefits) of national wealth 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 all humanity. It is, therefore, inappropriate to continue with 'business as usual' and to simply rebadge 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 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

Figure 1.1. The blue economy



Source: UNCSD, 2014.

disposal of waste; instead, it shifts the focus so that ocean values and 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.

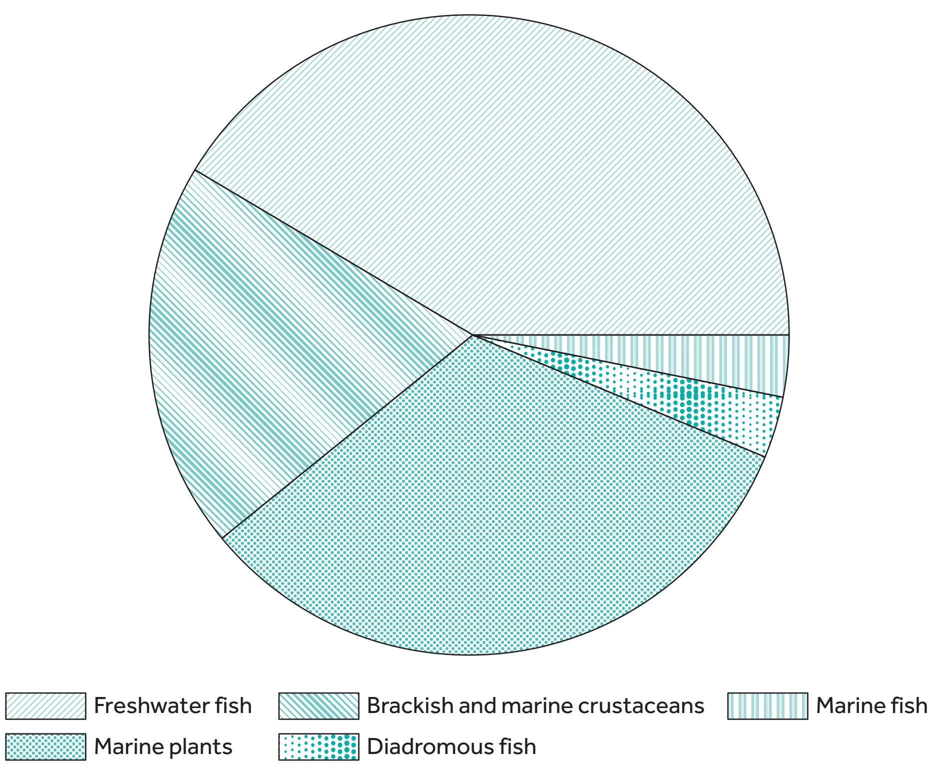
The blue economy will incorporate ocean values and services into economic modelling and decision-making processes, thereby helping SIDS and other maritime developing countries address equity in access to, development of and the sharing of benefits from marine resources. Optimising the benefits received 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 resources. 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 Aquaculture in small island developing states

Seafood and fisheries have traditionally been crucially important for the food security of SIDS. For some SIDS, seafood and fishery products represent the primary source of animal protein for the local population. This dependence is a function both of rich and abundant marine resources and of limited terrestrial space for crop and livestock production. Seafood is not only an important source of protein, but also a crucial source of many of the trace minerals and nutrients that are essential for human health, such as selenium, zinc and omega three oils. Traditionally, food from the sea has been hunted and collected from the wild, relying on the natural productivity of our oceans to meet growing demand. However, global fisheries have reached capacity, with 77 per cent of global fish stocks at or above their sustainable limit. In response to the decline in availability of wild-caught fish, there has been a massive expansion in the farming of fish and shellfish (including freshwater fish), known as aquaculture. This development of the aquaculture industry has been so rapid that aquaculture is now the fastest-growing food production sector in the world, and more than half of all the fish and shellfish we now consume is produced through aquaculture. It has been predicted that this will rise to 65 per cent by 2030. The majority of this production is based in Asia; however, there is a relatively long history of aquaculture in SIDS, dating back to the 1970s.

There are three current major sectors in SIDS aquaculture: freshwater fish; brackish water and marine crustaceans; and marine plants (Figure 1.2). Freshwater fish production is

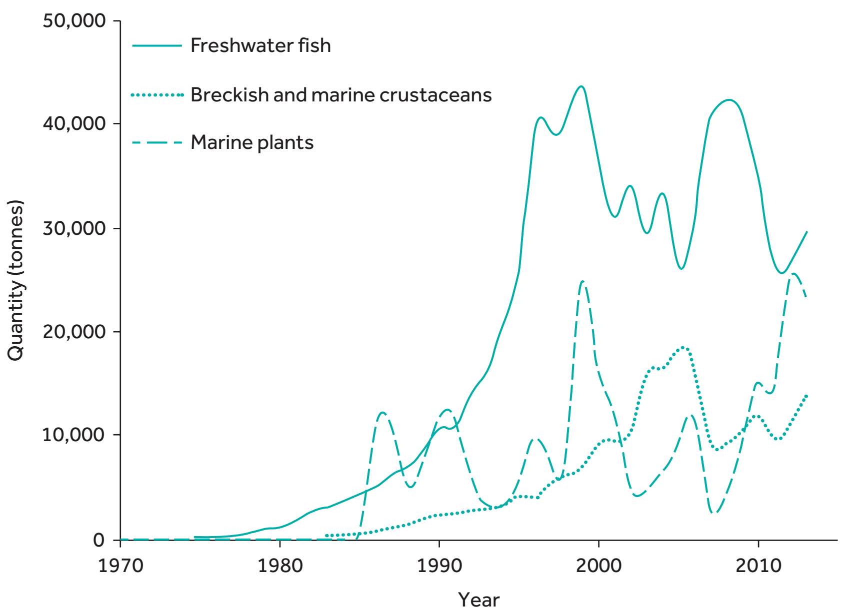
Figure 1.2. The current key species groups currently being produced in SIDS



dominated by silver carp (*Hypophthalmichthys molitrix*), which is a species native to China and reared in inland ponds. Marine crustacean production is dominated by white leg shrimp (*Litopenaeus vannamei*), which is produced in brackish or fully saline ponds. Seaweed production is dominated by red algae, predominantly *Euchema* species, which are native to the Philippines (and have been introduced to SIDS for the purpose of aquaculture); red algae is cultured in shallow subtidal areas. Current and past aquaculture development within SIDS has been based on the import of non-indigenous species and has been dominated by freshwater pond cultivation.

Figure 1.3 shows the historical trend of aquaculture development in SIDS, with freshwater fish aquaculture commencing in the late-1970s and expanding to around 30,000 tonnes of production by the mid-1990s. The growth in brackish water and marine crustacean production has been relatively steady since the mid-1980s, to around ca. 18,000 tonnes, but it declined in the late-2000s to just above 10,000 tonnes. Marine plant aquaculture production also increased in the mid-1980s, but total production has fluctuated between around 2,000 tonnes and 25,000 tonnes to the present day.

Figure 1.3. The history of aquaculture development in SIDS



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Chapter 2

Enabling Conditions

Chapter 2
Enabling Conditions

2.1 Aquaculture and the blue economy

Aquaculture clearly falls within the definition of marine resources as a development space and is listed in the '*Blue economy concept paper*' prepared for the 2014 Blue Economy Summit (Anon. 2014) as one of the seven main opportunities under the blue economy. To fulfil the criteria for the blue economy, any development in the aquaculture sector must:

1. optimise the benefits received from the development of the marine environment;
2. promote national equity, including gender equality, and in particular the generation of inclusive growth;
3. incorporate the value of natural capital in its development;
4. respect ecological parameters throughout the cycle of production;
5. create sustainable, quality employment;
6. offer high-value commodities for export.

These six criteria represent laudable aims; however, there needs to be a mechanism for taking these aims and embedding them in the operation of an aquaculture industry. The six criteria for aquaculture development within the blue economy are in line with previous attempts to understand how aquaculture development can be made sustainable, most notably the framework developed by the Food and Agriculture Organization of the United Nations (FAO) and termed the ecosystem approach to aquaculture (EAA), which is based on three principles (see below) that encompass the aspirations of the blue economy. It is the three principles of the EAA that will be used in this publication as a guide to defining what aquaculture development within the blue economy context would look like and to identifying mechanisms for the development of the aquaculture industry in line with the blue economy.

2.2 The ecosystem approach to aquaculture and the blue economy

The EAA (Soto et al. 2008) strives to balance diverse societal objectives by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems, including their interactions, flows and processes, and applying an integrated approach within ecologically and operationally meaningful boundaries (FAO, 2005) For this approach to be successful, it should be applied at a range of organisational levels, from farm to policy development. The EAA has to respond to three principles:

1. *Aquaculture should be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience capacity;*
2. *Aquaculture should improve human wellbeing and equity for all relevant stakeholders;*
3. *Aquaculture should be developed within the context of (and integrated with) other relevant sectors.*

There are clear links between the aspirations of the blue economy and the three principles of the EAA. As the EAA framework is well developed and accepted at the international level, is recommended that, when SIDS are developing an aquaculture industry within a blue economy framework, they use the EAA as the basis for that development.

It is important to remember that integration across the marine sectors is an important component of the blue economy and, when considering the three principles of the EAA, it is crucial that they are placed in the context of a wider blue economy development framework for the entire marine sector and not just for the aquaculture sector. As stated above, the EAA should be implemented at a range of scales, from the farm level to the policy development level.

2.3 Aquaculture policy development for the blue economy

For any meaningful aquaculture activity to take place, there must be a clear legal framework for the industry to exist within. This legal framework is generally located at the national level and is in line with that applicable to any other economic activity. The regulation of an aquaculture industry will typically straddle many government departments, and the legislative framework will draw upon multiple sources. If there has been previous aquaculture development within a SIDS, it is likely that this regulatory framework already exists to some extent. The framework is likely to be an amalgam of environmental, food, trade, planning, property, animal health, financial, import and public health legislation (Glenn and White 2007). Even if this is the case for a SIDS, it is crucial to understand the full range of areas that aquaculture activities encompass and that are required to be included within a comprehensive aquaculture regulatory framework (Table 2.1).

Table 2.1. Areas of aquaculture to be included within a regulatory framework (after Bermúdez 2008)

Issue	Component of the legislation
Allocation of aquaculture activity/sitting	Permitted areas Forbidden areas Interaction with protected areas Operation licence First nations/artisanal fishing communities' rights
Production systems	Monospecific Polyculture Integrated systems Environmental product and process standards Product safety and traceability Animal welfare Genetically modified organisms
Control of production volume	Restriction Restriction with specific conditions Increase of production only with previous permission
Water use	Use rights Emission standards Water quality Sedimentation models

(continued)

Table 2.1. Areas of aquaculture to be included within a regulatory framework (after Bermúdez 2008) *(continued)*

Issue	Component of the legislation
Environmental impacts	Accidental release of farmed species Disease and parasites Therapeutants and other chemicals used Transport of species Interactions with other species Waste management
Education, research and development	Training, education and awareness raising Research and development Capacity-building
Control mechanisms	Environmental impact assessment Periodic environmental reports Economic instruments Certification systems Self-monitoring Citizens' participation
Food safety	Testing and limits for bacteriological safety Testing and limits for algal toxins

If aquaculture is to be included as one of the pillars for the development of the blue economy for a SIDS, it is recommended that these different regulatory strands be brought together under a specific aquaculture instrument, and that aquaculture be included in a broader blue economy framework. The lack of an overarching and dedicated legal framework represents a significant barrier to the development of an aquaculture industry within a SIDS and can be a significant disincentive to investment. An explanation of these risks can be found in Box 2.1 (after Bermúdez 2008).

2.4 Management framework for aquaculture

If the decision is made to create a unified management framework for aquaculture within the blue economy, it will be necessary for that framework to reflect the EAA. Such a management approach must provide 'comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take actions on influences that are critical to the health of ecosystems, thereby achieving sustainable uses of ecosystem goods and services and maintenance of ecosystem integrity' (Rice et al. 2005). This approach explicitly acknowledges the link between ecological and social systems and the importance of evidence-based policy and

Box 2.1. Risks for SIDS associated with the development of an aquaculture industry in the absence of a full aquaculture or blue economy policy framework

Unclear distribution of responsibilities among national authorities: as stated above, aquaculture regulation spans many areas, and thus it may be unclear who is responsible for enacting or enforcing legislation, which may lead to poor or inconsistent implementation.

Contradictory legislation: there may be conflict between federal and state legislation or between or within national and local legislation. Where such conflict exists, it will be difficult for the aquaculture industry to comply, leading to greater expense and disincentivising investment.

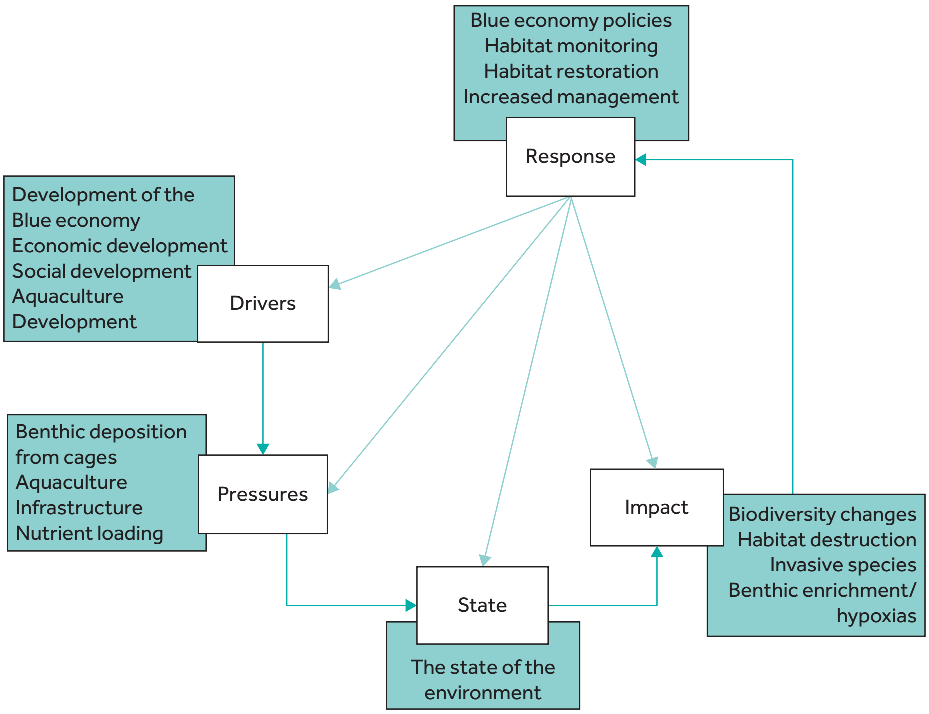
Incomplete legislation: if the expansion of the aquaculture industry has been rapid prior to the development of the blue economy/ aquaculture framework, then it is likely that the economic growth of the industry will have moved faster than the legal framework. In such a case, the industry will find itself trying to develop within a policy and/or regulatory vacuum. This could halt development or put the industry at risk of bearing the cost of complying retrospectively.

Legislation does not take into account all cultivation systems and opportunities: existing legislation may prevent the development of new production systems that are more in line with the concept of the blue economy, such as integration of operations or co-location of different marine industries.

Geographic, economic and technical limitations to law enforcement: although compliance with regulation is traditionally through mutual consent, where there is a need for enforcement there are specificities of the aquaculture industry that make this more complicated than for other industries. In the case of SIDS, these may include difficulties in accessing offshore sites, lack of technical knowledge within the regulatory body or budgetary constraints. This lack of enforcement may prevent the development of a mature and sustainable aquaculture industry, as those companies that comply may be put at an economic disadvantage compared with those that do not comply.

management. One way to ensure that this approach is integrated in the management framework is to use an aquaculture management framework that encompasses these linked ecological and social systems by recognising environmental impacts, the drivers that are causing those impacts and the appropriate responses (Cranford et al. 2012). This framework has been adopted by the European Environment Agency (EEA) and is known as the DPSIR framework. DPSIR stands for 'Driving forces – Pressures – State – Impact – Responses' (see Figure 2.1). This approach can encourage

Figure 2.1. The DPSIR management framework for aquaculture within the blue economy



Source: Cranford et al. 2012

and support decision-making, by pointing to clear steps in the causal chain, and where the chain can be broken by policy action (EEA 2007).

Within the DPSIR management framework, it is understood that social and economic development will result in increased pressure on the environment, resulting in a change in the state of the environment. This change will then have impacts such as reduced productivity or increased risks of detrimental effects to human health. These effects will in turn cause a response from society that will alter the drivers of change or the impact on the state of the environment through adaption or curative action (Figure 2.1). In fact, the development of a blue economy initiative by a SIDS will be a response to already-existing or anticipated drivers, such as the need for economic and social development. In the case of a SIDS developing a blue economy, it will already be recognised that these drivers have the potential to create pressures on the environment that could lead to a change in its state. As many SIDS are critically dependent on ecosystem services to deliver major economic value through tourism or fisheries, it is understood that a change in state will have both an economic and an environmental impact. Therefore, the adoption of a blue economy is a way for a SIDS to respond to this ongoing or anticipated change in state. The blue economy initiative allows a direct mechanism for the management of environmental pressures and monitoring of the state of the environment and the impact on it. The instruments for management will be contained within the aquaculture policy, while the response will come through feedback from regulators and stakeholders to policy-makers.

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Chapter 3

Sectoral Options

Chapter 3

Sectoral Options

In order for aquaculture activities to fall within the remit of the blue economy those activities must be in line with the three principles of the EAA, namely:

Principle 1: aquaculture should be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience capacity;

Principle 2: aquaculture should improve human wellbeing and equity for all relevant stakeholders; and

Principle 3: aquaculture should be developed in the context of other sectors, policies and goals.

These three principles can be used as guidelines to inform the development and management of aquaculture.

3.1 EAA Principle 1

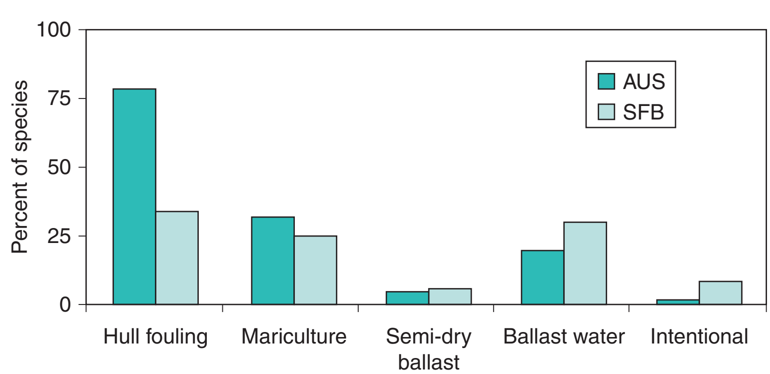
Most of the impacts of aquaculture can be managed to ensure that ecosystem resilience is not threatened, using the natural capacity of the ecosystem to recover over time. However, there are specific cases where changes caused by aquaculture will be non-linear and may be irreversible.

3.1.1 The use of indigenous species and local brood stock

Biological invasions are one of the greatest threats to marine biodiversity (Molnar et al. 2008) and are second only to habitat destruction in causing global loss of biodiversity (Wilcove et al. 1998). They also cause massive economic and ecological damage (Vitousek et al. 1997; Pimentel et al. 2005). The estimated cost to the US economy is US$120 billion a year (Pimentel et al. 2005), principally through losses in crops, fisheries, forestry and grazing capacity (Mack et al. 2000). In addition to their economic consequences, invasive species have huge ecological impacts. Biological invasions can significantly alter community structure and ecosystem function. For example, the zebra mussel (*Dreissena polymorpha*) in the Great Lakes, Canada (Johnson and Carlton 1996), the European green crab (*Carcinus maenas*) (Grosholz and Ruiz 1995) in California and green alga (*Caulerpa taxifolia*) in the Mediterranean Sea (Balata et al. 2004) have all caused the extinction of native species and completely altered the ecosystems they invaded.

Aquaculture is known to be a major cause of the introduction of invasive species into the marine environment, second only to international shipping (Figure 3.1). There are two mechanisms through which aquaculture can act as the conduit for the introduction of invasive species: through direct introduction as a species to be farmed and through accidental introduction of invasive species that 'hitchhike' on brood stock or seed/juveniles. Examples of deliberate introduction in aquaculture include the introduction of the seaweed Kappaphycus to Hawaii throughout the 1970s. It was imported in an attempt to start a seaweed

Figure 3.1. Probable mechanisms of invasion for known introduced species in Australia (AUS) and San Francisco Bay (SFB)



Source: Bax et al. 2003

farming industry in Hawaii and was placed in open reef culture sites and in pens. Initial scientific advice suggested that the seaweed would not become invasive because of a combination of the life history traits of the seaweed and the physical and biological parameters of the cultivation site. However, 25 years later (Conklin and Smith 2005) the seaweed had dispersed over a six km stretch of reef and was overgrowing the coral colonies of the reef, leading to habitat loss and a reduction in commercial and recreational fisheries.

Another good example is the introduction of the Pacific oyster (*Crassostrea gigas*) to Europe (Nehring 2006). This species was introduced in multiple locations throughout the twentieth century for aquaculture production. Where any scientific consultation took place before its introduction, it was stated that the oysters would not reproduce at the latitudes in question. However, in many locations where the oyster was introduced in Europe, it has become invasive (Figure 3.2). This has led to a displacement of native species and habitat change.

The second route for the introduction of invasive species into the environment through the activities of aquaculture is the hitchhiking of invasive species on imported brood stock or juveniles from hatcheries or producers outside the area they are being imported into. For example, of the 45 species of algae and molluscs that have been introduced to California through aquaculture activity, only 9 (20 per cent) were deliberately introduced, while the other 80 per cent hitchhiked on imported

Figure 3.2. Reefs of Pacific oysters have become invasive in Europe, although risk assessments at the time of their introduction stated that they would not

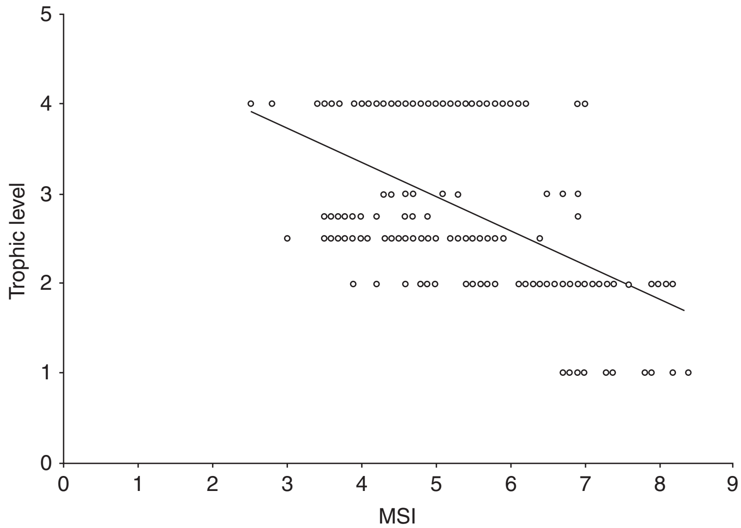
brood stock or juveniles, including those of native species. These hitchhiking species include many fouling species, parasites, predators and pathogens (Grosholz et al. 2015). Of these hitchhikers, approximately 85 per cent have become established, including known shellfish pathogens and parasites. So again, there is a clear risk to the principles of the blue economy from hitchhikers on brood stock or juveniles imported to SIDS for the purposes of aquaculture. Once an invasive species becomes established, it can be very difficult or impossible to remove or confine. Even if attempts to eradicate the species are successful, there is normally a significant cost involved. Therefore, it is strongly recommended that aquaculture hatcheries are developed within SIDS for the species they wish to cultivate, where appropriate.

3.1.2 Promotion of the culture of low-trophic level species

Global aquaculture production is based on the production of species at the bottom of the food web, or low-trophic level species (such as aquatic plants, herbivores, detritivores and omnivores), as opposed to higher-trophic level species such as carnivores. The production of low-trophic level species outweighs the production of higher-trophic level species nine-to-one (Neori and Nobre 2012). There is a direct relationship between the trophic level of a species in production and its sustainability, as described by the Mariculture Sustainability Index (MSI): the lower the trophic level of the species, the higher the MSI score (Figure 3.3). The MSI (Trujillo 2008) is calculated on 13 categories including habitat impact, employment and waste discharge and ranges from 1 (totally non-sustainable) to 10 (ultimately sustainable). There are a number of reasons for this relationship. The culture of carnivorous species requires diets that are rich in fish meal and oil (predators need more protein and energy); however, supply of this fish meal and oil comes from already overexploited fish stock. In addition, the feeding and conversion rates of carnivorous species tend to be low, with carnivorous fish retaining only approximately 20–30 per cent of the added feed.

Conversely, low-trophic level species such as aquatic plants and filter feeders extract their food from the environment, relying on the system's natural productivity. Often, this natural productivity is fuelled by anthropogenic nutrient enrichment, so the culturing activity can be deemed to be a type of wastewater treatment or bioremediation. This facet of bioremediation aquaculture may be of particular interest to SIDS. Many SIDS are fringed by coral reefs that provide valuable ecosystem services for the SIDS. However, in the past 30 years there has been significant degradation of coral reefs across the globe.

Figure 3.3. The relationship between the trophic level of a cultivated species and its MSI score (after Trujillo 2008)



Following the large-scale mortality of reef-building corals due to coral bleaching events, recovery is sometimes limited by the occurrence of macroalgae, which overgrow the damaged reefs and stop regeneration. The growth of these macroalgal communities is enhanced by increased levels of nutrients (Szmant 2002), and so low-trophic level aquaculture may offer an innovative management option to reduce nutrient loading and help facilitate the recovery of the coral reefs. There are a number of groups of species that fall into this low-trophic group that offer the potential for significant aquaculture operations in SIDS (Table 3.1).

Table 3.1. List of possible low-trophic level aquaculture species groups that offer significant aquaculture potential for SIDS

Group	Market	Notes
Seaweeds	The global seaweed market is worth approximately US$6 billion annually; it is used mainly for direct human consumption or as a food ingredient.	Globally, most of the production comes from aquaculture. There are a number of species indigenous to SIDS, for which both a market and cultivation techniques exist.
Sponges	Large specimens attract a premium for the bath sponge market, and take approximately two years to grow to size.	Sponges have a range of commercial uses, including in cosmetics, collagen and bioactive compound production, and are relatively simple to culture.

(continued)

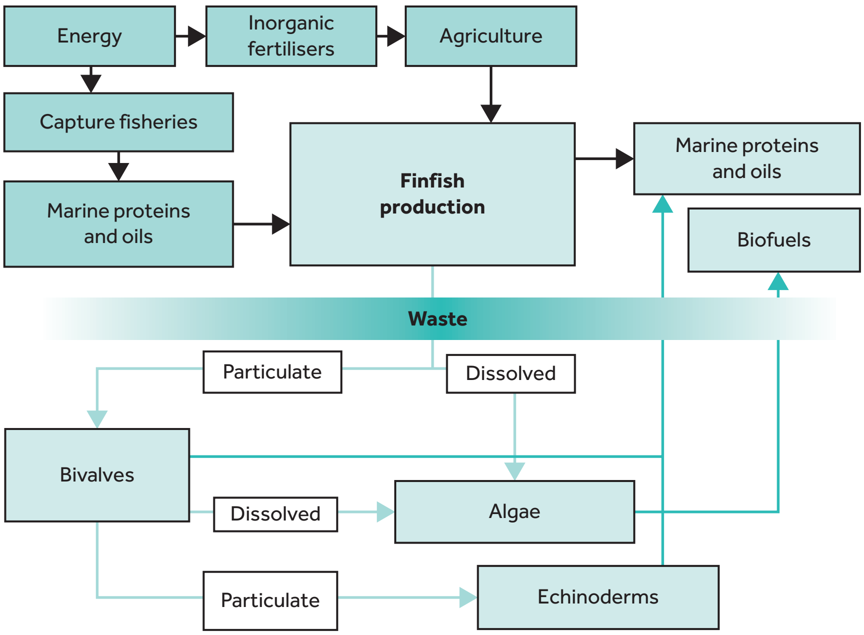
Table 3.1. List of possible low-trophic level aquaculture species groups that offer significant aquaculture potential for SIDS *(continued)*

Group	Market	Notes
Sea cucumbers	A fishery for sea cucumbers exists globally in the tropics, but stocks have become severely depleted. Currently, China produces 10,000 tonnes per annum through aquaculture.	In many SIDS, there is an existing fishery for sea cucumbers, including *Holothuria scabra*, for which there is a well-established aquaculture industry in Asia.
Black-lipped oysters	The price of pearls is largely regulated by their quality, but the market average is approximately $14,000/kg.	This industry is based on the implantation of a seed into a pearl-forming oyster, and then the harvesting of the pearl after approximately 18–24 months. The implantation of the seed is a specialised job, but the value of the resultant pearls can be very high.
Corals	The trade in live corals for aquariums has grown at approximately 9% per annum since 1990, and on average coral retails at $56 a piece in the US.	Aquaculture production is normally by fragmentation of donor colonies. In the beginning, these donor colonies are from wild coral colonies on reefs.
Aquacultured live rock	Traditionally, Fiji islands has been the main source of live rock for import to the US. The value of this trade is $50 million globally.	Live rock is much used in ornamental aquariums and can be easily cultivated.
Mud/ mangrove crabs	The grow-out period is approximately 6 months, and the crabs are worth approximately $6/ kg when full-grown.	Where these animals are endemic, there is often an artisanal fishery for them. Collection and hatching of berried females, or juveniles, and their subsequent on-growing offers a sustainable alternative to the wild harvest.

3.1.3 Co-location of different aquaculture activities

The co-location of different aquaculture activities can have potential economic and environmental benefits. Feed is a core operational cost for most finfish aquaculture operations. However, approximately 70 per cent of the nitrogen and 80 per cent of the phosphorus in costly fish feed is lost to the environment through excretion and faeces. This is both economically wasteful and potentially environmentally damaging. Integrated multi-trophic aquaculture (IMTA) is a practice in which the by-products (wastes) from one species are recycled to become inputs (fertilisers, food and energy) for another (Figure 3.4).

Figure 3.4. The flow of nutrients and energy through a model IMTA system



When implemented correctly, fed aquaculture species (e.g. finfish/shrimps) are grown alongside selected organic extractive species (e.g. suspension feeders/deposit feeders/herbivorous fish) and inorganic extractive species (e.g. seaweeds) (Chopin et al. 2006). While the secondary co-cultured species (usually shellfish and/or seaweeds) are typically premium 'cash crops' of some kind, alternatives may be considered for extraction of natural products (e.g. pharmaceuticals, nutraceuticals, functional foods, cosmeceuticals, botanicals, pigments, agrichemicals and biostimulants). IMTA is widely practised in Asia; however, its adoption in Europe has been slow, with one reason cited being the lack of provision in national regulations for the co-cultivation of different species.

3.2 EAA Principle 2

The second principle of the EAA deals with the social impacts of aquaculture development; the aim should be to ensure that the benefits of the development occur at all socioeconomic levels and that there is stakeholder participation in both the management and the operation of the aquaculture industry. This may be especially important in SIDS with existing marine industries, such as fishing and tourism, already occupying much of the marine landscape.

In this case, the development of the aquaculture industry may be perceived as detrimental to these existing industries.

3.2.1 Resolving the tension between food security and export earnings

One of the key tenets of the blue economy is to use aquaculture to create high-value commodities for export (Anon. 2014). Therefore, there is a clear tension between the role of aquaculture in national food security and the desire to earn export revenue. This tension needs to be carefully managed at a governmental level through policies fed back into the industry. There are three ways in which aquaculture can actually decrease local food security (Abila 2000):

- In order to maximise returns, aquaculture products are normally processed prior to entry to the market, as opposed to in traditional fisheries, where whole fish may be the usual product. Once processing capabilities are developed, both aquaculture and fisheries products will be processed. High prices paid by processing factories make fish unaffordable to local consumers, and so, rather than the products of aquaculture and fisheries being used for subsistence by the local population, cheaper, less nutritious alternatives such as tinned meats are substituted for them.
- As markets develop for fish outside the local community, the price premium for high-quality fish grows. The export market takes all the high-quality fish, leaving only poorer-quality fish for the local market. These fish may have a shorter time until spoilage or a lower meat yield.
- An aquaculture operation may reduce access to traditional fisheries, or environmental degradation may reduce local fishery yields. This can occur if aquaculture operations are located within traditional fishing areas, or if they have an impact on important fishery habitats such as mangrove forests. In doing so, they reduce the capacity of the population to undertake subsistence or small-scale fishing and thus reduce the supply of fish to that local population.

This can lead to a 'sell fish to buy fish' conflict, which is well recognised in the fisheries and aquaculture sector, and this concept may already be incorporated into the SIDS' fishery management and policy, either explicitly or implicitly. Export of fish can still lead to greater food security if those export earnings are used to import a larger quantity of cheaper fish (Kent 2003). However, in practice it is more likely that the export earnings will be used by a relatively small proportion of the population to buy products other than cheap fish. These unintended social consequences of aquaculture development occur in the case of inward investment as well in the case of export profits. In the shrimp industry, transnational companies and wealthy individuals have been the main recipients of national aquaculture development funding (Rivera-Ferre 2009). Although it is argued that aquaculture provides jobs for the poor, there is strong evidence that it provides fewer jobs than traditional uses of the marine environment and that the loss of access to marine resources associated with aquaculture development exacerbates rural poverty (Johnson and Carlton 1996).

One way to ensure that aquaculture contributes to national food security would be to ensure that the products produced were directed at the domestic market (Ahmed and Lorica 2002). Another way to promote social equality through aquaculture is with community-based aquaculture (CBA), as developed in a number of coastal communities. However, these schemes can lead to dependence and economic exploitation if the community fails to control the value chain effectively (ibid.). With this end in mind, it is possible to use national policies to focus the aquaculture industry on the targets of both greater food security and reduced poverty. This can be achieved through increased institutional support for the diversification of the industry and the integration of production systems with post-harvesting and value-adding activities.

3.2.2 Building stakeholder 'buy-in' through participatory community-based aquaculture

CBA has been seen as a mechanism for diversifying rural coastal economies away from subsistence fisheries and for providing a means of sustainable development (Little et al. 2012). CBA offers a mechanism for locals, communities or individuals to gain ownership in the developing aquaculture industry at the level of owner operator or entrepreneur. This level of participation allows for community or individual engagement, mitigating possible negative social consequences associated with aquaculture development, such as reduced fishing area or reduced visual amenity. Such community groups or individuals can act as local champions for aquaculture and provide invaluable leadership in the development of stakeholder acceptance of aquaculture. However, the barriers to entry can be substantial in terms of capital investment, the technical knowledge required or the regulatory burden. Therefore, a blue economy-based aquaculture framework would support CBA or small enterprise-based aquaculture by helping individuals, community groups and small enterprises to navigate these barriers. However, when CBA is used in a development context, the success of these schemes has been largely based on the provision of donor support, with limited longevity once the donor support is removed (Ateweberhan et al. 2014). Therefore, care should be taken to understand how the donor will exit the CBA relationship, ensuring that the new business is economically sustainable in the long term.

3.2.3 Ensuring local participation and benefit through capacity-building

Unless there is an established aquaculture industry within a SIDS, it is unlikely that any native capacity will exist within the state for aquaculture development. If this is the case, the SIDS has two options:

i. to bring in external knowledge, expertise and labour; or

ii. to develop that capacity internally.

The action taken will probably be a combination of the two options, depending on the current state of the industry and the complexity of the aquaculture operations that are being developed. In terms of development within the blue economy, an approach that improves human wellbeing and equity for all relevant stakeholders should be taken. The development of local capacity has clear benefits in helping to achieving these goals (Subasinghe et al. 2009) by ensuring that local populations have the capacity to be employed by, manage and own the developing aquaculture industry. The development of local capacity beyond the operational level will require further and higher education training programmes, along with local research capacity to support the industry's development.

3.3 EAA Principle 3

The blue economy offers a natural framework for the development of all marine sectors, and therefore any development of aquaculture in the context of the blue economy will already be in alignment with other sectors' development and their associated goals.

3.3.1 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 future 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. Additional recommendations are listed below; these address the full range of factors that need to be in place to implement a robust, successful blue economy.

3.3.2 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.

3.3.3 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.

3.3.4 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. 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.

3.3.5 Scientific research strategy

A co-ordinated research and development strategy is needed to address specific sector requirements and the broader implementation of the blue economy. This should involve local higher education institutes 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 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.

3.3.6 Mobilising critical mass

Capacity-building, effective international networking and collaboration, and skills transfer from foreign academic organisations and technology providers, in addition to regional co-operation, 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. One approach that has proved effective in achieving these results is the development of technology incubators, science parks etc.

3.3.7 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.

3.3.8 The role of marine spatial planning in the blue economy

Comparative analysis of different scenarios within a blue economy context is not yet an established practice, but presents a critical step in envisaging what is feasible and desirable in any individual SIDS. To enable this, there is a need for consistency in the assessment and understanding of the risks and benefits to all sectors, with regard to implications for the socioecological system, whether economic and cultural benefits or potentially detrimental environmental effects. The governance of the blue economy framework needs to enable this, and ensure that options are investigated and assessed transparently, robustly and fairly.

It is increasingly clear that strategic planning (i.e. taking an overarching view of sector development) is a more streamlined and effective approach to accounting for broad and interrelated aspects, such as the value chain of impacts or the supply chain (infrastructure requirements), and integration of land and marine options. Marine spatial planning provides a valuable tool to address strategic issues and is recommended as a key operational tool to support the development of the blue economy.

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Chapter 4

Development Pathways

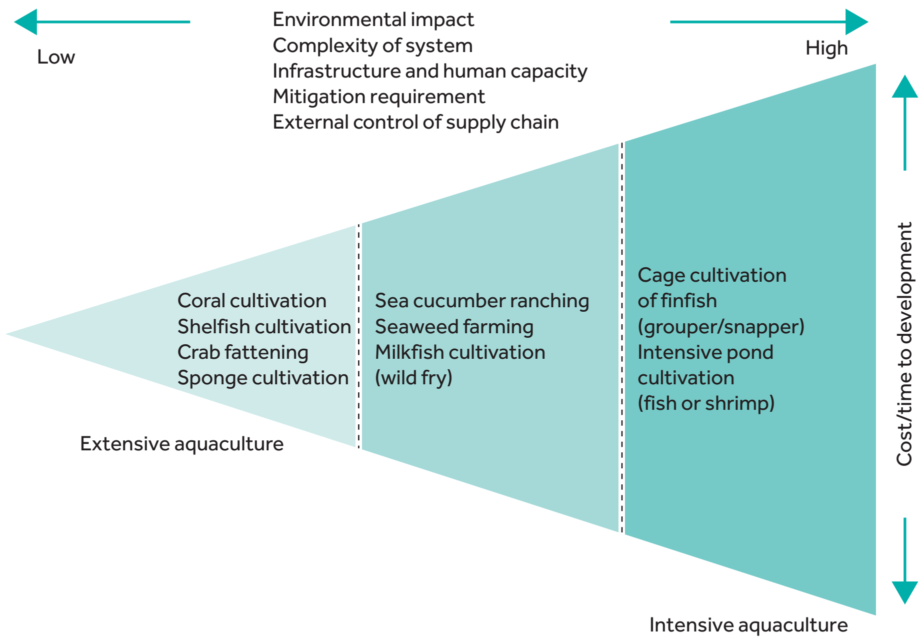
Chapter 4

Development Pathways

Aquaculture covers a very diverse range of activities, spanning a range of habitats from terrestrial freshwater ponds to the open ocean, and a range of organisms at different points on the food chain, from single-celled algae to pelagic predators such as tunas and groupers, and ranging from extensive production to intensive systems. All these activities can fit within a blue economy framework for aquaculture. However, as systems become more complex and more intensive, and culture organisms further up the food chain, there is an associated increase in environmental impacts and a need for more complex infrastructure and greater human capacity (Figure 4.1). There is also an increase in the cost of and time required for development as aquaculture systems get more complex.

The species considered for culture by any one SIDS will be decided on following consideration of a large number of factors that will be specific to that particular SIDS, such as local environmental conditions, local market drivers and available knowledge and capacity. However, the species selection should be in line with the principles of the EAA; in particular, the species chosen should be native to the environment where it is to be cultured, and brood stock (if necessary) should be sourced from local populations and produced in local hatcheries. In many cases, this is not the easiest option. It requires that the life cycle of local species has been closed for aquaculture production and that the facilities exist locally to produce brood stock. Either of these requires a level of technical knowledge that the SIDS may not

Figure 4.1. The relationship between the complexity of an aquaculture operation and how it fits into a blue economy framework



have. In this case, it is strongly recommended that the capacity to develop these capabilities be developed or imported, rather than importing seed, brood stock or non-native species. This issue can be avoided by developing low-complexity systems that do not require the provision of brood stock.

4.1 Low-complexity systems

The lowest-complexity systems rely on ecosystem services to provide many of the requirements of the aquaculture production system, such as feed or a supply of juveniles. Good examples of these types of production systems include shellfish production, where spat is obtained from natural spat fall (Figure 4.2). In these systems, all that is required is an appropriate surface for the larvae naturally present in the water column to settle on. Once settled, the shellfish will filter the feed they require from the plankton in the water column. Therefore, no hatchery or feed production system is required. This means there are relatively low technological and capacity requirements, and low investment costs. Another example of this low level of complexity is the production of coral nubbins for the aquarium trade. These can be produced by harvesting a limited number of parent coral nubbins from the wild. These can then be grown on using a simple culture

Figure 4.2. An example of shellfish that have settled out of the water column as part of a low-complexity aquaculture system

system at sea and further fragmented to produce coral nubbins for sale. A further example is the cultivation of red seaweeds in shallow intertidal areas. In these systems, adult plants are fragmented and put out to sea to increase their biomass. They are then harvested, leaving a portion of the mature plant out at sea to regrow again. These types of systems are directly in line with the principles of the blue economy and especially suitable for CBA and small enterprises.

4.1.1 Case study: coral aquaculture for the aquarium trade in Fiji

As noted above, there is a global trade in live coral fragments, as well as what is termed 'live rock' and 'live sand' for the aquarium trade. Live coral fragments are used to improve the aesthetics of hobbyists' aquariums, while live rock and sand have an important role in providing habitats for natural microbiological communities that are beneficial to the health of the aquarium. It is estimated that approximately 11–12 million pieces of live coral are traded annually and that the live rock trade is worth US$50 million annually. Most of this trade is in wild collected specimens. However, there is significant potential for aquaculture of these corals, mainly through fragmentation. One such example of the development of aquaculture production of live coral and rock is

Figure 4.3. Coral fragments being propagated in Fiji

Source: Walt Smith

on the island of Viti Levu in Fiji (Figure 4.3). Here, corals and live rock are produced for export to the aquarium trade. In the case of the live coral, this is done through the fragmentation method described above. The live rock is produced by placing dyed terrestrial rock in the open sea for up to a year to allow the establishment of a natural fouling community including coralline algae. The live rock retails for approximately $10/kg in the US, and a 10 cm nubbin of *Acropora* coral retails for approximately $80.

4.2 Medium-complexity systems

The range of species that can be produced in low-complexity systems is relatively small and levels of productivity can be low, as there is little opportunity to domesticate the species or to increase growth rates beyond the levels of primary production that the ecosystem naturally supports. The next level of complexity takes one phase of the life cycle of the organism being cultured and brings it under direct control. In many cases, it will be the larval or juvenile stage that is brought under close control through the hatchery production of either larvae or juveniles. This allows for greater certainty about the number of larvae that can be produced and is the first step towards domestication, as it allows for the selection of brood stock with desirable traits. However, it does represent a significant increase in the complexity of the aquaculture production system, and requires significant investment in both infrastructure (the hatchery) and capacity in terms of operating the hatchery. In addition to the hatchery itself, many aquaculture species have a larval or juvenile stage during which microalgae are required for their feed. Therefore, the hatchery will need to include an algal production facility, which again can be expensive and requires a high level of technical expertise for its effective operation. Such a hatchery and algal production facility can be used to produce a range of invertebrates that can then be transported to the open sea or to ponds for on-growing to market size. This grow-out can be in an extensive system that requires no additional feeding, such as for bivalves, which filter feed plankton from the water column, or sea cucumbers, which can be ranched using the organic matter in sediments as feed. Therefore, there are very low costs associated with the majority of the production cycle (the grow-out period).

Another option for a medium-complexity system is to collect juveniles from wild populations and then culture them to market size under more controlled and intensive conditions. In this case, the need for a hatchery is circumvented, along with the associated cost and technical requirements. However, it does preclude domestication of the species, and production will always be limited by the natural availability of juveniles, which can fluctuate from year to year. Once the juveniles have been collected from the wild, they are cultivated in ponds or open-water cages. In such a system, there is a need to provide feed until the animal reaches market size. This can represent a significant cost to the operation and requires either the importation of the feed or the capacity to produce the feed within the SIDS. A good example of this type of production is the cultivation of milkfish (*Chanos chanos)*, where traditionally the milkfish fry are collected from the wild and then placed in earth ponds or sea cages to reach market size.

4.2.1 Case study: sea cucumber aquaculture in Madagascar

Sea cucumbers (family *Holothuriidae*), or bêche-de-mer, are commercially valuable with extensive markets in China and Asia. This demand has traditionally been supplied through diver-based fishery of natural stocks. However, there has been serial overexploitation of these natural stocks, and so there has been extensive development of an aquaculture industry, based mainly in China, for these organisms. Like most marine vertebrates, sea cucumbers have a two-phase life cycle. The adult sea cucumber can be induced to spawn through chemical or temperature shock. The gametes are then mixed in the hatchery and the resultant free-swimming larvae are then fed on a microalgae diet until they are ready to settle out of the water column and metamorphose into young adult cucumbers. This first stage, from spawning to metamorphosis, must take place in the hatchery, while the subsequent grow-out can occur in either ponds or shallow enclosures. The sea cucumber fishery in Madagascar followed a similar pattern of overexploitation of local populations of the commercially valuable species *Holothuria scarba* (known as sand fish). In 2003, a hatchery was built in the grounds of Toliara Marine Science Institute. The hatchery is capable of producing tens of thousands of juvenile sea cucumbers. These juveniles are then transferred to ponds, where they reach market size in approximately 10–12 months. This operation is also currently supplying juveniles to local farmers, who are growing the juveniles to market size in shallow fenced enclosures as part of a CBA development.

4.3 High-complexity systems

Medium-complexity systems are reliant on ecosystem services either to provide the juveniles for culture or for the feed for the grow-out of the hatchery-produced juveniles. The next level of complexity is to fully close the life cycle of the species being produced and to bring it entirely under the control of the aquaculture production system. In this case, all life stages of the organism to be cultured need to be managed. This means that brood stock needs to be held and conditioned prior to spawning (usually in land-based tanks at the hatchery), then induced to spawn, the eggs fertilised and then cared for and fed through the larval stage, until they are juveniles ready for on-growing. The juveniles are then generally transplanted out to ponds or open-sea cages and fed formulated diets until they are ready for market. If this process is to be undertaken within a SIDS, it represents a large investment in terms both of infrastructure and of the technical capacity to run the hatchery and the grow-out operations. If the aquaculture development is to be in line with the blue economy, there must also be indigenous species suitable for domestication. This type of intensive production system is usually based around finfish production, and it is likely that most SIDS will have a large number of indigenous finfish species that can be candidates for aquaculture. In some cases, the life cycle of these species or similar species will have been closed elsewhere in the world. Where this is the case, that expertise can be imported. Where this is not the case, there is the need to develop that technical expertise within the SIDS, which represents a significant investment in time and capital.

As these complex systems tend to be more intensive, there is a greater potential for environmental degradation associated with their operations. Therefore, there is an increased need for effective management of these sites, and effective mitigation measures to ensure that ecosystem resilience is not exceeded. This management could include fallowing periods, limits on biomass at a site or integration with extractive aquaculture operations.

It is important to understand that all these systems can be developed in line with a blue economy ethos; however, the further you develop the complexity of the aquaculture operation, the larger the investment in facilities and capacity that is required (see Table 4.1), and the more complex the monitoring and management of the operation needs to be if it is to be regarded as being within the blue economy. In addition, as costs, investment and management complexity increase, it becomes more difficult to absorb the pressure from industry to move away from the blue economy model and return to a more standard 'business as usual' development model. Therefore, one option for development in a SIDS without an existing aquaculture industry would be to start at the low-complexity end of the spectrum of development and allow the aquaculture industry to grow organically (supported by government investment) and to move up the complexity spectrum as local capacity and infrastructure develop.

Table 4.1. The infrastructure and knowledge requirements for different complexities of aquaculture development

Low complexity	Medium complexity	High complexity
Low-tech moorings	Algal production	Algal production
Sea ranching	Invertebrate hatchery	Live feed production
Basic infrastructure to operate at sea	Feed production (low protein/lipid)	Feed production (high protein/lipid)
Disease management	Disease management	Vertebrate hatchery
	Brood stock management	Disease management
	Moorings and cages at sea	Pharmacological disease control
		Genetic management
		High-performance containment at sea

Chapter 5

Conclusions and Recommendations

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

The development of an aquaculture industry is fully in line with a SIDS' desire to base its development on a blue economy model. In fact, there are already accepted frameworks within which this development can take place, such as the EAA, whose guiding principles are parallel with the principles of the blue economy. The model that any one particular SIDS chooses for the development of an aquaculture industry will be dependent on a number of factors that are intrinsic to that SIDS, such as the environment, available infrastructure and local markets. For the industry to fully develop, it is crucial that there is local capacity in terms of infrastructure and a knowledge base. This needs to be coupled with the right regulatory conditions to allow investment to flow into the industry and to allow the industry to grow in a sustainable manner, with a good level of 'buy-in' from stakeholders and consumers at all levels. However, in all cases it is crucial that the development of the aquaculture industry takes place in the context of other marine sector development, and within a dedicated aquaculture policy framework.

5.2 Recommendations for fostering the development of an aquaculture industry within the blue economy

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

- **Initial sectoral prioritisation**
  The products of aquaculture are globally traded and it is unlikely that a SIDS will be able to compete on the global market on the basis of price. Therefore, the SIDS should look to develop aquaculture products for the domestic market or niche products that attract a higher price, such as eco-labelled products or products that can obtain added value by trading on the image of the SIDS.
- **Developing in step with local capacity**
  There are options for basing the aquaculture development of a SIDS on expertise, technology and investment from outside the SIDS. While this is entirely possible, it poses significant risks in terms of the economic, social and environmental sustainability of the industry. Allowing the industry to grow at a slower pace using indigenous capacity enables greater social acceptance of the enterprise and ensures that markets, infrastructure and technical expertise can all be developed within the SIDS, reducing the overall risk.
- **Creating a management and regulation framework based on the EAA**
  A comprehensive aquaculture policy based on the EAA will allow the industry to develop within a framework that provides economic and environmental sustainability. Management, regulation and policy should be based on sound scientific principles and evidence.
- **Investing in creating institutional capacity and links between industry, academia and regulators**
  It is likely that, unless there is an existing aquaculture industry, the SIDS will have a small or non-existent research capacity in aquaculture. This capacity should be built with specific regard to making the outputs relevant to both industry and regulators, and resources should be used to ensure that there is direct access for regulators and industry to the research community.

Glossary

Agrichemicals are chemicals, for example pesticides and fertilisers, used in agriculture to improve the production of the crop.

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

Botanicals are plant parts or extracts that are used in medicinal or cosmetic products.

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

Detritivores are organisms that feed on and break down dead plant or animal matter, returning essential nutrients to the ecosystem.

Herbivores are animals adapted to eating plant material as the main component of their diet.

Marine spatial planning is a spatial, cross-sectoral approach to the optimisation of marine activities, minimising negative social and ecological effects.

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.

The Mariculture Sustainability Index (MSI) was developed as a framework for evaluating the sustainability of aquaculture production using a score between 1 (poor) and 10 (very good).

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.

Trophic level is the position that an organism occupies in a food chain, such as primary producer, herbivore, primary carnivore, etc.

The Commonwealth

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 small island developing states (SIDS).

This second volume, Aquaculture, explores the potential for the development of a blue economy mariculture industry, as well as specific enabling conditions that could assist in moving towards economic reality where opportunities exist.

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