Aquaculture in the Seychelles: A review on challenges within the sector

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Introduction

Increased population numbers and the growing demand for food security globally has seen an increase in the effort towards more sustainable practices across different sectors and markets. Historically, and presently, the fishing sector is a significant contributor to the economies of many countries and states internationally, especially within the Western Indian Ocean (Christie, 2013; Groeneveld, 2015a). However, overfishing, coastal development, natural disasters and the impacts of climate change have put enormous pressure on this sector (Groeneveld, 2015a; EU, 2017) and the need for alternatives has become pertinent in recent times. According to the EU Food from the Ocean Report (2017), the most feasible alternative with greatest potential to contribute to sustainable fisheries is mariculture, or marine aquaculture, of especially lower trophic level organisms such as algae, molluscs and crustaceans.

Dwindling fish stocks not only impact food security, but most species of economic value are keystone species within the ecosystem and their removal from such positions have cascading effects on the trophic interactions and ultimate functioning of those systems (Baum and Worm, 2009), be they top-down (i.e. high tropic level predators) or bottom-up (i.e. low trophic level primary producers) interactions. Such changes could have dire consequences for biodiversity and the resilience of coastal systems to climate change, as well as for food security for a country or region. Another consideration that must be noted is the increased prevalence of contaminants in higher trophic level organisms, such as heavy metals and pesticides that tend to bioaccumulate and pose a risk to human health and wellbeing.

Within Seychelles it is estimated that nearly 60 kilograms of fish is consumed per person per year (Jiddawi, 2012; Groeneveld, 2015b), the highest level of consumption for the island nations of the Western Indian Ocean (i.e. Mauritius, Madagascar, Tanzania and Zanzibar, Kenya, Mozambique and Comoros). According to the FAO (2016), global per capita consumption of fish averages between 11 and 12 kg. This highlights the high dependence of Seychelles on fisheries as a protein source and, consequently, its vulnerability should there be a collapse in the sector.

In addition to the local consumption of fish, Seychelles also has a large tuna processing and canning factory that accounts for nearly 95% of its domestic exports (Heilemann et al., 2009; ASCLME, 2012). Furthermore, artisanal fishing is important socially and economically for the communities of Seychelles with most catches being sold at local markets. Seychelles has an Exclusive Economic Zone (EEZ) of approximately 1.4 million km^2 which is mainly exploited by foreign longliners and purse-seiners that target larger pelagic species (Groenewald, 2015a). As with most other countries, Seychelles is faced with a number of challenges regarding its fisheries, which include illegal, unreported or unregulated (IUU) fishing, coastal habitat destruction including coral bleaching, harmful algal blooms (HABs), and a lack of resources to adequately manage and enforce regulations. In addition, the reliance on the fishing sector for economic benefit and food security increases the vulnerability posed in light of climate change (SAPEA, 2017; EU, 2017). Accordingly, alternatives have been identified and are being sought to address these issues. In 2011, the Seychelles Mariculture Master Plan was formulated with the focus being developing marine aquaculture within the coastal regions of the Islands, which coincides with the Sustainable Development Strategies (2012 – 2020) and the Blue Economy Roadmap for Seychelles (2018 – 2030). Mariculture has also been highlighted as a means to create new economic sectors that would be sustainable and drivers of employment for the local communities in the long term.

Mariculture, despite showing global growth of 6.8% to 9% per year since the 1980s (FAO, 2012; Mmochi, 2015; SAPEA, 2017), is a new industry in many coastal African countries and Small Island Developing States (SIDS). In spite of this growth, development of mariculture in Seychelles has been slow, seldom passing the feasibility studies for a number of targeted species.

Global projections for future consumption of fish highlights the significant contribution that aquaculture can make. According to FAO data (2014), the global production from aquaculture, both freshwater and marine, peaked in 2012 to approximately 90 million tonnes of fish and plant biomass, and in 2015 estimates from mariculture production alone was set at 56 million tonnes (FAO, 2016). This was on par with wild caught fish production and highlighted the importance of more sustainable practices and the consequent increased food security for a number of countries, such as Tilapia production in Egypt. Furthermore, it is estimated that aquaculture contribution (mainly freshwater) to fish consumption by 2025 could be as high as 28.5 million tonnes, assuming a growth rate of 1.5% per year (FAO, 2016), while the World Bank (2013) estimates consumption growth of 1.1% per year by 2030 with substantial contribution by aquaculture. This potential growth of the aquaculture sector depends on factors such as the target species and their protein requirements (fish-in, fish-out ratio); wild caught stocks; human population growth, and; nutritional challenges and security (incl. food sources high in micronutrients, fatty acids and vitamins) (SAPEA, 2017). To date Asia, especially China, is the main producer of mariculture and aquaculture products (90% of the sector), whilst Europe contributes approximately 5% to global aquaculture production, South and North America approximately 4%, and Africa and Oceania the remainder (i.e. 1%; FAO, 2014, Mmochi, 2015).

The objective of this review is to critically evaluate the feasibility of mariculture for economic growth and food security within the context of a Small Island Developing State. Although there are ample policies and frameworks already developed and adopted by numerous countries and states, they can only come into fruition when there is public and stakeholder support.

The need for alternative fish sources and food security

It is well known that the human population has increased significantly over the last century and is set to continue to grow to a staggering 11 billion people by 2100 (UN Projections). It is therefore expected that fish consumption globally is also set to increase significantly (Krause et al., 2015). According to SAPEA (2017), approximately 8 million tonnes of fish were consumed in 1976, a period when the human population size was estimated at 4 billion people. More recent figures (2012) showed global fish consumption to be 58 million tonnes at a time when global human population reached 7 billion people and 138 million tonnes in 2015 (Fig. 1). This points to a potential ten-fold increase in fish consumption (directly and indirectly) in relation to population increase, highlighting the potential future demand for fishery resources.

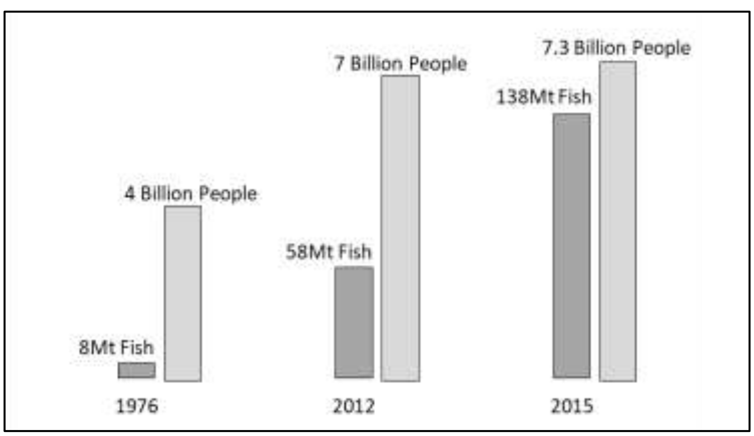

Figure 1. Total human population numbers and fish consumption in 1976, 2012 and 2015, highlighting the significant increase in consumption over a period of nearly 40 years
(Mt = million tonnes)

With increased demand, there is a need for enhanced food security. Alternatives, such as mariculture, would need to address issues such as: 1) sufficiency of the species/sources in meeting the needs and preferences of the people; 2) nutritional and safety concerns; 3) whether the sources are sustainable for present and future generations; 4) resilience of sources to adverse conditions; 5) legal and ethical standards; and 6) accessibility and affordability of the sources to all (SAPEA, 2017). Ingram et al. (2011) summarise these aspects into three main components, namely: 1) Utilisation – nutritional and social value, and food safety (incl. biosecurity); 2) Access – the affordability, allocation and preference of the stocks to people; and 3) Availability – the production, distribution and exchange of resources locally, regionally and globally. How, then, does regional and local mariculture production address these components and issues? Additionally, how is the natural environment likely to respond to both land- and cage-based aquaculture operations?

Regional mariculture production

Within the Western Indian Ocean, fish production is a major source of economic growth and food security to countries and communities. Mainland countries of the region such as Mozambique, Tanzania (including Zanzibar), and Kenya, as well as Madagascar, can greatly supplement their fishery production with agricultural food production. SIDS such as Seychelles, Mauritius, Reunion, Mayotte and Comoros, however, rely heavily on their artisanal and small-scale fishing for food security and livelihoods for their citizens. All these countries are extremely vulnerable to climate change and economic instability in light of their fishing resources, and alternative food production has been sought in all of these nations (FAO, 2014). Aquaculture within the East African countries (i.e. Mozambique, Tanzania and Kenya) has mainly focused on freshwater species such as *Oreochromis mossambicus* (Mozambique tilapia), *O. niloticus* (Nile tilapia), *Clarias gariepinus* (African catfish), and some *Onchorynchus mykiss* (rainbow trout) (Rukanda, 2016; Van Duijn et al., 2018; Van Der Heijden et al., 2018). Marine aquaculture is mainly centred at the coasts of these countries and includes species such as *Chanos* (milkfish), *Mugil cephalus* (mullet), *Peneaus modon* (tiger prawn), and several different seaweed species, i.e. *Kappaphyrus alvarezii, Eucheuma* sp., *Saccharina japonica, Gracilaria* sp., *Undaria pinnatifeda* and *Pyropia* (*Porphyra*) species (Table 1). The success of these operations varies between countries and regions, and currently are underdeveloped and under-exploited in most.

Table 1. Common species cultivated in mariculture systems within the Western Indian Ocean SIDS
(x = currently in production, x* = experimental production, x = discontinued production)**

Species	Common Name	MZ	TA	KY	CO	MD	SY	MA	RE#
Seaweeds									
Eucheuma denticulatum	Red algae	x	x			x			
Kappaphycus alvarezii	Red algae	x	x			x			
Kappaphycus striatum	Red algae		x						
Spirulina	Blue-green algae					x			
Mollusks									
Anadara antiquata	Clams		x*						
Crassostrea cucullata	Oyster			x**		x*			
Holothuria scabra	Sea cucumber		x*			x			
Isognomon	Oyster		x*						
Pinctada margaritifera	Black-lipped oyster		x*				x		
Pteria pengiun	Winged pearl Oyster		x*				x		
Tripneustes gratilla	Sea Urchin						x*		
Crustaceans									
Artemia	Brine shrimp					x*			
Penaeus indicus	Prawn	x							
Penaeus monodon	Tiger prawn	x		X		x	x**		
Scylla serrata	Mud crab		x*	X			x*		
Finfish									
Argyrosomis japonicas	Dusky kob	x							
Chanos	Milkfish	x	x	X		x*			
Mugil cephalus	Mullet	x		X					
Oreochromis mossambicus	Mozambique Tilapia	x							
Oreochromis nilotus	Nile Tilapia		x						
Rachycentron canadum	Cobia	x							x
Rhabdosargus sarba	Seabream							x*	x
Scyanops ocellatus	Red drum							x	x
Siganus sutor	Rabbitfish		x						

MZ = Mozambique, TA = Tanzania (incl. Zanzibar), KY = Kenya, CO = Comoros, MD = Madagascar, SY = Seychelles, MA = Mauritius, RE# = Reunion and Mayotte

Reunion and Mayotte have shown considerable success in mariculture since establishment in the 1990s. Developments in these regions are actively pursued and spearheaded by 'l'Association Réunionanaise de Développement de l'Aquaculture' (ARDA) and the Mayotte Aquaculture Development Association (AQUAMAY), which is supported by the IFREMER (Institut français de recherce pour l'exploitation de la mer). This highlights the valuable contribution that science and innovation can make, and has made, to the sector, especially with regards to feed production and reproductive technologies. Tanzania also has a longstanding aquaculture sector that started in 1946, primarily with Nile tilapia and rainbow trout. This industry has grown from 925 tonnes production in 2010 to ~2800 tonnes in 2015 consisting chiefly of tilapia and catfish. Its mariculture sector has also seen growth since the 1970s to include a production of approximately 1170 tonnes of dry seaweeds in 2015 (Rukanda, 2016) with further ~ 320 tonne production of milkfish, crab, oysters and shrimp production in pond systems along the coasts. However, very high feed and production costs pose risks to the continued success of these sectors. Kenya has several different experimental operations for aquaculture species based both in ponds and cages, and production from these were estimated at approximately 12,000 tonnes in 2013 (Rothius et al., 2014). However, due to a lack of funding, knowledge and skills, most of these operations did not progress past the experimental phase and were discontinued (Iltis and Ranaivason, 2011; Lesperance, 2011; Mirera, 2011; Mmochi, 2015).

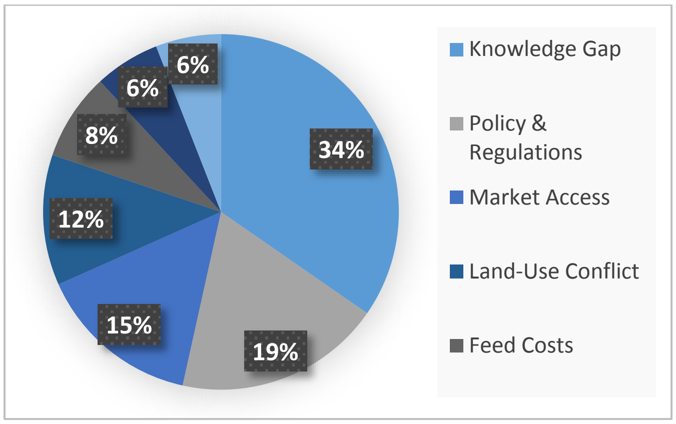

Figure 2. Challenges to aquaculture development within the WIO based on desktop analyses of literature (frequency of occurrences)

Similar instances of experimental aquaculture studies are found for the region and similar reasons for the lack in progress to full production are given in Table 2.

Table 2. Highlighted constraints on mariculture development within SIDS of the Western Indian Ocean.

		MZ	TA	KY	CO	MD	SY	MA
Policy & Regulation	Political conflict	x						
	Restrictive policies		x	x			x	
	Lack of investment	x	x	x	x		x	x
Land-Use	Insufficient space		x				x	
	Unreliable infrastructure		x			x	x	
	Environmental constraints		x					
Knowledge	Lack: Skilled workers	x	x	x	x	x	x	
	Lack: Biological	x	x	x	x		x	
	Lack: Production	x	x	x	x	x	x	
	Biosecurity & disease risk		x					
Feed	High feed costs		x			x		
	Poor quality feeds	x	x					
Seed/Spat	Access to broodstock		x				x	
	Quality: Seed / Spat		x					
Markets	Market access	x	x	x		x		
	Poor market performance					x		
	Competition with established markets			x			x	
Other	High operational costs					x	x	
	Historical dependence on wild caught fisheries						x	

MZ = Mozambique, TA = Tanzania (incl. Zanzibar), KY = Kenya, CO = Comoros, MD = Madagascar, SY = Seychelles, MA = Mauritius

Environmental restrictions to mariculture

Aside from the highlighted constraints provided in the above table, there are some natural restrictions to mariculture that would influence its success within SIDS. Adequate space, be it land-based or sea-based facilities, and the environmental impact of aquaculture operations on natural systems are concerns often highlighted in environmental impact assessments (EIAs) from stakeholders and the public. Another possible restriction is water quality for both the intake to the aquaculture facilities and the discharge of effluent from them. If intake water quality is poor, it would necessitate the pre-treatment either through filtrations (e.g. drumfilters, foam fractionators, settling ponds) and/or chemical reactions (e.g. pH buffering, ozone or UV treatment). This could increase capital and operational costs significantly through infrastructure development, equipment purchase and maintenance, employment of skilled labour, and continuous water quality testing. If the operation is based within the natural environment (i.e. sea-based cages), poor water quality would have impacts on the production output of the facility, be it reduced growth, poor animal health, biosecurity concerns or high levels of contaminant accumulation in the animals/production units. More recently, effluent quality has also been highlighted as a concern. Most land-based mariculture facilities, including hatcheries, quarantine areas and early rearing tanks, operate on flow-through systems where water is pumped from the coast, through tanks or ponds, and then discharged back into the coastal environment. Mariculture facilities often use formulated feeds in their production systems, including high densities of animals that all produce waste, meaning that the effluent is generally high in nutrients and suspended particulates that can potentially lead to adverse impacts within the discharge zones (FAO, 2018). The concept of dilution at discharge outfall points is disputed between scientists, environmentalists, authorities and owners of lines. It has, however, become increasingly relevant that precautionary measures be taken with regards to limitations being set on the quality of water being discharged back into the environment. Standards for effluent discharge quality have been and are being set for various mariculture operations, and are often included in the permit regulations for the facility. According to the EU (2018), the cumulative effect of mariculture and anthropogenic impacts must be considered when determining the overall spatial impact of the operation, and this should include discharge outfall. Linked to discharge is the concern of accidental escape of commercial stock into the natural environment including gametes released during random spawning events. Land-based operations would require sufficient screens or sterilisation processes prior to discharge of effluent into the environment. For sea-based operations, routine inspection and repair of cages and nets will have to be conducted to ensure escapees are prevented as far as possible. Escapees pose a threat to the natural environment for reasons such as: 1) potentially being an invasive exotic species to the respective environment and affecting biodiversity in the long-term; 2) impacting the genetic health of the natural population as commercial stocks are generally selected for specific traits; and 3) acting as vectors for disease that can be introduced into the natural environment (FAO, 2018). To this end, many policies and regulations for mariculture are based on the risk posed by target species for cultivation, with exotic species generally limited to highly controlled and isolated facilities, e.g. land-based recirculation tanks, or through mandating sterile stock being used in grow-out production, e.g. infertile males or females. The high-density stocking of animals in aquaculture production systems often increases the risk of disease and parasitic infection (Lafferty et al., 2015) and pose a threat to production output and the surrounding environment. Therefore, biosecurity systems are vital to healthy, productive aquaculture facilities and must be pro-active and preventative, rather than reactive (FAO, 2018). Examples of disease incidences within the mariculture sector include Red Sea Bream Iridoviral disease that caused major mortalities in farmed *Pagnus major* in Japan in 1990 – the disease can infect a number of other finfish species as well (IOE, 2019); and *Perkinsus marinus* infection in oyster and clam aquaculture production systems that cause high mortalities in both juveniles and adults (IOE, 2019). Consequently, sound policies and regulations must be developed, adopted and implemented at national government level. Due to the interconnectivity of ocean systems however, it is also important that biosecurity concerns are discussed and managed through bi- or multilateral agreements with neighbouring or regional countries. To this end, the FAO has been implementing a regional dialogue regarding biosecurity within specifically the Southern African Developing Community (SADC) since 2014 which highlights some areas for collaboration and improvement. Within Seychelles, biosecurity concerns are legislated in the Animal and Plant Biosecurity Act of 2014, previously falling under the Principal Veterinary Officer within the Ministry of Natural Resources and Industry, and currently under the new National Biosecurity Agency within the Ministry of Fisheries and Agriculture. The main focus being on the health requirements for import and export control. Globally, health certification is required for the export of live aquaculture and very limited wild caught species for human consumption, with the standards being set by the market as well as some international standards such as TRACES (Trade Control and Export System), International Sanitary Certification (OIE Listed diseases control), and importing country specifications (FAO, 2018). It should be noted that live export also includes the exportation of eggs, larvae/spat and juveniles for grow-out on other aquaculture operations, and would entail more stringent requirements being met for animal health in the country of destination as per the *OIE Aquatic Animal Health Code and Manual of Diagnostic Tests for Aquatic Animals*. The regulatory authority for each country is thus responsible not only for the certification of live aquatic animals for export, but also for the importation of live animals (and animal products) that are certified healthy and free from relevant OIE-listed diseases. Within Seychelles, very little importation of live aquatic animals occurs, being limited to some freshwater ornamental species for aquariums. Currently, these do not require an aquatic animal health certificate, but should be accompanied by a certificate of good health and attestation regarding freedom of OIE-listed diseases (FAO, 2018). Import applications for Seychelles are managed by the Ministry of Environment which grants approval prior to the issuing of a veterinary import permit. This could cause confusion regarding where the responsibility lies with regard to the implementation of legislation, policies and regulations, testing and development of contingencies, as the Veterinary Services are situated in the Ministry of Fisheries and Agriculture, whilst at the same time the Fish Inspection and Quality Control Unit and the Seychelles Bureau of Standards sits within another department altogether. For the export of live aquaculture animals, Seychelles is currently formulating the required policies and regulations under the Biosecurity Agency's Biosecurity Operation Manual for the Inter-Island transportation of regulated articles.

Seychelles mariculture

Mariculture has been highlighted as an opportunity for Seychelles not only with regards to food security but also as part of its drive towards a Blue Economy. Some of the advantages listed in the Mariculture Master Plan (2011) include: diversification of economy (i.e. new financial opportunities), food security, reduced fishing pressure on wild caught species (e.g. snapper and grouper), education, and social and economic upliftment of communities through job creation within the value chain. Through initial government support, Environmental and Social Impact Assessments (ESIA) have been completed for the Mariculture Master Plan (MMP) that highlighted potential areas for mariculture development, including potential target species for production, together with Environmental Management Plans (EMPs) for the various stages of development that will aim to mitigate against any negative environmental impacts. Key aspects for consideration of mariculture development in Seychelles are listed in Table 3. In the ESIA the feasibility of selected target species has been investigated mainly through a desktop study and is presented in Table 4.

Due to progress in the development of pilot mariculture projects in Seychelles being slow, it cannot yet be established whether the proposed mitigation steps would be feasible within the Seychelles systems over the short term. Nevertheless, steps have been taken towards some of these through policy formulation and some training of key personnel with regards to animal health and biosecurity (www.seyaquaculture.com). The Seychelles Aquaculture Regulation and Standards however, have yet to be gazetted and the postponement thereof could result in compounded delays. Construction of the broodstock holding and quarantine facility has commenced and would house locally caught mature individuals of emperor red snapper, grouper, pompano and marine ornamentals. In addition sea urchin holding and seaweed tanks are being set up in a separate area adjacent to the brood stock facility. Acclimation of broodstock and induced spawning would then have to be determined through research trails to determine optimal conditions for the Seychelles systems. Post-spawning handling of larvae and the cultivation of microalgae would also be required through research trails. Such trails can be extensive and would require skilled and knowledgeable staff to ensure progress is made and the operation is successful.

Table 3. Key aspects of concern during the operational phase of mariculture finfish cage culturing in the Seychelles as identified in the ESIA (SFA, 2016a; 2016b)

Aspect	Risk Level	Addressed in EIA	Legislative / Policy Support
Water Quality: TSS, Organic Waste & Nutrients	Localised – Deep water, sandy unconsolidated sediment	Yes, 2016 ESIA Report (pp 117- 118)	Seychelles Aquaculture Standards (yet to be gazetted)
Water Quality: Chemical Pollution	Limited – Controlled used of veterinary medicines; Environmental friendly disinfectants		Seychelles Aquaculture Standards (yet to be gazetted)
Disease & Parasites	Moderate – animal health management programme; Biosecurity standards		Animal and Plant Protection Act (No 10) of 2014
Genetic Cross-overs	Limited – Use wild caught broodstock; Physical barriers	Yes, 2016 ESIA Report (pp 120 – 130)	Seychelles Aquaculture Standard: Hatchery Biosecurity Protocol, Responsible Finfish Cage Aquaculture
Physical Hazards (entanglements)	Limited – Use of bright colour mooring lines & nets; Regular inspections; Correct mesh sizes		Environmental Authorisation (MEECC/WEP/EAPS/Class 1/SEYCHELLES MARICULTURE MASTER PLAN/NOA)
Top Predator Interactions	Limited – Visual deterrents; Correct husbandry for target stocks (fish handling, grading)		Environmental Authorisation (MEECC/WEP/EAPS/Class 1/SEYCHELLES MARICULTURE MASTER PLAN/NOA)

Seaweeds (with the exception of limited production for inclusion in feed of sea urchin projects) have been omitted from the list of potential target aquaculture species for Seychelles. Considering the global trend in using aquaculture to produce organisms of lower trophic levels, especially seaweeds, and the success of seaweed cultivation in Tanzania, it is surprising that this option is not being explored by Seychelles. The environmental impacts of *in situ* seaweed cultivation is limited and production costs are generally low due to almost no requirement for chemicals or feeds in the production system (Mmochi, 2015). Including seaweed production in an integrated polyculture production system could ensure that water quality issues be ameliorated through nutrient uptake, whilst also providing natural feed to species and thereby reduce feed costs. Numerous seaweed species also have alternative uses that have high commercial value such as the cosmetic industry (carrageenan and agar extraction), pharmaceuticals (e.g. PhycoTrix™ bio-fibres (Dinoro, 2016)), health additives (Winberg et al., 2011) and more recently as alternatives to plastic products (Ferrero et al., 2014) and as packaging material (e.g. edible food wrappers (Siah et al., 2015)).

Common Name	Scientific Name	Diet	Biology	Reproduction	Larval Stage	Larval Diet	Grow-out Stage	Market Size
Emperor Red Snapper	*Lutjanus sebae*	Carnivorous	Slow-growing, Late Maturity (8-9yrs)	Broadcast spawners, year-round	40 days	Mixed micro-diet & starter feed	6 - 22 months	400 g - 2.5kg
Mangrove Snapper	*Lutjanus argentimaculatus*	Carnivorous	Slow-growing, Late Maturity (13-14yrs)	Broadcast spawners, year-round	35 day	Mixed micro-diet & starter feed	6 - 22 months	400 g - 2.5kg
Brown-Marbled Grouper	*Epinephelus fuscoguttatus*	Carnivorous	Slow-growing, Late Maturity (~ 9yrs) *Protogynous	Broadcast spawners, Nov-Feb	45 days	Mixed micro-diet & starter feed	10 - 18 months	1 - 2kg
Pompano	*Tachinotus blochii*	Carnivorous	Fast-growing, Early Maturity (>1yrs)	Broadcast spawners, year-round	24 days	Mixed micro-diet & starter feed	9 – 10 months	450g
Black-Lipped Pearl Oyster	*Pinctada margaritifera*	Filter-Feeding	Slow-growing, Late Maturity (>2yrs) **Protandrous	Broadcast spawners, seasonally / year-round	18 days – larvae 60 days - spat	Mixed microalgal diet	12 months - Spat bags; 18 - 48 months	10 - 14mm pearls
Sea Cucumber	*Holothuria scabra*	Detritivores	Fast-growing, Early Maturity (~1yr)	Broadcast spawners, seasonally / year-round	12 - 16 days – larvae 25 – 30 days - spat	Mixed micro-diet & macroalgae	12 months	200 - 400g
Sea Urchin	*Tripneustes gratilla*	Herbivorous	Fast-growing, Early Maturity (<1yr)	Broadcast spawners, year-round	3 - 30 days – larvae 30 – 60 days – spat 60 – 80 days - juveniles	Mixed micro-diet, settlement plates, macroalgae & starter feed	8 months	15 - 24% Gonad to body mass

Table 4. List of targeted species for Seychelles aquaculture development and their basic requirements for production (Advance Africa, 2019)

Considerations for mariculture in Seychelles

The impacts of mariculture operations are mainly driven by the type of facilities required (cage, ponds, tanks), the species selected, intensity of the operation (tonnage and production output), technology (i.e. domestication, selective breeding programmes), surrounding environment, waste production and water quality, and biosecurity concerns (Troell et al., 2011; Mmochi, 2015). Obtaining broodstock for commercial production requires the collection of wild, mature breeding stock and conditioning them to scheduled spawning induction. Firstly, this may result in a decrease in natural breeding stocks with potential impacts on natural populations and trophic interactions, but this is likely to be limited and potentially offset by the decrease in pressure on wild caught fisheries through aquaculture production output in the long run. Secondly, parentage of wild stocks are not known and should breeding programmes include commercial offspring (F3 and upwards generations), the risk of inbreeding may be present. Genotype investigation can help in reducing this risk, and over time may contribute to selective breeding programmes. However, such analyses and programmes require technical skills and knowledge, and incur additional costs to operations. Aquaforsk Genetics® is an example of how selective breeding programmes within the aquaculture industry have ensured continued high production output with stocks that are disease resistant and fast growing for various species including salmon, tilapia, prawn and abalone to name a few (www.aquaforskgenetics.com). However, decades of specialised research and technological innovations have been needed to obtain these results. Finfish and prawn also have relatively fast growth and reproduction rates, making such selective programmes easier to implement as opposed to programmes with slow-growing species such as abalone, which are slower in reaching sexual maturity, or in the case of Seychelles red snapper and grouper (~9 years). Commercially important species such as prawn and finfish also require a high protein- (often fishmeal) based diet (FAO, 2014). This demand further increases the pressure on natural fish stock, and innovative methods are and have been developed to ensure that fish by-products and bycatches can be utilised instead of whole natural fish. The use of insect derived proteins is also being explored as alternatives to fish- and/or poultry-meal (Biancarosa et al., 2019; Fontes et al., 2019) and can aid in reducing the dependency on wild caught fisheries to sustain the aquaculture sector. Including natural feeds such as microalgae, macroalgae and seaweeds can further ensure that formulated feed consumption is reduced whilst maintaining productivity. In addition, integrated multi-trophic polyculture systems may ensure the optimal use of any fish and feed waste, thereby increasing production output. Human health and food hygiene and safety are also important considerations with regards to the large-scale production of any organism within confined spaces. Aspects such as chemical and veterinary drug residues are priority areas with regards to ensuring food (especially from animal origin) is fit for human consumption. More recently, the presence of micro-plastics has also been highlighted with regards to food safety and can potentially have huge impacts on food production from the ocean (SAPEA, 2017; EU, 2017). Continuous monitoring by the Seychelles Fishing Authority (SFA) has shown that selected contaminants such as heavy metals are well below the World Health Organisation's (WHO) limits for human consumption for a number of top predatory fish (SFA, Unpublished data). Nevertheless, some concern exists with regards to leachate from waste dumping areas within the coastal zones of the Inner Islands and can pose some risk to aquaculture production in the future if left unchecked (Lesperance *pers. comm*.). Plastic pollution also poses a risk and warrants additional research. Currently, the University of Plymouth, through the Oceans Without Limits Foundation, is conducting research on marine plastic pollution and micro-plastics within Seychelles. Results from this and similar studies will aid in elucidating the impact of plastics on fisheries in Seychelles.

Progress to date

Considerable steps have been taken towards the development of aquaculture within Seychelles. In 2015, Lesperance and Hecht provided an overview of the history of aquaculture in Seychelles and highlighted challenges faced at that time and previously (Table 5). Since then the Mariculture Master Plan has been finalised, ESIA and EMPS have been formulated, Environmental Authorisation has been granted, and construction on the broodstock, acclimation and quarantine holding facility has been started. Policies and standards have been formulated, i.e. Seychelles Aquaculture Regulation and associated Standards, however these have yet to be gazetted and applied. Training of key personnel has started, although there is still a heavy reliance on foreign skilled technical staff and expertise. Investment opportunities should arise with improvements in Seychelles fiscal standings and its financial sector. There has also been an active drive to promote public interest in aquaculture and the Blue Economy, to both garner support for the sector as well as increase local knowledge about aquaculture and the associated opportunities within the value chain.

The lack of progress beyond the experimental phase, however, is cause for concern. Initial investments into these programmes require sustained drive and motivation to support them in the long-term. It is often envisaged that aquaculture facilities will provide income, employment and revenue to stakeholders and the country within a couple of years of operation. However, these expectations are often unrealistic as the return on investment can take up to 10 years, even for species with very high market value such as abalone. Consequently, feasibility studies must include long-term operational goals and key performance indicators that will drive the process beyond the initial phases, as well as employ skilled personnel, specifically in the operational and logistical roles for animal production units. Development of infrastructure can also be phased and grow-out expanded as the production capacity increases. This will ensure that the projects are not over capitalised initially. Leasing infrastructure may also aid in reducing the initial capital investment of smaller companies, or even the small-scale aquaculture sector. Market access is another vital aspect of aquaculture, and presently access to established markets is key to the success of any venture. Often, partnerships with companies that already have that access is encouraged, and for SIDS this may be a viable solution to gain market access. Locally, government support for aquaculture ventures must extend to sound policy formulation and enabling regulations that do not place unnecessary restrictions on the industry. These can include clear tax incentives, well-managed import and export regulations, and skilled observers with regards to animal health and food safety and hygiene. The value chain of aquaculture should also be clearly highlighted in the feasibility studies and should include the support services to operations such as electricity and water supply, maintenance artisans (including mechanics, plumbers, and millwrights), quality assurance, processing, canning/drying, warehousing, and logistics. Showcasing the added benefits to various sectors will further garner support and investment into the sector, and will further highlight the interdisciplinary nature of a true Blue Economy.

Table 5. Previously identified challenges to aquaculture development in Seychelles and their progress to date

Challenge	Addressed	Way forward
Poor knowledge	Partially	Drive to promote Aquaculture & Blue economy
Lack of public interest	Partially	Active demonstrations, visitor centre, mainstream media involvement
Competition with artisanal fishery	Partially	Will require continuous engagement and providing alternatives to livelihoods (i.e. value added chain)
Lack of strategic planning	Yes	MMP & Blue Economy Roadmap (currently) Aquaculture Sector Development Plan, SFA Strategic Plan & Aquaculture Policy (awaiting approval)
Lack of investment (due to poor fiscal performance of country post 2008)	Yes	Overall Seychelles financial status has improved and should continue to do so thereby appealing to potential investors.
High operational costs	No	Extremely high costs of electricity compared to other countries Construction costs also very high in Seychelles
Scientific / Technical skills shortage	Partially	Some training has occurred with regards to animal health and biosecurity, however, foreign expertise is still required
Legislative frameworks	Partially	Aquaculture Standard and Regulations have been formulated, but yet to be approved and applied.
Government support	Yes	MMP and Blue Economy Roadmap. It is vital that there be a champion for aquaculture that will continue to garner support for the sector. In addition, institutional support through creation and staffing of the Aquaculture Division within SFA.

Conclusion

Increased demand on wild caught fisheries have and will continue to have a significant impact on natural stocks and consequently on food security and the economy of Seychelles. Aquaculture, globally, has increased substantially over the last few decades with countries such as China, Korea, Norway, Chile and many more leading the way in innovative technologies and production systems. The Western Indian Ocean region has great potential for aquaculture development, especially in light of the high dependence on fisheries for economic and food stability. However, to date, very little progress has been made in this sector despite experimental trials in a number of countries within the WIO. Challenges most often include lack of adequate knowledge and skills in this sector, difficulty in obtaining investment and market access, high operational and feed costs, and poor seed/spat quality, as well as poor infrastructure support such as electricity supply and transportation. For Seychelles in particular, high operational costs, lack of investment, insufficient knowledge and skills, as well as competition with a strong artisanal fishing sector have proven to be challenging in establishing aquaculture as a viable and productive sector of the economy. Nevertheless, great progress has been made over the last 5 years through strong government support and the Blue Economy platform garnering financial and local support for aquaculture development. To this end, the MMP has been developed, legislative frameworks have been formulated and better overall strategic planning has been conducted. The momentum that has been created however, must be maintained through continued research, engagement and the active pursuit of investment and markets. Partnerships with established companies within the aquaculture sector may be advantageous in this regard and should be pursued. The success of the broodstock facility will highly influence the way forward for aquaculture in Seychelles, both through the successful spawning of target species for grow-out production, as well as in developing local expertise and knowledge in the sector. Consequently, research and development must remain the focus during this initial phase, together with procedural development and skills training. Aquaculture development in Seychelles will be a long term process and would require a champion to ensure that support is maintained over the lifetime of the project from government, the public and investors.

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