THE FUTURE OF THE WESTERN CAPE AGRICULTURAL SECTOR IN THE CONTEXT OF THE 4TH INDUSTRIAL REVOLUTION

Review: Aquaculture

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1. Technology Overview and Detailed Description

Aquaculture, (also known as fish or shellfish farming) refers to the breeding, rearing, and harvesting of plants and animals in all types of water environments including ponds, rivers, lakes, and the ocean. Researchers and aquaculture producers are "farming" all kinds of freshwater and marine species of fish, shellfish (crustaceans), molluscs, algae (phytoplankton, microphytes, or planktonic algae) and aquatic plants. Aquaculture produces food fish, sport fish, bait fish, ornamental fish, crustaceans, molluscs, algae, sea vegetables, and fish eggs.

Aquaculture includes the production of seafood from hatchery fish and shellfish which are grown to market size in ponds, tanks, cages, or raceways. Stock restoration or "enhancement" is a form of aquaculture in which hatchery fish and shellfish are released into the wild to rebuild wild populations or coastal habitats such as oyster reefs. Aquaculture also includes the production of ornamental fish for the aquarium trade, and growing plant species used in a range of food, pharmaceutical, nutritional, and biotechnology products.

Marine aquaculture refers to the culturing of species that live in the ocean. Marine aquaculture primarily produces oysters, clams, mussels, shrimp, and salmon as well as lesser amounts of cod, moi, yellowtail, barramundi, seabass, and seabream. Marine aquaculture can take place in the ocean (that is, in cages, on the seafloor, or suspended in the water column) or in on-land, manmade systems such as ponds or tanks. Recirculating aquaculture systems that reduce, reuse, and recycle water and waste can support some marine species.

Freshwater aquaculture produces species that are native to rivers, lakes, and streams. U.S. freshwater aquaculture is dominated by catfish but also produces trout, tilapia, and bass. Freshwater aquaculture takes place primarily in ponds and in on-land, manmade systems such as recirculating aquaculture systems.

Kinds of aquaculture include fish farming, shrimp farming, oyster farming, mariculture, algaculture (such as seaweed farming), and the cultivation of ornamental fish. Methods include aquaponics and integrated multi-trophic aquaculture, both of which integrate fish farming and plant farming.

Aquaculture techniques: In lieu of the different types of organisms harvested through aquaculture, the techniques of harvesting have also evolved. Table 1 below is a summary of the techniques employed in aquaculture, as well as the species applicable to each.

Table 1: Aquaculture techniques

Technique	Description	Examples
Extensive fresh water aquaculture	Ponds are maintained to promote the development of aquatic fauna at a yield greater than that found in the natural ecosystem. Fish numbers are kept low and fish feed naturally, although feed can be supplemented.	Carp, in mixed farming with other species (whitefish, zander, pike, catfish.
Aquaculture of marine species in shore-based installations	Marine fishes (particularly flatfishes) can also be bred in artificial shore-based tanks supplied with seawater, so that the recirculation of the water form a closed and controlled environment that is optimized for production in hatcheries and nurseries for marine species.	Turbot, common sole, Senegalese sole, sea perch, gilt-head sea bream
Extensive brackish water aquaculture	The animals (often brought in by the marine flow) are kept in lagoons developed for this purpose. The semi-extensive nature of this breeding is reinforced by introducing hatchery fry and supplementing feed, and is important for natural coastal heritage conservation	Sea perch, eel, common sole, Senegalese sole, sea bream, mullet, sturgeon, shrimps and shellfish.
Intensive fresh water aquaculture	Here, fish are bred in tanks until they reach marketable size. There are two techniques: (a) continuous flow (river water enters tanks upstream and leaves downstream) and (b) recirculation (the water remains in a closed circuit and is recycled and 'recirculated' in the tanks). Recirculation systems are costlier (because of higher energy consumption), but allow for better control breeding conditions such as temperature and oxygen, as well as water quality.	Rainbow trout, eel, catfish, sturgeon, tilapia,
Marine cage aquaculture	The fish are reared in cages that are anchored to the seabed, and maintained on the surface by means of floating plastic frameworks. The breeding is practiced in covered zones near the shore, however more sophisticated techniques, which incorporate submersible cages, remote monitoring, automatic feeding may make it possible to move the cages further from the shore.	Atlantic salmon, sea perch, sea bream, meagre,
Shellfish farming	Shellfish farming is based on the collection of wild or hatchery spat, which feed on natural nutrients found in the environment (filter-feeding animals), and accounts for 90% of European production of oysters using this technique.	Oysters (oyster farming), mussels (mussel farming), clams and abalones.

2. Application Examples and Case Studies

The literature contains several examples of successful aquaculture establishments, with statistics on their performance. The reader is directed to cited literature[1, 2] for details of case studies.

3. Technology or Application Life Cycle: Current Status and Expected Development in 2020 and 2025

Aquaculture lends itself to technological advances, and therefore expected applications by 2020, and 2050. These expectations are listed below in Table 2.

Table 2: Expected technology applications in aquaculture

Technology Area	Current application in agriculture	Expected applications in agriculture by 2020	Expected applications in agriculture by 2050
Aquaculture	Recirculation systems or closed fish systems (energy-efficient and produce less waste)	Increased interest in the re-use of residual flows, such as the remains of processed fish products, offal and shells of mussels and oysters; Advanced water purification systems with no required for the addition of chemicals	The further intensification of aquaculture due to the application of advanced biotechnology

4. Business Eco-System View

Aquaculture overlaps with the following technologies:

- Biorefinery and biofuels
- Synthetic biology
- Genetics
- Protein transition
- Sensor technology
- Renewable energy

5. Benefits and Risks

Aquaculture has become the most rapidly growing agricultural production system in the world over the last four decades[3]. Production of both fish and crustaceans has boomed, with an annual growth rate of 7.8% worldwide between 1990 and 2010[4]. This growth was enabled by realization by most countries, especially South-Saharan African countries that food security and resource use are linked to job creation and economic growth[5], and by the expansion of the area dedicated to aquaculture production and the intensification of aquaculture systems following important investments in the sector.

Technological (e.g. breeding systems, feeds, vaccines) and non-technological (e.g. improved regulatory frameworks, organizational structures, market standards) innovations have

enabled the growth of the aquaculture sector within a broad spectrum of production systems[6,7]

The benefits and risks of aquaculture are listed below in Table 3[8].

Table 3: Benefits and risks of aquaculture

Benefits	Risks
Job creation in community	Conflict with other users of water bodies such as lobstermen, fishermen or migrating fish
Increase city, state and national level revenue	Excess pressure on wild stocks used to create high protein feed pellets
Reduction in seafood trade deficit, and in fish price export earnings	Amplification and transfer disease and parasites to wild fish populations
A source of protein feed	Pollution of water systems with excess nutrients (fish feed & wastes), chemicals and antibiotics
Attraction of local investment	Compromise of native gene pools if farmed fish and native species interbreed
Increase in scientific knowledge and technology	Can threaten livelihood of fishermen
Emphasize protection of coastal waters from pollution, especially in the case of mollusc and seaweed culture.	An unpredictable enterprise for small local communities due to its susceptibility to severe weather, predators, disease, and global competition
Can provide a viable socio-economic alternative to capture fisheries, especially in over-fished municipal waters	Can compromise the aesthetic beauty of coastline
Reduction in fishing pressure on certain wild stocks through aquaculture	Environmental damage which enhances the risk of import bans from the EU and the US because of environmental concerns.
Increase in fish supplies	Conflict over resource usage and the creation of a resource sink
Conservation of social structure	Limited attention to the social role of aquaculture, inadequate support to smallholder farmers
Improved infrastructure in rural areas	Trade restrictions, if not targeted at achieving sustainable practices, can limit economic development and local food supply
A cheap source of animal protein for the masses in rural areas, including those countries with no access to the sea;	Restricted domestic and intra-regional markets, dearth of market information; restrictive trade barriers, challenges to implementing international standards, including lack of support mechanisms to achieve this goal
Can be developed on land which is no longer suitable for farming and/or on land in conjunction with other farming systems, or major water bodies whose natural productivities have shown signs of decline from over-exploitation or environmental degradation l lagoons, man-made lakes, and floodplains	
Can be operated either on a small scale, at low cost, and utilizing family/community labour, or on a large scale, at high cost, and utilizing more machines and less hands and in both instances, fulfil the objectives for which it was established	
Can be small- or large-scale, can be carried out on land-based sites and in fresh, brackish, or saline	

Benefits	Risks
environments, can make use of extensive, semi-intensive, or intensive methods for a great variety of culture species with different economic values	
Products can be sold fresh or processed in either domestic or international markets	

6. Potential Economic, Social, Ecological (Environmental) and Political Developments and Impacts

Economic Developments and Impacts

With an average annual growth rate of 8.8% over the last 30 years, aquaculture is the world's fastest growing agro-food sector. Mean annual global fish consumption climbed from 16 kg per capita in 2000 to a record high of 18.6kg per capita in 2010, because of this rapid expansion. By 2018, half the fish used for direct human consumption will be farmed[9] and by 2022, aquaculture is forecast to provide an additional 22 million tons of fish; an increase of 35% over current levels[10].

A study[11] showed that in Bangladesh, aquaculture growth was driven by the achievement of greater technical efficiencies, which in turn resulted in a decrease in the price of fish over a period of ten years, or that the prices remained constant over this period. This trend had the effect of generating greater demand (and therefore more commercialization) and accordingly, more supply of fish to the extremely poor and moderately poor. Similar trends were observed by others[12, 13,14] in studies conducted in Thailand, India and other global territories.

The FAO published the following updated statistics:
World aquaculture production continued to grow in 2013, reaching 97.2 million tonnes (live weight) with an estimated value of USD157 billion. A total of 575 aquatic species and species groups grown in freshwater, seawater and brackish water have been registered in the FAO Global Aquaculture Production statistics database.

- The production of farmed food fish (finfish, crustaceans, molluscs and other aquatic animals) was 70.2 million tonnes in 2013, up by 5.6% from 66.5 million tonnes in 2012. The production of 27 million tonnes of farmed aquatic plants was a 13.4% jump on the 23.8 million tonnes of 2012.
- The contribution of aquaculture to the world total fish production reached 43.1 %, up from 42.1% in 2012. It was only 30.6% a decade ago in 2003. Meanwhile, world

production of aquatic plants, mostly seaweeds, is still overwhelmingly dominated by aquaculture (95.5% in 2013).

- On a global scale, the production of major non-fed species contributed 30.7% to world food fish aquaculture production in 2013, including 13.9 million tonnes of bivalves and 7.7 million tonnes of filter-feeding carps. The great potential of marine bivalve aquaculture in most maritime countries in Africa and Central America remains untapped.
- Following Asia, Africa improved its share in world farmed food fish production, up from 1.3% in 2003 to 2.3% in 2013. The shares of the Americas and Europe declined gradually to all-time lows of 4.4 and 4 %, respectively, in 2013. Oceania has held steady at 0.3% since 2001. The overall situation of highly imbalanced aquaculture development status and uneven distribution of production remains largely unchanged.
- Globally, inland finfish aquaculture has been the most important driver for total increase in annual output. This subsector contributed 64.9% to the 2003–2013 increase in world farmed food fish production.

The global production of food fish from inland aquaculture and mariculture by continent is shown in Table 4.

Table 4: Food fish production by continent (tons, live weight)[15]

		2004	2006	2008	2010	2012	2013
Africa	Inland aquaculture	546 229	739 383	928 296	1 273 583	1 467 979	1 594 069
	Mariculture	12 659	15 096	14 632	12 858	17 408	21 539
	Subtotal	***558 888***	***754 480***	***942 929***	***1 286 441***	***1 485 387***	***1 615 608***
Americas	Inland aquaculture	732 546	752 019	828 429	977 186	959 599	986 017
	Mariculture	1 410 204	1 616 511	1 673 956	1 604 020	2 018 361	2 082 738
	Subtotal	***2 142 750***	***2 368 530***	***2 502 386***	***2 581 206***	***2 977 959***	***3 068 755***
Asia	Inland aquaculture	22 792 152	26 045 457	30 187 149	34 065 292	39 065 422	41 645 016
	Mariculture	14 102 439	15 734 314	16 813 938	18 375 080	19 890 348	20 901 648
	Subtotal	***36 894 591***	***41 779 771***	***47 001 087***	***52 440 372***	***58 955 770***	***62 546 664***
Europe	Inland aquaculture	468 204	442 954	478 623	466 615	461 480	455 722
	Mariculture	1 704 980	1 749 764	1 851 427	2 077 363	2 415 246	2 325 403
	Subtotal	***2 173 184***	***2 192 718***	***2 330 050***	***2 543 978***	***2 876 726***	***2 781 125***
Oceania	Inland aquaculture	1 546	2 392	2 217	3 691	4 231	4 042
	Mariculture	137 899	158 397	172 839	181 957	177 226	173 653
	Subtotal	***139 445***	***160 789***	***175 056***	***185 648***	***181 458***	***177 695***
World	Inland aquaculture	24 540 677	27 982 205	32 424 714	36 786 367	41 958 711	44 684 866
	Mariculture	17 368 181	19 274 082	20 526 792	22 251 278	24 518 589	25 504 981
	Subtotal	***41 908 857***	***47 256 287***	***52 951 509***	***59 037 646***	***66 477 300***	***70 189 848***

Figure 1 below is a diagrammatic representation of Table 4.

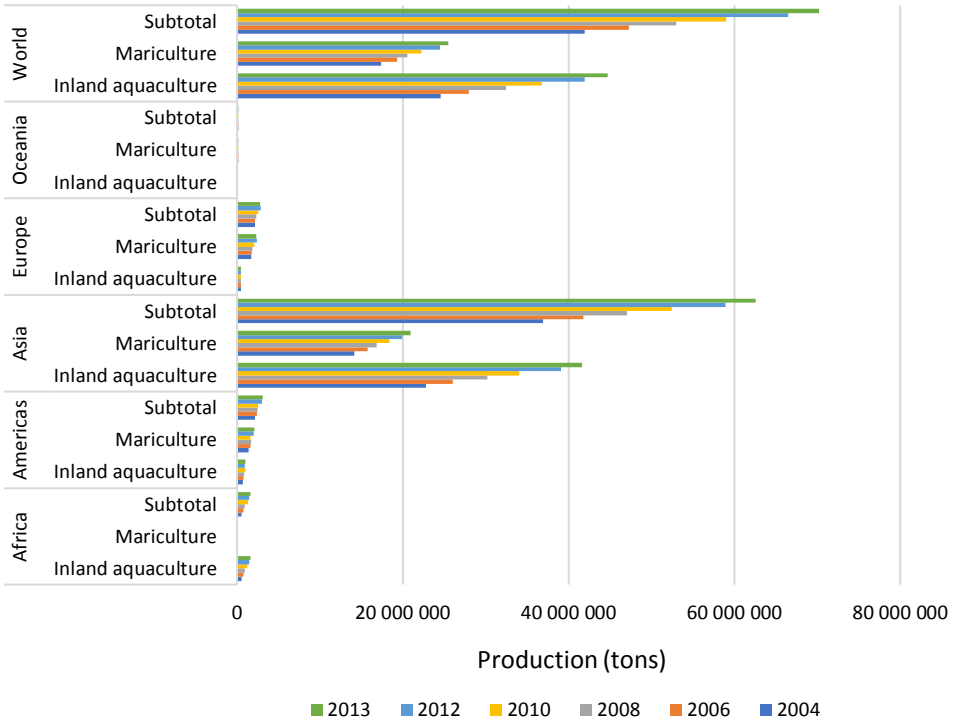

Figure 1: Food fish production by continent

The low performance of Africa is ascribed to sub-optimal use of water and land resources, poor infrastructure, lack of production inputs (and therefore lower productivity and yield). This can be reversed if positive perceptions about aquaculture are promoted, sound national policies are developed, nutrient inputs are made available, credit to commercial enterprises in availed, and if conducive investment incentives are put in place to attract private sector funding.

Table 5 below shows the top food fish aquaculture producers in Africa[16].

Table 5: Top food fish producers in Africa in 2012

Country	Tonnage	%age
Egypt	1 017 738	68.5%
Nigeria	253 898	17.1%
Uganda	95 906	6.5%
Ghana	27 450	1.8%
Kenya	21 488	1.4%
Zambia	12 988	0.9%
Madagascar	8 588	0.6%
Tunisia	8 577	0.6%
Zimbabwe	8 010	0.5%

Country	Tonnage	%age
South Africa	3 999	0.3%
Côte d'Ivoire	3 720	0.3%
Tanzania§	3 407	0.2%
Malawi	3 232	0.2%
DR of Congo	2 869	0.2%
Algeria	2 648	0.2%
Rest of Africa	10 849	0.7%
Totals	**1 485 367**	**100%**

§excludes Zanzibar

From Table 5 above, South Africa ranks tenth in Africa, producing close to 4000 tonnes in 2012, which represents 0.3% of the African continent's total production.

Global market access issues

Global market access issues in aquaculture include the introduction of a mandatory Hazard Analysis and Critical Control Point (HACCP) based strategy, risk assessment, consumer information and protection, labelling and traceability, and are particularly of concern to developing countries. The issues which are important for market access are related to: (i) design of trade-related standards; (ii) global support for the implementation of trade-related standards; and (iii) mechanisms for monitoring compliance.

Social Developments and Impacts

The rapid growth of the aquaculture sector, due to innovation developments, has had social impacts, such as privatization of common resources[17], exclusion of producers from global aquaculture value chains[18], reduction of incomes and employment in the fisheries sector[19]. The income distribution is often skewed in favour of largescale farmers and owners. Small farmers lack financial resources for investment in shrimp farming, processing or trading, and the gender balance in the shrimp export industry in many countries is biased toward male workers. Small-scale aquaculture farmers, local fish processors and traders, hatchery workers, owners of fish ponds and procurement staff of processing plants and auctioneers earn a moderate income. By contrast, the large-scale aquaculture producers and owners of hatcheries, depots, processing factories, ice plants, trading and export business are well-off and contribute to economic development in the region. They also contribute to economic activity in the societies in general through their higher demand in the production process as well as through their private consumption[20].

Aquaculture has also been a source of high quality protein for poor households and vulnerable groups in developing countries which, without any other options, would not afford

fish for their personal consumption. Aquaculture is also considered to be a contributor to rural development and poverty reduction as it forms an important component within agriculture and farming systems development. As such, many poorly-resourced people depend directly or indirectly on this sector for their livelihood[21].

Higher productivity, made possible by technological changes, and the associated reduction in production costs have been the main drivers of growth in modern aquaculture production and trade[22]. Shrimp and salmon are good examples of this. Aquaculture products are an increasingly important source of foreign exchange in many fish-producing countries, as well as a contributor to increased food production, employment and economic development in those countries. In poor countries, aquaculture contributes to poverty alleviation and food security through employment and income generation for several million people[23].

Ecological (Environmental) Developments and Impacts

Aquaculture has had the following reported impacts on the environment (destruction and pollution of coastal and aquatic ecosystems[24,25, 26, 27], salinization of land and aquifers[28], introduction of exotic species into ecosystems[29, 30], transmission of disease and parasites to wild populations[31], and depletion of wild fish stocks to produce fish meal and fish oil used in aquaculture feed[32,33, 34]).

Aquaculture clearly generates environmental and social costs, which vary with the scale, intensity and duration of farming operations. The environmental impacts of shrimp culture, for example, include increased soil salinity, reduction in agricultural production, decrease in livestock production, water pollution and the destruction of mangrove forests. Shrimp cultivation has also negative impacts on biodiversity through the destruction of trees, grasses and crabs in the areas of operation. Environmental problems are also observed in terms of displacement of wild population, genetic impacts, parasites and diseases, effects on wild life, aquaculture wastes, chemicals and antibiotics, and feeds and feed conversion ratio. In addition to the environmental effects, health and social issues have also been raised as major concerns. The human health impacts of farmed salmon have received attention in recent years due to high fat levels, existence of various contaminants and use of antibiotics[35].

The literature has reported on the possible environmental impacts of aquaculture, which are summarized in Table 6 below.

Table 6: Possible environmental impacts of aquaculture (modified from[36])

CULTURE SYSTEM	ENVIRONMENTAL IMPACT
EXTENSIVE	
1. Seaweed culture	May occupy formerly pristine reefs; rough weather losses; market competition; conflicts/failures, social disruption.
2. Coastal bivalve culture (mussels, oysters, clams, cockles)	Public health risks and consumer resistance (microbial diseases, red tides, industrial pollution; rough weather losses; seed shortages; market competition especially for export produce; failures, social disruption.
3. Coastal fishponds (mullets, milkfish, shrimps, tilapias)	Destruction of ecosystems, especially mangroves; increasingly non-competitive with more intensive systems; unsustainable with high population growth; conflicts/failures, social disruption.
4. Pen and cage culture in eutrophic waters and/or rich benthos (carps, catfish, milkfish tilapias)	Exclusion of traditional fishermen; navigational hazards; conflicts, social disruption; management difficulties; wood consumption.
SEMI-INTENSIVE	
1. Fresh- and brackish water pond (shrimps and prawns, carps, catfish, milkfish, mullets, tilapias)	Freshwater: health risks to farm workers from waterborne diseases. Brackish water: salinization/acidification of soils/aquifers. Both: market competition, especially for export produce; feed and fertilizer availability/prices; conflicts/failures, social disruption.
2. Integrated agriculture-aquaculture (rice-fish; livestock/poultry-fish; vegetables - fish and all combinations of these)	As freshwater above, plus possible consumer resistance to excreta-fed produce; competition from other users of inputs such as livestock excreta and cereal brans; toxic substances in livestock feeds (e.g., heavy metals) may accumulate in pond sediments and fish; pesticides may accumulate in fish.
3. Sewage-fish culture (waste treatment ponds; latrine wastes and septic tank wastes used as pond inputs; fish cages in wastewater channels)	Possible health risks to farm workers, fish processors and consumers; consumer resistance to produce.
4. Cage and pen culture, especially in eutrophic waters or on rich benthos (carps, catfish, milkfish, tilapias)	As extensive cage and pen Systems above.
INTENSIVE	
1. Freshwater, brackish water and marine ponds (shrimps; fish, especially carnivores - catfish, snakeheads, groupers, sea bass)	Effluents/drainage high in BOD and suspended solids; market competition, especially for export product; conflicts/failures, social disruption.
2. Freshwater, brackish water and marine cage and pen culture (finfish, especially carnivores -groupers, sea bass, including omnivores such as common carp)	Accumulation of anoxic sediments below cages due to faecal and waste feed build-up; market competition, especially for export produce; conflicts/failures, social disruption; consumption of wood and other materials.
3. Other - raceways, silos, tanks	Effluents/drainage high in BOD and suspended solids; many location-specific problems.

Political Developments and Impacts

The fisheries sector of South Africa contributes roughly 0.1% to the GDP, which is small, even by agricultural standards. However, it is more important for economic development in the Western Cape where 11 of the 13 proclaimed fishing harbours are situated. These contribute

more the 5% to the Gross Provincial Domestic Product. The total output is estimated at 600 000 tons worth about R6 billion, depending on the pelagic catch of pilchards and anchovy, which could be as much as 600 000 tons.

It is estimated that the direct employment in the industry constitutes approximately 27 000 jobs (16 000 in the primary sector and 11 000 in the secondary and tertiary sectors), while an additional 81 000 people are indirectly employed in industries that are at least partially dependent on the fishing sector. Fisheries output is determined by catch volumes, which, in turn, depend on the health and management of fish stocks, varying according to ecological changes and subjected to overexploitation through illegal, unreported and unregulated fishing activities.

In-shore species are especially vulnerable to stock depletion, as they are easily accessed, especially illegally. According to one study, 68% of commercial line fish stocks have collapsed, and another 11% is overexploited. DAFF seeks to prevent overexploitation by means of assigning total allowable catch (TAC) and/or total allowable effort (TAE) per species, which are adjusted on a regular basis, depending on the estimated state of the resource. DAFF has also sought to promote transformation in the sector through inclusion of small-scale fishing communities. The amended Marine Living Resources Act (MLRA) will grant small-scale fishing communities better access to fishing rights and resources.

The effective management of the existing 12 harbours and proclamation of additional new harbours will support resource management. Although wild catch fisheries appear unlikely to expand beyond their present levels, aquaculture is becoming more important as a substitute for wild capture fisheries. While the marine-based “mari-culture” part of aquaculture has been around for some years, focusing on species such as abalone, oysters and mussels, freshwater aquaculture is experiencing a rapid expansion, owing in part to government`s multipronged aquaculture promotion campaign.

In 2011 the total output of aquaculture was 1 884 tons with an estimated value of R0,5 billion. Growth of production in this sector has been increasing at the rate of 7% per annum since 2010, providing 3 000 direct jobs and another 3 000 indirect jobs. Unlocking the economic potential of the ocean along the 3 000 kilometre coastline was crystallised through the Operation Phakisa initiative. Operation Phakisa focused on the pillars of the oceans economy, each of which was treated as a laboratory and which developed several aspirations. The aspirations of the aquaculture laboratory, if all the identified inhibitors are addressed, are that aquaculture will by 2019 be grown to a R3 billion sector, producing 20 000 tons of fish and 15 000 direct jobs. Therefore in 2015/16, 23 projects will be piloted to find lasting solutions to the inhibitors facing the sector and to create and enabling environment for the sector to achieve the projected aspirations.

Challenges to South Africa's fisheries sector

The fisheries sector is a small, yet significant contributor to the country's economy and provides food and jobs for many South Africans. However, this sector, like many other traditional economic sectors, has been experiencing a considerable decline over the past few years. Challenges in this regard include the international economic recession and increasing global competition and shrinking markets; environmental factors such as migratory patterns of marine species and climate change, increasing illegal fishing and poaching and a higher demand for access to the finite marine resources. These challenges necessitate strategic shifts in the way in which resources are allocated, accessed, managed and policed.

- **Limited natural resources:** The sector is facing declining, and in some instances, collapsing fish stocks, while at the same time the country is experiencing a growing reliance on the fish resources as a source of food security. The challenge to the department is to address recovery and rebuild measures for depleted stocks; to allocate the finite resources in a way that deals with the competing challenges of transforming the sector; to provide access to resources to the previously excluded small-scale fishing sector, while remaining globally competitive, but managing the resources sustainably; broadening the scope of aquaculture and supporting fishing communities to find alternative livelihood avenues in order to ensure sustainable food security.
- **Access to markets:** Persistent changes in the global market conditions continue to pose challenges to the fisheries sector's ability to access markets for the exportation of fishing products and economic growth.
- **Climate change:** This has resulted in the migration of natural resources from their original habitat, therefore leading to increasing levels of poverty, unemployment, infrastructure dilapidation owing to either closure and/or relocation of fish-processing facilities to other areas.
- **Illegal fishing:** Fisheries generally is a highly contested industry, both locally and globally. It is plagued by syndicated crime, overexploitation of high-value species, corruption and poor compliance levels. The department, therefore, should introduce comprehensive responses to this complex, highly technical and technologically advanced challenge by intensifying its monitoring and compliance efforts and working in close cooperation with other law enforcement agencies[37]

Department of Agriculture, Forestry and Fisheries (DAFF) response

The purpose of DAFFs fisheries Programme is to promote the development, management, monitoring and sustainable use of marine living resources and the development of South

Africa's fisheries sector. To date, the following steps have been taken by DAFF in response to the opportunities presented by the aquaculture sector:

- Aquaculture has been identified as one of the key priorities in DAFFS 5-year strategic plan
- A Chief-Directorate responsible for aquaculture management has been established
- The National Aquaculture Strategic Framework (NASF), discussed below, has been finalised.

Sustainable livelihoods will be promoted through aquaculture growth and fisheries economic development. The programme comprises five sub-programmes, namely Aquaculture and Economic Development; Fisheries Research and Development; Marine Resources Management; Monitoring, Control and Surveillance and Fisheries Operations Support.

Aquaculture Competitiveness Improvement Programme (ACIP)[38]

Globally, aquaculture is expanding rapidly at an average of approximately 9% annual growth rate. The contribution of aquaculture to total fisheries consumption has increased, however, South Africa's contribution towards global aquaculture production remains very low at less than 1%. The following are critical constraints that must be addressed to enable growth, as identified by DAFF:

- Insufficient primary infrastructure in rural areas.
- Research & Development is fragmented and is not align with industries' needs. This is linked to limited extension support services, and lack of awareness of the sector as a career option
- Lack of access to quality inputs. Quality seed, fingerlings and feed are critical to the health and quality of the products, and, due to the limited scale, there are a limited number of quality input suppliers to the sector, as this adds to an increase in the cost of production
- Limited participation by youth, women and black people in the sector
- Unsupportive legislative and regulatory environment - current regulation and governance systems are not supportive in terms of reducing the compliance burden (a barrier to the sector), addressing the exclusion of the aquaculture sector is often excluded from spatial planning
- The aquaculture sector is not readily financed, and is considered a high-risk sector.
- Accessibility to markets is limited, as the sector value chains are underdeveloped.

National Aquaculture Strategic Framework

The DAFF, together with its partners in the government and private sector, have developed a National Aquaculture Strategic Framework and its Action Plan that guides the development

of an equitable, diverse, viable, competitive and sustainable aquaculture sector for South Africa. Cabinet approved the National Aquaculture Policy Framework (NAPF) for implementation, and the Operation Phakisa initiative is expected to fast track the deployment of aquaculture. Major interventions identified include an integrated approach to promoting investment in production and support infrastructure, funding for research and development, establishment of industry/farmer support and management programmes, and most importantly personnel and capacity building.

The NAPF is summarised into ten high-level interventions as specified below.

The Ten Point Plan will:

- Create an enabling, integrated regulatory and operational environment for developing an equitable and globally competitive aquaculture sector for South Africa.
- Increase access to available public and private land and water bodies for utilisation for aquaculture purposes.
- Ensure that appropriate funding instruments are put in place to attract private and public investments into the sector.
- Make provision for a reliable supply of good-quality and affordable seed and feed to all fish farmers.
- Ensure adequate investment in the undertaking of aquaculture research and development to ensure technical knowledge and transfer of technology which will make the aquaculture sector highly competitive.
- Implement environmental and biosecurity programmes to assure food safety and enhance quality of aquaculture products.
- Increase South African aquaculture products' market share locally and internationally.
- Ensure information management and dissemination to create awareness and promote aquaculture as a socially, environmentally and economically viable activity.
- Create partnerships and coordination between various government departments, industry and the private sector.
- Invest in capacity building and skills development in government, fish farmers and the private sector.

Working for Fisheries Programme (WfFP)

The WfFP serves to render a programme management support function to the DAFF Fisheries Branch. The main objective of the programme is to contribute towards poverty alleviation through interventions that are public-directed while advancing the mandates of the DAFF and the EPWP's Environment and Culture Sector Plan. The programme, through the implementation of projects, aims to contribute towards the alleviation of poverty while

empowering beneficiaries to participate in the mainstream fishing economy in a manner that aligns the programme and projects to government outcomes. The programme focuses on supporting three key directorates within the department in terms of both mandate and the projects funded. These directorates are:

- Aquaculture and Economic Development
- Monitoring, Control and Surveillance
- Marine Resource Management.

Resource allocation

Funding allocated for fisheries development by DAFF is illustrated below in Table 7, supported by an implementation strategy.

Table 7: Resources allocated by DAFF to the fisheries sector

Per Sub-programme	2015/16	2016/17	2017/18
	R'000	R'000	R'000
Management	2 168	2 283	2 427
Aquaculture and Economic Development	32 298	34 010	36 152
Monitoring, Control and Surveillance	72 950	76 818	81 656
Marine Resources Management	19 653	20 694	21 998
Fisheries Research and Development	57 575	60 625	64 445
Marine Living Resources Fund	258 623	268 441	281 864
Total	443 267	462 871	488 542

Annexure 1 illustrates the alignment of Aquaculture with the key policy mandates of DAFF, articulated in the NDP, and APAP, and illustrates where Aquaculture and possibly technologies of the future may be used to support the delivery of the South African governments proposed interventions as articulated in the APAP.

The South African aquaculture industry

Aquaculture in South Africa consists mainly of freshwater species such as Rainbow trout, brown trout, Koi carp, crocodiles, Ornamental fish, African catfish, Mozambique and Nile tilapia, Marron and Waterblommetjies; and marine species such as abalone, white prawns, oysters, seaweeds, Spanish & Brown mussels, Dusky & Silver Kob, yellow tail, Atlantic Salmon, Clownfish, White Margined Sole, West& East coast rock Lobster, Scallop and Blood Worm. Freshwater species are generally farmed in re-circulating systems, earth ponds or raceways whereas the marine molluscs are farmed on raft or long-lines, and abalone are produced in

tanks through which marine water is pumped. The technology and services are well established for species such as trout, crocodiles, catfish, abalone, prawns and oysters, mussels while still lacking for species such as eel, tilapia, cob, tuna and seaweed. Abalone remains the prominent success story of South African aquaculture.

By the end of 2012 a total of 195 aquaculture farms were in operation with 34 marine and 161 freshwater farms. Although, there are more than 195 farms operational in aquaculture, a greater proportion of them are small -scale farmers producing with a production out of 5 to 50 tons.

The Western Cape province of South Africa has the largest number of farms of aquaculture (50 in number) accounting for 26% of South African farms, followed by Mpumalanga 22%, Gauteng 12%, and Limpopo 10%. The remainder of the provinces in South Africa account for less than 10% of farms. Marine aquaculture production dominated in the Western Cape accounting for 87% of the total production (1 986 tons) (the marine **and** freshwater sub-sector produced a combined total of 2 574 tonnes in 2015, which was the highest recorded production of all the provinces in South Africa)[39], followed by the Eastern Cape with 12% (290 tons) and Northern Cape and KwaZulu Natal accounting for less than 1% each.

The aquaculture sector on the other hand, employed 2,227 people directly on farms during 2012 on a full-time basis. This number could be doubled if indirect jobs and services such as; feed manufacturing, fish processing, security, transport, packaging, manufacturing of equipment, and research and government services is taken into consideration. The number of job opportunities is expected to increase with the projected increase of more than 100% by 2020. To unlock this potential, the South African government's Operation Phakisa Aquaculture Lab (Unlocking the Economic Potential of the Oceans) developed an inspiration to increase aquaculture growth by five-fold in the next five years from 4,000 to 20,000 tons, and further create 15,000 jobs and increase the contribution of aquaculture towards GDP.

The key constraints to the South African aquaculture industry are the following:[40]

- Uncoordinated institutional environment;
- Lack of appropriate technology;
- Difficulties in obtaining suitable culture sites;
- Inadequate public-sector support measure to pioneer farmers;
- High production costs;
- Lack of local quality feed; and
- Lack of access to suitable water quantity and quality for freshwater aquaculture

The Western Cape Aquaculture industry

Elsewhere in this report, high-level statistics of the aquaculture industry in the Western Cape were presented. In addition, research was commissioned by the Department of Economic Development and Tourism (DEDAT) in collaboration with the Department of Agriculture (DoA) and the Western Cape Aquaculture Development Initiative (WCADI), which resulted in a (draft) Aquaculture Market Analysis and Development Programme/Strategy. The research output was primarily on matters of market development, for identified fish species, and certain strategic country markets. Specific recommendations were made on how to develop the market for each of the identified fish species, however, broader recommendations were made with respect to the aquaculture sector of the Western Cape province, which by the nature of these regional recommendations, could be extended to national level. These broader recommendations are summarised below:

a. Targeted research agenda

This report provides insight into those species / species groups that show market potential. Research should focus on those species that show the best market potential in the short term, for those where existing technologies or technology transfers are already available. In consultation with the tertiary research institutions, industry players, and national and provincial government departments, research needs must be identified and coordinated into an integrated national and provincial research agenda. Research funding must be solicited in accordance with this research agenda to ensure that research funding is channelled appropriately and utilised in accordance with market demands. Furthermore, it would be appropriate to engage the private sector, industry, national and provincial government departments and programmes that have research / technology development mandates (e.g. DAFF, DST Innovation fund, DoA - WCARF THRIP, NRF) to align their research funding with the national and provincial research agenda. Further research could relate to production, processing and packaging, e.g.:

- Commercialisation of production technologies e.g. cage culture.
- Product selection to meet market requirements and premium e.g. larger abalone, environmentally sustainable production methods
- Processing for improved yield, quality characteristics or shelf life e.g. pressure sealed oysters
- Modified atmosphere packaging

b. Investment support

To promote capital investment into the sector, value propositions need to be developed to attract government and private sector investment and funding. Support from government can include funding/incentives and in-kind support e.g. state land for the

development and establishment of Aquaculture Development Zones (ADZ"s). There are overall areas where interventions are required, for example, there has been substantial primary research on feed technology. However, support is required is to assist feed manufacturers to secure machinery and technology to produce high quality aquaculture feeds. Currently the size of the South African aquaculture market is not large enough to warrant heavily capital investment in specialised aquafeed production (specialist extrusion machines, pelletisers, for example) by private feed companies. Government incentives would be helpful to encourage this investment, and could potentially be accommodated within existing enterprise development incentives. Assistance is also needed for capital investments for primary production and processing, for bivalves and finfish where production capacity is less established (whether through incentives, development finance or risk or venture capital).

c. Capacity building and training

Capacity and training need to be developed at all levels. At present, there is a lack of capacity of professionals and training institutions specialising in technology development, technical training or skills development for middle services, basic training for unskilled workers, and a lack of supporting skills training for HDIs participating in SMEs. Training must be done in step with the development of the sector so that it addresses the real need of the sector at all levels.

d. Product safety

Product safely issues and the requirements for phytosanitary measures to export shellfish are currently constraining enterprise sustainability and successful exporting. Traceability protocols are increasingly required by retailers and distributors and need to be developed for all sectors producing aquatic products for human consumption. The Department of Agriculture, Forestry and Fisheries (DAFF), the Department of Trade and Industry (the DTI) through the National Regulator for Compulsory Standards (NRCS) and the South African Bureau of Standards (SABS) are responsible for providing standardisation services that improve the competitiveness of South African industry, products and services. These institutions need to provide support and guidance in terms of providing cost effective phytosanitary services to the industry.

e. Compliance with legislation

Compliance with environmental legislation South Africa's environmental legislation represents a major potential challenge to sector development. There are important initiatives underway to support the development of the Aquaculture Sector in the context of environmental regulation, e.g. the Development of Standards for the Aquaculture Sector by the Department of Environmental Affairs and Development Planning (DEA&P) in collaboration with the Department of Environmental Affairs (DEA)

and DAFF. Proactive intervention is therefore necessary as environmental legislation affects all stages of aquaculture development. There is an argument to provide facilitated compliance with legislation.

Such facilitation could take many forms such as assisting companies, Aquaculture Development Zones (ADZs) with the EIA / basic assessment processes, assisting in the cost of compliance with shellfish sanitation and monitoring, NRCS testing for drug residues, traceability and health certification. Assistance should also be provided in relation to site permitting, water permitting and compliance with other regulations. Any such assistance would need to be structured so that the support was offered until industry reaches a critical mass.

7. Conclusions

The introduction of semi-intensive and intensive farming practices revolutionized aquaculture, as producers started to actively influence the growing conditions of the fish with feeding, breeding and other technological interventions. The control of the production process that was obtained also allowed several productivity-enhancing innovations to be implemented.

Aquaculture production primarily takes place in the developing world, and particularly in Southeast Asia. It is a source of economic growth as well as increased food production in many countries of this region. This tremendous growth has provided several opportunities with respect to greater food security, improved livelihoods and reduced poverty.

A lower production cost due to productivity growth is the main engine for growth in aquaculture production. Lower production cost makes aquaculture production of different species profitable in many countries. As lower production costs increase profitability, this will lead to increased production and lower prices. This also makes aquaculture products competitive in the markets where they are sold, whether these be export or domestic. This productivity growth is possible because of the higher degree of control over the production that is present in aquaculture relative to traditional fisheries. To obtain this control, one also needs to move towards relatively intensive production techniques.

While most aquaculture production takes place in developing countries, the research seems more focused on species that are farmed in developed countries. Hence, there seems to be a further productivity growth potential if more research is focused on tropical and subtropical species. Such research has the potential to be very valuable with respect to food security and economic development.

As aquaculture production increases, this will limit and possibly reduce the prices paid to fishermen for most species. As this reduces the profitability in the fisheries, it will reduce fishing effort and pressure on the fish stocks. Another likely positive effect will be that of increased food production and, therefore, lower prices. This will not only make healthy and affordable food available to more people, but will also reduce land-based food production as this becomes less profitable for farmers. The result may therefore be a reduced pressure on soils and forests.

Recommendations

1. Invest in research[1]
2. Embrace digital technologies in aquaculture, such as 3-D printing of hydroponic systems, fish feed, autonomous robotic fishing cages, the use of drones to collect marine data, the use of smart sensors to control, for example feeding rate, the use of artificial intelligence for decision-making, and the incorporation of blockchain in transactions involving fish (from fishery to plate).
3. Encourage expansion of aquaculture, by establishing public feed systems, cold stores, fish marketing facilities and coordinated energy supplies.
4. Apply trade measures carefully, by reducing regional trade barriers, and harmonizing import/export regulations
5. Improve the transparency of trade measures
6. Address aquaculture's environmental problems
7. Improve management practices, including implementing coordinated spatial plans, which consider climate change adaptation (CCA) and disaster-risk management (DRM) strategies
8. Develop and support regional networks of excellence
9. Implement nutritional programmes which promote local procurement

The role of government

Government must ensure that the fish farmers are provided with the necessary support in their production endeavours, mainly by way of:
(i) adequate market infrastructure facilities and services (e.g., farm-to-market roads, fishing ports, processing plants, ice plants and cold storage facilities);
(ii) effective training and extension services;
(iii) continuing research and development efforts; and

[1] High quality, cheaper feeds for specific species and life stages, hatcheries, seed guarantee and certification systems, commercial viability, value-chain improvement, impact pathways, veterinary services

(iv) credit/funding assistance, including the provision of financial incentives like tax credits and the tax-free import of essential equipment/machinery and supplies and materials.

Critical success factors

The success of an aquaculture venture is possible if the following critical success factors are met:

- the market for the product is assured;
- the selected species is amenable to culture and fulfils the standard criteria for a good candidate species;
- the site selected is suitable for the species to be cultured;
- the technology for the selected species and type/method of culture is available;
- the production and support facilities are properly designed and built;
- the operation is efficiently managed so that the various production inputs are properly utilized and are made available at the right time;
- adequately trained and skilled labour is available to run and operate the enterprise; and
- adequate funding is in place and/or credit is available for development and operation

8. Synthesis and key trends from the literature

The following trends in the aquaculture sector in Sub-Saharan Africa were described, and are summarized in Table 8 below.

Table 8: Aquaculture sector industry trends in Sub-Saharan Africa (SSA) (adapted from an FAO report[41]).

Category	Issue	Trend
Resources/ services/ technology support	Land and water	Water is scarce, mainly due to drought; there is competition for access to water by different users; degradation of water sources (pollution) is prevalent.
	Seed/fingerlings	Reliable and abundant seed/fingerling sources are very scarce in SSA countries.
	Genetic resources	Public and private sector breeding programmes for certain fish types are advanced.
	Feed	Feed mills are being developed, and expanded, although price differentiation is caused by imports and availability.
	Animal health support	Government sources are frequently relied upon.
	Financial support	Credit is not readily extended to aquaculture farmers, although this has improved.
	Infrastructure	Basic infrastructure is lacking in SSA.
	Technical capacity	Modern technology is embraced, especially in seed development, feed and genetic resources.
Environmental aspects	Availability of land and water	Land and water resources to support aquaculture are scarce in SSA.
	Nutrient loading	Nutrient discharge from residential homes and farms contaminate aquaculture facilities.
	Biodiversity integrity	The introduction of alien species has negative environmental effects.
	Land ownership	Tenure and ownership of land are disrupted by aquaculture practices.
	Environmental stability	Integrated aquaculture systems have been applied in drought-prone regions.
	Public perceptions	There is misalignment between sustainable environmental practices and public perceptions of aquaculture.
Markets and trade	Marketing and distribution	Marketing, processing and distribution of fish is done primarily by women in SSA.
	Exports and imports	Internal demand is met through imports from territories outside SSA.
	Value chain development	Aquaculture value chain is not well developed because of poor infrastructure, policies, and limited access to capital.
	Food safety and certification	Exporting countries have adopted certification and labelling as marketing tools for product.
	Increased product demand	Four developments will increase the demand for aquaculture (1) increasing population (2) lowering of wild fishery reserves (3) awareness on the health benefits of fish (4) preferred and affordable animal protein.
Food security, social & economic development	Supplies	The per capita fish consumption in SSA in 2014 is projected to increase due to rising income, urbanization and awareness of the nutritional value of fish, not found in staples foods such as rice, cassava, wheat or maize.
	Employment wealth and income	Aquaculture is a year-round, better-paying job creator (farm technicians, temporary employment for youths and women) in several countries; larger farms have become hubs of knowledge and technology transfer for new players.
	Gender redress	34% of employees in the aquaculture sector are women, where they own 16% of the operating farms, involved directly in post-harvest processing and marketing of the fish.

Category	Issue	Trend
	Industry organization	Farmers' associations exist in some fish producing countries; private sector involvement in the training of the next generation of farmers and student interns takes place on private farms with less reliance on government extension services; larger hatcheries provide (paid) training programmes to their customers; some private individuals or farmers' associations sell aquaculture supplies, equipment, feed, chemicals, pharmaceuticals and fertilizer, and also provide information for beginners or established fish farmers.
Challenges to the sector	Climate change - temperature	Water depth, algal blooms and unexpected hot weather threaten the sector.
	Sea level rise	Sea level rises cause land erosion, salinization and flooding.
	Acidification	Increasing levels of atmospheric carbon dioxide have a direct effect on oceanic pH.
	Water levels	Low annual rainfall, higher temperatures and high evaporation rates threaten the existence of small ponds.
	Extreme weather	Tropical storms and cyclones cause flash floods and lower salinity.
Governance in the sector	Policies, frameworks and plans	These exist, and need to be aligned to support measures; long time lapses between policy formulation, adoption and action plans often cripple initiatives.
	Legislation	Certification and quality standards for export, including HACCP systems have been met by some countries
	Transboundary governance	Principles such as that of the EAA in the Volta water body ecosystem are being applied and improved upon.

End Notes

[1] FAO. 2016. *The state of world fisheries and aquaculture: contributing to food security and nutrition for all*. [Online] Available: http://www.fao.org/3/a-i5555e.pdf [Accessed: 23 October 2017].

[2] Satia, P. 2017. Regional review on status and trends in aquaculture development in Sub-Saharan Africa – 2015

[3] Food and Agriculture Organization of the United Nations (FAO). 2016. The state of world fisheries and aquaculture. Rome: FAO.

[4] Troell, M., Naylor, R.L., Metian, M., Beveridge, M., Tyedmers, P.H. *et al*. 2014. Does aquaculture add resilience to the global food system? *Proc. Natl. Acad. Sci*., **111**, 13257-13263

[5] Satia, P. 2017. *Regional review on status and trends in aquaculture development in Sub-Saharan Africa – 2015.* FAO Fisheries and Aquaculture Circular No. 135/2. Rome: FAO.

[6] Klinger, D. & Naylor, R. 2012. Searching for solutions in aquaculture: charting a sustainable course. *Annu. Rev. Environ. Resour*., **37**, 247-276.

[7] Lebel, L., Mungkung, R., Gheewala, S.H. & Lebel, P. 2010. Innovation cycles, niches and sustainability in the shrimp aquaculture industry in Thailand. *Environ. Sci. Pol*., **13**, 291-302.

[8]. Neiland, A.E., Shaw, S.A. & Bailly, D. 1991.The social and economic impact of aquaculture: An European review. In N. de Pauw & J. Joyce (eds), *Aquaculture and the environment*. European Aquaculture Society Special Publication No. 16. Gent, Belgium, 469-482.

[9]Food and Agriculture Organization of the United Nations (FAO). 2012. *The State of World Fisheries and Aquaculture*. Rome: Fisheries and Aquaculture Department, FAO.

[10] Organisation for Economic Co-operation and Development and Food and Agriculture Organization (OECD-FAO). 2013. *OECD-FAO Agricultural outlook 2013–2022 highlights*. OECD-FAO.

[11] Toufique, K.A. & Belton, B. 2014. Is aquaculture pro-poor? Empirical evidence of impacts on fish consumption in Bangladesh. *World Development*, **64**, 609-620.
[12] Belton, B., Little, D. 2008. The development of aquaculture in Central Thailand: Domestic demand versus export-led production. Journal of Agrarian Change, 8(1), 123–143.
[13] Kumar, P., Dey, M. M., Paraguas, F. J. 2005. Demand for fish by species in India: Three-stage budgeting framework. Agricultural Economics Research Review, 18(2), 167–186.
[14] Tveterås, S., Asche, F., Bellemare, M.F., Smith, M.D., Guttormsen, A.G. *et al*. 2012. Fish is food: The FAO's fish price index. *PLoS ONE*, **7**(5), E36731.
[15] Food and Agriculture Organization (FAO). 2015. *Global aquaculture production statistics database updated to 2013*. Fisheries and Aquaculture Department. [Online] Available: http://www.fao.org/3/a-i4899e.pdf [Accessed: 24 October 2017].
[16] Food and Agriculture Organization (FAO). 2014. *Global aquaculture production volume and value statistics database updated to 2012*. Rome: Fisheries and Aquaculture Department.
[17] Hall, D., 2004. Explaining the diversity of Southeast Asian shrimp aquaculture. *J. Agrar. Chang*., **4**, 315-335.
[18] Islam, M.S. 2008. From pond to plate: towards a twin-driven commodity chain in Bangladesh shrimp aquaculture. *Food Policy*, **33**(3), 209-223.
[19] Stevenson, J.R. & Irz, X. 2009. Is aquaculture development an effective tool for poverty alleviation? A review of theory and evidence. *Cah. Agric*., **18**, 292-299.
[20] Asche, F. & Khatun, F. 2006. *Aquaculture: Issues and opportunities for sustainable production and trade*. ICTSD Natural Resources, International Trade and Sustainable Development Series Issue Paper No. 5. Geneva, Switzerland: International Centre for Trade and Sustainable Development.
[21] Asche, F. & Khatun, F. 2006. *Aquaculture: Issues and opportunities for sustainable production and trade*. ICTSD Natural Resources, International Trade and Sustainable Development Series Issue Paper No. 5. Geneva, Switzerland: International Centre for Trade and Sustainable Development.
[22] Asche, F. & Khatun, F. 2006. *Aquaculture: Issues and opportunities for sustainable production and trade*. ICTSD Natural Resources, International Trade and Sustainable Development Series Issue Paper No. 5. Geneva, Switzerland: International Centre for Trade and Sustainable Development.
[23] Asche, F. & Khatun, F. 2006. *Aquaculture: Issues and opportunities for sustainable production and trade*. ICTSD Natural Resources, International Trade and Sustainable Development Series Issue Paper No. 5. Geneva, Switzerland: International Centre for Trade and Sustainable Development.
[24] Hamilton, S. 2013. Assessing the role of commercial aquaculture in displacing mangrove forest. *Bull. Mar. Sci*., **89**, 585-601.
[25] Primavera, J.H. 2006. Overcoming the impacts of aquaculture on the coastal zone. Ocean Coast. *Manag*., 49, 531-545.
[26] Rico, A., Satapornvanit, K., Haque, M.M., Min, J., Nguyen, P.T. *et al*. 2012. Use of chemicals and biological products in Asian aquaculture and their potential environmental risks: A critical review. *Rev. Aquac*., **4**, 75-93.
[27] Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A. *et al*. 2001. Forecasting agriculturally driven global environmental change. *Science*, **292**, 281-284.
[28] Paez-Osuna, F. 2001. The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. *Environ. Manag*., **28**, 131-140.
[29] De Silva, S.S., Nguyen, T.T.T., Turchini, G.M., Amarasinghe, U.S., Abery, N.W. 2009. Alien species in aquaculture and biodiversity: a paradox in food production. *Ambio*, **38**, 24-28.
[30] Naylor, R., Hindar, K., Fleming, I.A., Goldburg, R., Williams, S. *et al*., 2005. Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. *Bioscience*, **55**, 427-437.
[31] Diana, J.S., Egna, H.S., Chopin, T., Peterson, M.S., Cao, L., Pomeroy, R. 2013. Responsible aquaculture in 2050: valuing local conditions and human innovations will be key to success. *Bioscience*, **6**3, 255-262.
[32] Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M. *et al*. 2000. Effect of aquaculture on world fish supplies. *Nature*, **405**, 1017-1024.

[33] Klinger, D. & Naylor, R. 2012. Searching for solutions in aquaculture: charting a sustainable course. *Annu. Rev. Environ. Resour*., **37**, 247-276.
[34] Deutsch, L., Gräslund, S., Folke, C., Troell, M., Huitric, M. *et al.* 2007. Feeding aquaculture growth through globalization: exploitation of marine ecosystems for fishmeal. *Glob. Environ. Chang*., **17**, 238-249.
[35] Weber, M.L. 2003. *What price farmed fish: A review of the environmental and social costs of farming carnivorous fish*. Providence, RI: SeaWeb Aquaculture Clearinghouse.
[36] Pullin, R.SV. 1989. Third world aquaculture and the environment. *NAGA, The ICLARM Quarterly*, January.
[37] Department: Agriculture, Forestry and Fisheries (DAFF). 2015. *Strategic Plan 2015/16 to 2019/20*. [Online] Available: http://www.daff.gov.za/doaDev/topMenu/DAFF_SP_%20complete.pdf [Accessed: 23 October 2017].
[38] Department: Agriculture, Forestry and Fisheries (DAFF). 2015. *Agricultural Policy Action Plan (APAP) 2015–2019*. [Online] Available: https://agbiz.co.za/uploads/documents/news/Newsletter/2015/3%20March/15_03_12%20APAP%2012%20November%20(3).pdf [Accessed: 23 October 2017].
[39] Wesgro. 2016. *Fish and Aquaculture sector fact sheet*. [Online] Available: http://www.wesgro.co.za/research?ResearchID=-1qHqiYNzz [Accessed: 2 November 2017].
[40] Department: Agriculture, Forestry and Fisheries (DAFF). 2015. *A profile of the South African aquaculture market value chain*. [Online] Available: http://www.nda.agric.za/doaDev/sideMenu/Marketing/Annual%20Publications/Commodity%20Profiles/field%20crops/Aquaculture%20market%20value%20chain%20%20profile%202015.pdf [Accessed: 28 October 2017].
[41] Satia, B.P. 2017. *Regional review on status and trends in aquaculture development in Sub-Saharan Africa – 2015*. Rome: FAO.