AN OVERVIEW OF THE STATUS OFAQUACULTURE IN THE WESTERN INDIAN OCEAN REGION: A REVIEW

By

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ABSTRACT

The aim of this review is to give a detailed overview of the status of aquaculture in the Western Indian Ocean Region. Emphasis is based on the legislation, cultured species and candidate species for aquaculture. The review also describes the most recommended species for aquaculture in the region in terms of biology, environmental constraints and factors that inhibit a successful growth. This review covers the Western Indian Ocean (WIO) countries: South Africa, Mozambique, Tanzania, Kenya, Madagascar, Mauritius and Seychelles. Different sources of information are used such as annual reports of each country from Food and Agriculture Organisation (FAO), governmental reports, countries profiles available in the internet. Extensive and semi-intensive aquaculture systems are the most practiced in the WIO countries. Little information is available regarding the environmental impacts associated with aquaculture. The region presents a good potential for developing mariculture, although mariculture activities are not yet developed and cannot satisfy the local and international demand for aquatic products. South Africa presents a noticeable development in rearing abalone *Haliotis midae* while Madagascar and Mozambique the marine shrimp *Penaeus monodon*. *P. monodon* is the main species reared in the WIO region. Marine species are the most recommended for the region, as opposed to freshwater species, due to the vast coastline. Generally, improvements in the current legislation relating to aquaculture are needed in most of the WIO countries. Mozambique and Madagascar present significant progress in the development of legal framework relating to aquaculture; however, similar efforts have been seen in all countries evaluated. The results of the SWOT (Strengths, Weakness, Opportunities, and Threats) analyses show that the major strength presented by the region is the availability of suitable areas for the aquaculture development. The main strengths regarding aquaculture are the availability of good water quality and Government commitment in developing the sector. The WIO region presents good opportunity to improve the coordination between institutions, avoiding duplications in the process of application for permits. The weaknesses are related mostly to the lack of aquaculture development plans and, although many countries have come as far as drafting such plans, the implementation thereof is still low. The review provides an overview of the current status of aquaculture in the WIO region as well as provides recommendations for best aquaculture practices and species that are economically and ecologically suitable. Recommendations are made based on the SWOT analyses for the individual WIO countries from well established aquaculture practicing countries.

PREFACE

The literature review describes the current status of aquaculture in the WIO region. The review evaluates in detail seven countries, namely South Africa, Mozambique, Tanzania, Kenya and the islands Madagascar, Mauritius and Seychelles. The evaluation is based on the assessment of legislation of each WIO country and the species cultivated. SWOT analyses for each country are performed and a summary of the main aquaculture issues is provided, as well as recommendations for future aquaculture development.

This dissertation represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

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DECLARATION – PLAGIARISM

I, **ELISA CLOTILDE INGUANE VICENTE**, declare that:

1. The results reported in this dissertation, except where otherwise indicated, is from my original research.

2. This dissertation has not been submitted for any degree or examination at any other university.

3. This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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    a. Their words have been re-written but the general information attributed to them has been referenced
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Signed

Elisa Clotilde Inguane Vicente

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ACRONYMS

ACRSP	Aquaculture Collaborative Research Support Programme
AISA	Aquaculture Institute of South Africa
ASGISA	Accelerated and Shared Growth Initiative for South Africa
BLME	Benguela Large Marine Ecosystem
CSIR	Council for Scientific and Industrial Research
DA	Departments of Agriculture
DAFF	Department of Agriculture, Fisheries and Forestry
DEAT	Departmenet of Environmental Affairs and Tourism
DST	Department of Science and Technology
DTI	Department of Trade and Industry AASA Aquaculture Association of Southern Africa
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EFA	Enviro-Fish Africa
EIA	Environmental Impact Assessment
EL	Environmental Licence
FAO	Food and Agriculture Organisation
FOFIFA	National Centre of Applied Research and Rural Development
GDP	Gross domestic product
IAP	Institute for Animal Production
ICEIDA	Icelandic International Development Agency
ICT	Information Communication Technologies
IDZ's	Industrial Development Zones
IFTZ	Industrial Free-Trade Zones
IIP	National Institute for Fisheries Research

IMS	Institute of Marine Science
INAQUA	National Institute for Aquaculture Development
JICA	Japanese International Cooperation Agency
KMFRI	Kenya Marine and Fisheries Research Institute
MAEP	Ministry of Agriculture Livestock and Fisheries
MICOA	Ministry for Coordination and Environmental Affairs
NACA	Network of Aquaculture Centres in Asia-Pacific
NEPAD	New Partnership for Africa's Development
NGO	Non Governmental Organisation
NORAD	Norwegian Agency for Development Cooperation
ReCoMap	Regional Coastal Management Programme of The Indian Ocean Countries
SWOT	Strengths, Weakness, Opportunities, and Threats
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
WIO	Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association
WIORAIA	Western Indian Ocean Regional Assessment and Institutional Analysis
WRM	World Rainforest Movement

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DEDICATION

I proudly dedicate this dissertation to my husband Enoque Mendes Vicente and my daughters Kiana Jendaye Mendes Vicente and Luana Keyah Mendes Vicente.

1. INTRODUCTION

1.1 Definition, Purpose, Advantages and Disadvantages of Aquaculture

Aquaculture is the "farming of aquatic organisms such as fish, molluscs, crustaceans and aquatic plants, in closed/opened reticulated water systems whereby feed and aeration is provided for survival" (Pullin, 1993; Food and Agriculture Organisation of the United Nations (FAO, 2004). Aquaculture can be divided into two categories; freshwater aquaculture (also inland aquaculture) whereby inland operations are undertaken by utilising freshwater bodies such as rivers and lakes, while marine aquaculture, termed mariculture, utilises marine or brackish water ecosystems. Both mariculture and freshwater aquaculture can include aquatic plants (Brummett *et al*., 2008).

The main purpose of aquaculture is to enhance food production thereby ensuring food security for human consumption. In many African countries aquaculture has focused mainly on social objectives of improving food security in rural areas, the provision and supplementation of incomes and to create new opportunities of employment as economic prospects within rural communities are limited (Aguilar-Manjarrez and Nath, 1998). Currently, aquaculture is also viewed as an alternative means of supplying the deficit of wild caught fish and to reduce the fishing pressure on natural resources (FAO, 2006a).

According to Pullin (1993) and the FAO (2004), the advantage of aquaculture compared to other forms of animal production is the high quality and more digestible protein and essential fatty acids found within many aquatic organisms as opposed to terrestrial organisms. Fish protein may be more viable economically than that of livestock because fishes are able to convert food into body protein more efficiently by using less energy (Moffitt, 2006). The reasons are that fish, being cold-blooded, do not expend energy to maintain a constant body temperature and excrete ammonia via their gills hence reducing the metabolic cost of excreting excessive dietary nitrogen (Moffitt, 2006).

Aquaculture is currently becoming the fastest growing food production sector when compared to livestock production, accounting for almost 50 percent of the world's produce for edible fish and is considered to be the sector that is able to potentially supply the growing demand for aquatic food (FAO, 2006a; FAO, 2009a). Similar to food production in agriculture, aquaculture carries positive as well as negative aspects (Meserve, 2005). Positive aspects that successful aquaculture operations can contribute towards is an increase in fish availability for human consumption, either locally or globally, creating employment opportunities, enhancing infrastructure development and economic growth (Brummett *et al*., 2008) and decreasing the fishing pressure of wild caught fish . Negative aspects are related to environmental degradation and social disruption due to competition for resources such as water and land, high feeding costs and the lack of institutional and legal support and over-regulation (Welcomme and Barg, 1997).

The disadvantages of aquaculture are mainly related to ecosystems degradation. The effluents from aquaculture farms can release undesired chemicals to receiving waters and adjacent areas if not well managed, causing distress to ecosystems (International Union for Conservation of Nature (IUCN), 2007). Farmed organisms may escape from farms and impact the biodiversity by reducing the biodiversity through predation or increasing the level of hybridism of the population. Introduced animals may also carry foreign pathogens that can be spread to the environment and affect local populations (IUCN, 2007).

Inland aquaculture is the main contributor of the production of warm water species such as tilapias *Oreochromis* spp., followed by gray mullet *Mugil cephalus*, various species of carps *Cyprinus carpio* and *Hypophtalmichthys molitrix* and sharptooth catfish *Clarias gariepinus* as well as coldwater fish species such as rainbow trout *Oncorhynchus mykiss* (Hempel, 2006). Mariculture is still underdeveloped in the Western Indian Ocean region (WIO region) albeit there being huge potential in South Africa, Madagascar, Mozambique and Tanzania (Hempel, 2006). Most of the WIO countries have intensified the production of shrimp culture, fish, seaweed or shellfish. Kenya is also making noticeable advances in mariculture. Mariculture in the WIO region, like inland aquaculture is still at its developmental phase compared to other regions, and the black tiger shrimp *Penaeus monodon* is cultivated in most WIO countries (Hempel, 2006).

1.2 Current Status of Aquaculture in sub-Saharan Africa

Comparing the aquaculture production of the last fifty years, it is clear that the global aquaculture has increased from less than a million tonnes in the early 1950s to more than 59 million tonnes in 2004 (FAO, 2006a). Total production in Africa is about 1% of the world production (Figure 1), of which only 0.2 % comes from sub-Saharan Africa. This is an indication that the sub-Saharan region plays a minor role in aquaculture when compared to other regions in the world, despite it having great natural potential and has shown to increase production from 1950 to 2004 (FAO, 2006a).

Aquaculture production in sub-Saharan Africa increased from 46 882 tonnes to 80 434 tonnes during the period from 1998 to 2004, however, currently farmed fish supply cannot meet regional demand as there is limited investment to support existing fish farmers/projects and new initiatives (FAO, 2006a).

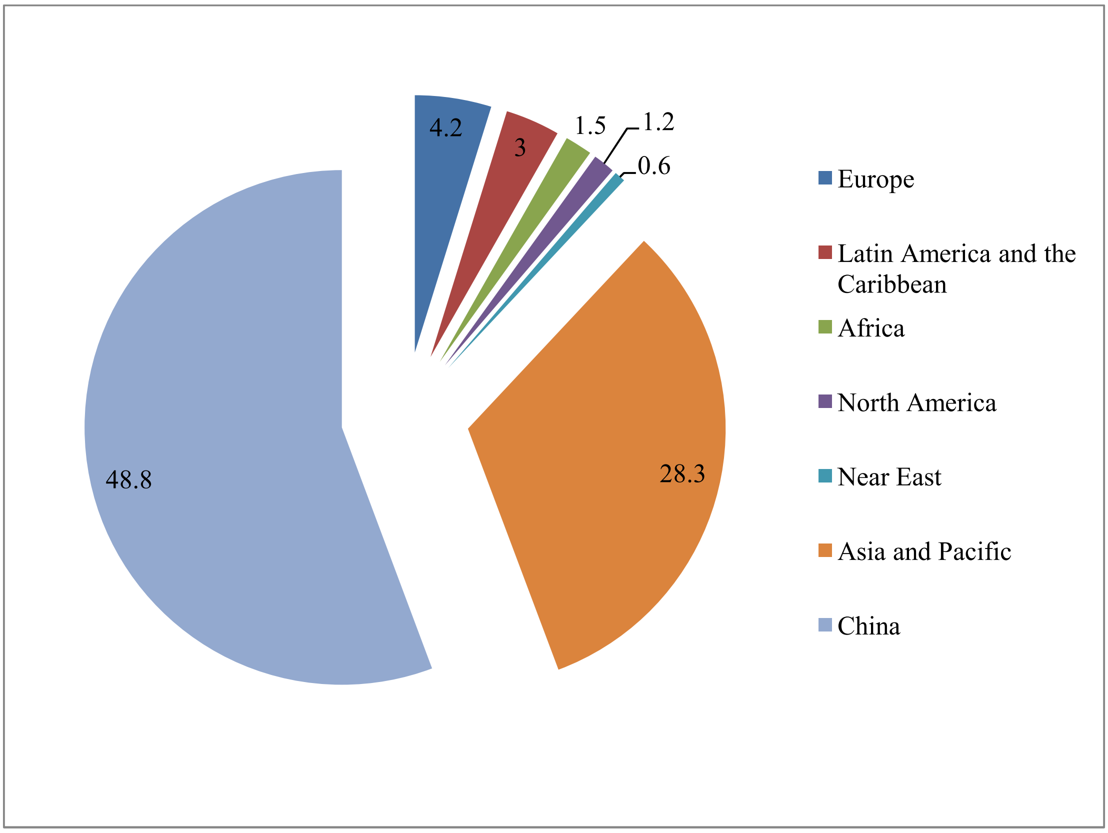

Figure 1 World aquaculture production per region for 2006 shown in percentages. Adapted from FAO (2009)

According to FAO (2009), small-scale aquaculture can be defined as a "continuum of (1) systems involving limited investment in assets, some small investment in operational costs, including largely family labour and in which aquaculture is just one of several livelihood enterprises and generally using informal management structure (also known as rural aquaculture or community based aquaculture) and (2) systems in which aquaculture is the principal source of livelihood, in which the family/operator has invested substantial livelihood assets (time, labour, infrastructure and capital) and may or may not be organized as an enterprise" (FAO, 2009). Large scale aquaculture is related to productivity and profit, although there are, other types of aquaculture between small and large scale operations; given their broad meaning, it would be meaningless and unnecessary to assign a name to every one of them (FAO, 2001b).

Small scale community based aquaculture projects are being carried out in some African countries including Cote d'Ivoire, Ghana, Malawi, Namibia, Nigeria and Zambia. Apart from these, large-scale commercial practices are well developed in Ghana, Kenya, Malawi, Namibia, Nigeria, South Africa and Zimbabwe (Hempel, 2006). Furthermore, there are few large-scale commercial aquaculture ventures that remain notable in Africa such as the seaweed export from Tanzania and new investments planned for Kenya with regard to rearing tilapia aimed at local markets. Most of these have been developed using foreign or foreign-earned capital and rely on foreign-trained technical expertise (Brummett *et al*., 2008).

Generally aquaculture aimed at the export market is conducted by international companies while those meant for the national market are driven by local and small-scale entrepreneurs (FAO, 2009a). A major problem is that when international companies establish themselves in Africa, they usually import consumables crucial for production (e.g. fish feeds) that are not available locally and export the end product to markets in Asia, Europe and North America. As a consequence they play a minor role at supplying fish to the local populace and contribute little towards the overall gross domestic product (GDP) of the country (FAO, 2009a). Failure by local small-scale entrepreneurs to meet local demands is primarily due to a shortage of highly skilled personnell and expertise in managing the rearing of healthy fingerlings and also a lack of much needed capital. In contrast, the export-orientated farms are usually joint ventures between locals and Asian entrepreneurs who are highly knowledgeable in the field and have the resources available to produce high quality seed (FAO, 2009a).

According to FAO (2006b) tilapia is the main cultured species in Africa; however, the degree by which it is produced is still low compared to other regions/countries. The African leader in terms of the production of freshwater fish (mainly tilapia) is Nigeria whilst Madagascar is leader in terms of shrimp *Penaeus monodon* production, Tanzania for its seaweed production (*Euchema* spp.) and South Africa for its abalone *Haliotis* spp. farming. These countries and Uganda and Zambia are the top six sub-Saharan African countries in terms of aquaculture production and the only ones that produce above 5000 tonnes per year.

Interest for aquaculture in Africa has increased and foreign investors are spreading their interests into many African countries, although the number of challenges are still high (FAO, 2006b; Hempel, 2006). As stated above, the percentage of African production is about 1, 5 % of the world production. Egypt is the only country that has shown a significant increase in yield over the past decade, reaching near 83% of the total African production (Hempel, 2006). The FAO (2009a) predicts that aquaculture in Africa will grow but not at a rate that is sufficient enough to cover the needs of the local and international markets. The predictions are that by 2015 the annual production may reach 20,000 to 30,000 tonnes (FAO, 2009a); however, this continues to be below the potential growth for supplying local demand, which is also expected to grow.

1.3 Historical Background of Commercial Aquaculture in Sub-Saharan Africa

Commercial aquaculture was introduced in sub-Saharan Africa during the 1950s, starting with various fish farming projects and programmes initiated by governments, dependent on external financial and expertise support. The FAO was the main organisation engaged in the development of the aquaculture sector in the 1960s in association with many Non-Governmental Organisations (NGOs) and national and international research communities (FAO, 2006b). According to FAO (2006b), the period between 1970s and early 1990s was regarded as the "golden age" in the aquaculture sector as many projects were developed on the continent with the help of financial support by foreign investors and NGOs. After the 1990s, support for aquaculture reduced significantly as most donors shifted their interest to other pressing issues such as health viz., HIV/AIDS, good governance, education and democratisation. This shift caused not only a decrease in aquaculture development, but also a sharp retreat since most of the aquaculture facilities were abandoned due to a lack of safety, failure to implement advanced technologies, prolonged periods and increased frequency of droughts and political instability (Aguilar-Manjarrez and Nath, 1998; FAO, 2006b).

Many international donor agencies established aquaculture as a tool for ensuring food security and economic development in rural areas, exceeding government's role as the main driving force at developing this sector (Brummett *et al*., 2008). Many projects were targeted directly at the small-scale sector, with the objective that the implementation of low cost systems could be more productive. Initially such initiatives proved to be successful; only to be terminated when external support ceased (Brummett *et al*., 2008). Even with subsidised projects, returns were too low to attract more investments (Brummett *et al*., 2008). An indication that international donors and institutions considering to develop aquaculture initiatives must be realistic in their expectations as many African governments priority key areas are education, health care and other social services above aquaculture. Although aquaculture is considered economically viable, African governments and international donors have failed to successfully implement economically viable projects in Africa. The reason for this failure could be due to a disparity between the priorities of donors, governments and farmers and also the incompetence, a lack of willingness and corruption by many governmental officials (Brummett *et al*., 2008).

The Africa Regional Aquaculture Review organised by FAO in 1999 assembled African countries to assess the reason why aquaculture was not well established and not economically viable on the continent despite many efforts to mitigate the constraints and funds spent to promote it. One of the findings was that aquaculture failures in Africa could ascribe to lack of communication and knowledge/skills transfer whereby investments on Information Communication Technologies (ICT) should be considered in order to improve the global knowledge of African aquaculturists (Aguilar-Manjarrez and Nath, 1998; Moehl, 1999). The establishment of ICTs brings a greater opportunity to facilitate the flow of information and technology services delivery to farmers, creating powerful social and economic networks, improving communication and the exchange of information to address directly developmental goals as implemented e.g. in India (Ravisankar *et al.,* 2009). ICTs can be cost-effective and can bridge the gap in knowledge, bringing changes in attitude and skills between farmers, extension providers and other stakeholders (Ifejika *et al.,* 2008; Ravisankar *et al.,* 2009). Coche *et al.* (1999), on the other hand, pointed out the inefficiency or unavailability of policies, poor extension services and lack of inputs such as fingerlings/seed projects and feed as major factors for the non-viability of aquaculture in Africa. Alternatives presented by Coche *et al*. (1999) to make aquaculture more sustainable is the privatisation of fingerling production and to upgrading extension services through improved information flow to producers. In terms of information and network sharing, its importance in developing the aquaculture sector is given by the Asian aquaculturists as they use, most effectively, the well established communication and knowledge transfer network, the Network of Aquaculture Centres in Asia-Pacific (NACA), (Aguilar-Manjarrez and Nath, 1998). Most recently, the FAO (2006b) recommended the participatory on-farm approach method as a tentative method to develop aquaculture in Africa. Participatory on-farm approach method is a tool which enables farmers to work on their own or with a facilitator to quantify and analyse the production and use of resources at their farms and present different decision outcomes (Dorward *et al*., 2007). This method is used mainly by donor supported projects, however, their long-term sustainability has not been tested (FAO, 2006b).

Most African countries including WIO countries share the same key constraints that hindered their aquaculture potential; although Kenya, Madagascar and South Africa, showed a positive progress in aquaculture development (FAO, 2006a). Furthermore, Madagascar, Mozambique and South Africa introduced applied product labelling while Tanzania developed legislation for labelling and Mauritius became an aquafeed exporter (especially shrimp food) (FAO, 2006b).

The non-commercial aquaculture (subsistence aquaculture) is still the most practiced in the region; however, the commercial sector is starting to gain renewed acceptance and appears to be on the threshold of a new horizon in the region (FAO, 2006a). Although commercial aquaculture is gaining renewed momentum in these regions, it is not clear whether commercial farming is being developed by farmers which have switched from non-commercial to commercial practices or if there is an introduction of new farmers starting in the sector (FAO, 2006a).

The establishment of aquaculture in poor regions of developing countries generally expands at the same pace as that of the countries' economy. A reason for this could be due to poor infrastructure such as rudimentary communications facilities and deficient transport systems that increase production costs when the products are intended to be sold outside of the vicinity of the farm (FAO, 2009a). To change this situation, access to foreign capital and markets can be a solution. Honduras is a good example where foreign capital helped developed tilapia culture that was sold in the United States of America markets at a profit, making a valuable contribution to the country's GDP (FAO, 2009a). Alternatively the outcome of foreign investment into Africa has been dismal as international agencies which have invested about $73.5 million into Africa and $171.3 million for Asia and the Pacific during 1978 to 1984 resulted in Asian countries producing 1000 times more fish than Africa (Brummett *et al*., 2008). This could be due to poor aquaculture management related to the lack of institutional structure to support the sector, lack of an affordable good quality fish feed and also the absence of business planning (FAO, 2006b). Other possibilities could the scarcity of water and cultural differences.

Due to the scenario presented above, many governments around the world are interested at helping the aquaculture industry in Africa to grow by identifying and removing the main constraints that hinder the growth thereof. Those aquaculture practices that are suitable for local conditions and that have a limited/minimal effect on the environment have also been considered (FAO, 2009a). Efforts to develop aquaculture include the need to increase the numbers of farmers and scientists who are skilled and have the necessary expertise. Moreover, the concerns of investors, equipment manufacturers and service providers have also been taken into account (FAO, 2009a).

2. AIM AND OBJECTIVES OF THIS REVIEW

The purpose of this review is to give a detailed overview of the status of aquaculture in the Western Indian Ocean Region (WIO Region) and identify the main constraints against and opportunities for the success of aquaculture. The WIO countries included in this review are South Africa, Mozambique, Tanzania, Kenya and the islands Madagascar, Mauritius and Seychelles (Figure 2). These countries were chosen because (i) they are coastal countries, located along the Indian Ocean, that are suitable for aquaculture ; (ii) the population have a culture of eating fish and other aquatic organisms and (iii) the governments of these countries are interested in increasing total aquaculture production (Moyo and Sara, 2010, pers. comn.). Reviews in aquaculture (see FAO, 2006b; Brummett *et al*. 2008; FAO, 2009a) are regularly conducted; however, updates of these reviews and studies are necessary as new research and knowledge becomes available.

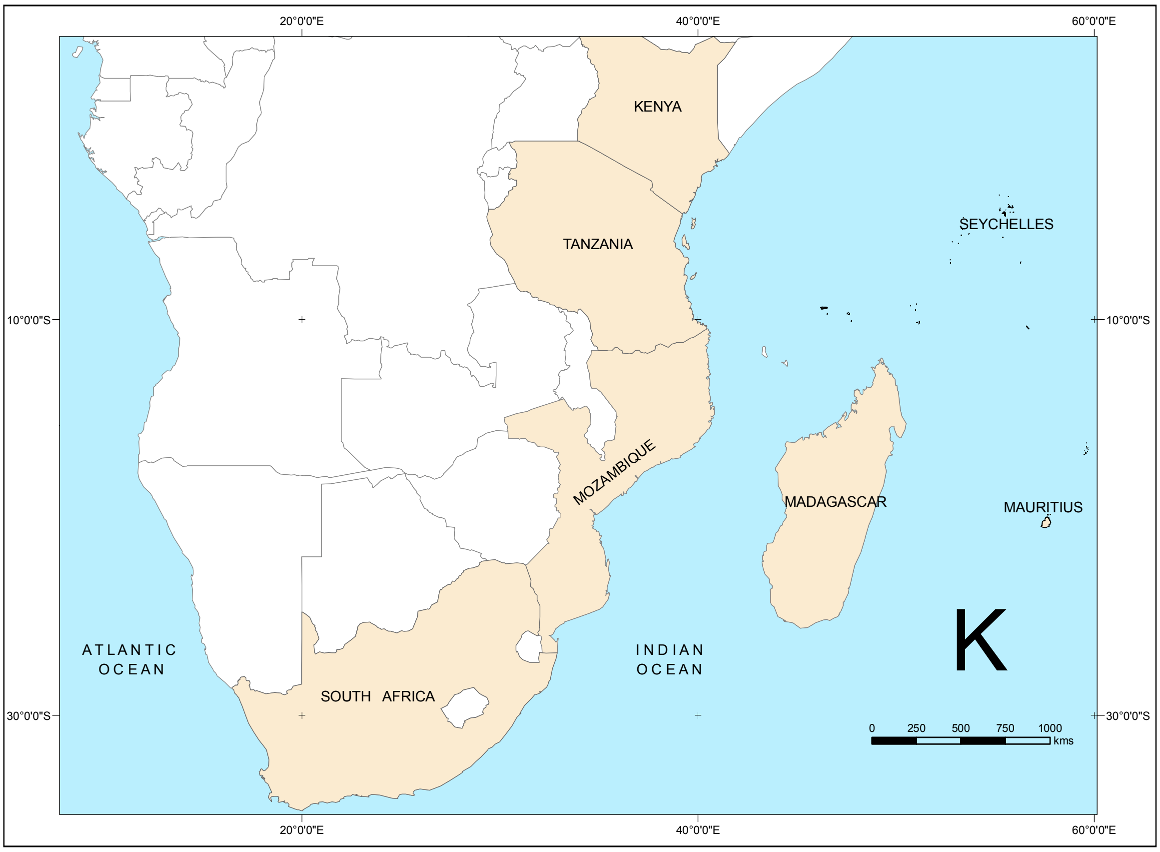

Figure 2 Geographical location of the Western Indian Ocean countries included in this review. The countries of interest are highlighted in orange.

The objectives of the review are to briefly highlight the different aquaculture practices and systems used according to stock density and the impact of aquaculture on ecological and socio-economic environments. The review also analyse the policies and legal frameworks related to aquaculture in WIO countries and identifies the suitable species for aquaculture in the region. A description in terms of the distribution of these species along the region, as well as their biology, environmental interaction and factors that promote and/or inhibit successful growth of farmed and candidate species for aquaculture in the region is also provided. Strengths, Weakness, Opportunities, and Threats (SWOT) analyses are undertaken to identify the main constraints and successes of the aquaculture sector in WIO region.

The objectives of this review are summarised as follow:

- Evaluate the state of aquaculture in the Western Indian Ocean Region ;
- Assess the suitable species for aquaculture;
- Provide recommendations for future of aquaculture development;
- Describe the categories of aquaculture systems and practices; and
- Assess the problems associated with aquaculture.

3. MATERIAL AND METHODS

Different literature and sources of information were used for this review such as:

- FAO reports;
- Governmental reports of the countries;
- Journal articles;
- Countries profiles (including official and nonofficial statistics);
- Acts, regulations and aquaculture policies from each country;
- Internet (To assess reports and other relevant documents).

Some limitations affected the compilation of this review. The most important limitation was to get relevant and updated information from each country in terms of tonnes production, thereby making difficult an assessment of aquaculture in the region and comparison of actual production between the countries. Key elements of aquaculture development strategy are outlined. Recommendations for best aquaculture practices, species that are economically and ecologically suited to the WIO region and recommendations to improve the current policies are also provided.

3.1 SWOT Analysis

Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis and is an informative tool usually used to assess the potential of a company or economic sector (Radheshyam, 2001; Foong, 2007). SWOT analysis examines strengths and weaknesses of a sector, the possible advantage of opportunities available and how to counter threats (AUT University, 2000; Foong, 2007). SWOT analysis can provide a good framework for understanding the main problems in the context of aquaculture, which can help with strategic planning and decision making thereby creating a more appropriate legislation, technology and measures, to increase the production and making, aquaculture more sustainable (AUT University, 2000; Radheshyam, 2001). The negative aspects of SWOT analysis are that they usually reflect and are based on one’s viewpoint which can be distorted to justify their actions rather than used as a means to reveal new possibilities (AUT University, 2000; Foong, 2007). SWOT analyses are time consuming and the data gathered may not be up to date, forcing one to formulate a conclusion based on a single past event (Foong, 2007).

Performing a SWOT analysis helps answer the following questions: (i) How can the strengths of any concern, in this case the aquaculture sector for a particular region, be used to take advantage of the opportunities identified? (ii) How can these strengths be used to overcome the threats identified? (iii) What needs to be done to overcome weaknesses identified and to take advantage of the opportunities? and (iv) How can the weaknesses be minimised to overcome the identified threats? (AUT University, 2000).

4. CATEGORIES OF AQUACULTURE SYSTEMS AND PRACTICES

The most accepted and used classification for aquaculture systems is based on feed/fertiliser input and the stocking density (Edwards, 1990). Rearing systems are divided into three categories which are extensive, semi-intensive and intensive systems. This classification is based on the feeding regime and stocking density (FAO, 2006b). In Africa the most widely used approach is extensive (e.g. subsistence tilapia farming); while in Asia it is semi-intensive (e.g. cyprinid farming); and in Europe the intensive approach (e.g. salmon farming) is widely practiced. A brief description of the three categories of rearing systems used in aquaculture practices is provided.

4.1 Extensive Aquaculture Systems

The extensive system does not require extra feed input, relying on natural productivity and physical conditions in ponds. The ponds are usually fertilised to promote excessive blooms of phytoplankton and, in turn, zooplankton (Pullin, 1993; FAO, 2006b). The main farmed species in Africa using this type of system are tilapia *Oreochromis niloticus*, sharptooth catfish *Clarias gariepinus* and common carp *Cyprinus carpio*, which can be stocked in earthen ponds or floating cages in lakes, dams or water reservoirs.

Stocking densities are usually very low and dependent on the natural carrying capacity of the pond environment. The farmed organisms are stocked at densities as low as specify and feed on phytoplankton, zooplankton, bottom-dwelling invertebrates and smaller fishes. Animal composts and agricultural by-products are commonly used as source of primary production stimulation. The extensive system can so be used in association with other crop production or livestock production (FAO, 2006b). Production yields for extensive aquaculture systems which are estimated to be between 500 to 1,500 $kg.ha^{-1}.year^{-1}$. In Kenya, for example, the extensive aquaculture system contribution makes up for approximately 10 % of the total country aquaculture production (FAO, 2006b).

Extensive aquaculture systems can cause negative impacts on the environment such as eutrophication, destruction of the natural environment like salinisation/acidification of soil and aquifers, ecosystems changes and other risks to the public health such as waterborne diseases, however, the level of impact is in general low compared to other rearing systems showed below (Pullin, 1993). Details on environmental concerns caused by aquaculture are given in the next section (Section 4).

4.2 Semi-Intensive Aquaculture Systems

The semi-intensive aquaculture system is dependent on fertilisation input to produce natural feed and additional feed is given to the organisms to complement their dietary requirements (Beveridge and Phillips, 1993). Application of this system is to increase the production beyond the normal levels only supported by the naturally available food (FAO, 2006b). The supplementary feed can consist of fishery and agricultural by-products, cereals or formulated feeds that are not available as natural foods (Beveridge and Phillips, 1993).

Most tropical inland aquaculture is semi-intensive. The organisms (e.g. Nile tilapia *Oreochromis niloticus*, catfish *Clarias gariepinus* and the common carp *Cyprinus carpio*) are usually reared using a polyculture approach whereby reared in combinations with other species stocked in earthen ponds or cages. The Nile tilapia is the most used species in semi-intensive system (FAO, 2006a). Generally the production in this system can reach 1 to 2.5 $tonnes.ha^{-1}.year^{-1}$. In Kenya the average tilapia production is 3 $tonnes.ha^{-1}.year^{-1}$ and contributes to more than 70 % of the total aquaculture production of the country (FAO, 2006a).

Negative impacts on the environment similar to those described for extensive systems aquaculture may occur when this system is implemented. The magnitude of these impacts is generally less when compared to an intensive system (Pullin, 1993).

4.3 Intensive Aquaculture Systems

This system aquaculture requires large inputs of nutritionally complete feeds. There is a decreased dependence on natural food availability and the cultured organisms are usually fed by dried pellets or moist formulations (Beveridge and Phillips, 1993; Landesman, 1994). Stocking densities are high in the intensive approach; thus requires aeration to elevate and/or sustain oxygen levels, mechanical and bio-filtration, and automatic feeders to increase production costs (Beveridge and Phillips, 1993; Landesman, 1994; FAO, 2006b). Although the intensive aquaculture system requires higher production costs compared to extensive and semi-intensive systems, there are advantages to rearing high-valued species of fish, molluscs and crustaceans. Intensive aquaculture earthen ponds, floating cages, tanks and raceway systems are implemented. The intensive aquaculture systems usually supply international markets as more and high-priced species are produced per unit area and the production can vary from 10 to 80 $tonnes.ha^{-1}.year^{-1}$, depending on the level of management employed (FAO, 2006a). However, high stocking densities in these systems increase vulnerability to disease outbreaks that can reduce pond yields dramatically (Landesman, 1994).

There are many environmental concerns connected to intensive aquculture systems. Due to high stocking densities, the high quantity of metabolic wastes in combination with uneaten feed can increase nutrient enrichment in water. If the metabolic wastes are discharges from ponds into the environment are not adequately treated, euthrophication may occur on receiving waters. Eutrophication may increase the quantity of suspended solids and accumulation of anoxic sediments. High load of metabolic wastes and uneaten feed is, most common in case of cage culture (Pullin, 1993).

5. PROBLEMS ASSOCIATED WITH AQUACULTURE

5.1 Environmental Constraints

5.1.1 Impacts of Aquaculture in Water Quality

All types of aquaculture practices interact with the environment as they require water and land (Burford *et al*., 2003). The most important concern in aquaculture is associated with water quality management as poor water quality may interfere on the growth of the organism (Casé *et al*., 2008). According to Casé *et al*. (2008), some organisms such as zooplankton and phytoplankton are very sensitive to changes in water quality and can therefore be used as good indicators of environmental conditions and of health ponds. Water discharged from shrimp ponds usually contain high concentrations of suspended solids and nutrients which can have a negative impact when discharged, causing algal blooms, changes in benthic communities and creating anoxic conditions (Burford *et al*., 2003; Biao *et al*., 2004).

There are water quality standards that need to be considered and monitored in aquaculture. In marine aquaculture practices the most important water parameters that need to be monitored are: alkalinity and hardness, ammonia, dissolved oxygen, nitrogen and phosphorus, pH, salinity, temperature, and turbidity (Larsson, 1994). The basis for water quality standards depend on the carrying capacity of the environment. Table 1 provides relevant water quality criteria to freswater aquaculture and mariculture. Biological indicators such as meiofauna are also important tools in environmental monitoring (Mazzola *et al*., 2000). Waste products are also a concern in aquaculture as the organic matter increases biological oxygen demand (BOD) in the environment and the inorganic nutrients, nitrogen and phosphorus, increase the primary production (mainly growth of microalgae) (Mazzola *et al.,* 2000).

The groundwater abstraction in coastal areas can result in intrusion of the saline wedge when the abstraction is greater than the recharge of aquifers. The over-exploitation of aquifers may increase the levels of groundwater salinity, affecting adjacent land and waterways (Primavera, 2006; Sousa *et al*., 2006). It is likely that the significance of this impact can be high given the possibility of ultimate degradation of water quality and the negative consequences resulting there from."In Thailand, for example, the government banned the practice of inland fish farming in 1998 because of salinisation (Primavera, 2006). The water exchange rates may also cause fluctuations in the salinity levels (usually an increase causing hypersalinity); however, this can be used as an advantage in case of mullet *Mugil cephalus*culture to control the excessive growth of the algae *Ulva lactuca* and the gut weed *Enteromorpha intestinalis* (Primavera, 2006).

Table 1 Summary of water quality standards/criteria relevant to and mariculture

Parameter	Unit	Freshwater aquaculture	Mariculture
pH		5.0 - 9.0	6.0 - 9.0
DO	mg/L	3.0 - 7.0	3.0 - 7.0
NH4	mg/L	< 1.0	< 1.0
NH3	mg/L	< 0.03	0.01-0.05
NO3	mg/L	10-50	< 100
NO2	mg/L	0.06-0.4	0.05-0.1
P	mg/L	0.05-0.2	0.015
PO4	mg/L	0.05-0.1	<0.05
TSS	mg/L	25-40	10-30
TDS	mg/L	500-1200	1200
Faecal coliform	count/100 ml	Not desired	Not desired

Turbidity is another concern and can affect fish production as well as deteriorate the aquatic environment endangering fisheries (Andren, 1975). In Madagascar the water turbidity is a cause of concern to fisheries authorities as it threatens the capture of shrimp stocks and other resources in the wild. Alternatively, the turbidity caused by aquaculture activities especially cage culture can influence benthic organisms by affecting and changing the characteristics of the benthos whereby some organisms become smothered (Andren, 1975). Moreover, high turbidity reduces light penetration considerably which in turn limits photosynthesis and sometimes food uptake. In Tanzania and Kenya there are concerns in oyster culture as the oysters are very sensitive to high particle content in suspension which can interfere with oxygen and food intake (Andren, 1975).

5.1.2 Impacts of Aquaculture on the Surrounding Natural Habitats and the Biota Found Therein

Coastal areas compared to inland areas are usually more affected, ecologically, by aquaculture activities; more aquaculture manly shrimp farming, is practiced in the coast, (Primavera, 2006). Shrimp culture practices usually cause modifications or loss of natural habitats and decrease the abundance of certain organisms through to the excessive wild seed/spawners harvest for breeding stock (Bunting, 2006; Primavera, 2006).

Many aspects need to be considered to evaluate the ecological impacts of aquaculture. The method and type of aquaculture, the level of production, biological characteristics of the species and water physico-chemical parameters are the principal factors that can cause ecological changes to adjacent environments (Aguilar-Manjarrez and Nath, 1998). Usually the intensive and large-scale production of shrimp, seaweeds and bivalves are the main source of ecological changes (Aguilar-Manjarrez and Nath, 1998; Biao *et al*., 2004; Primavera, 2006).

Tropical regions are suitable for shrimp farming (FAO, 2006b). However, many studies have shown that marine tropical ecosystems are more susceptible to eutrophic conditions than temperate regions (Sowles, 2003; Lin and Fong, 2008). According to Lin and Fong (2008) excess of nutrients is associated with the deterioration of seagrass and coral reef ecosystems. The excess nutrients can affect the farm through self-pollution, due to poor management of the water that is discharged and then recirculated back into the farm, thereby causing diseases or reducing productivity. This is a major challenge to aquaculture industry whereby nitrogen waste needs to be reduced to improve the economic efficiency through the development and implementation of an integrated approach (Jackson *et al*., 2003). In addition, it will be necessary to improve the feed formulation to reduce waste and the management of effluent discharged (Jackson *et al*., 2003).

Mangroves play an essential role acting as nurseries for fish and crustaceans and also provide protection to the coast against soil erosion and floods (Primavera, 2006). More than a third of mangrove forests were lost worldwide in the last 30 years being aquaculture activities responsible for 35% of this decline (Primavera, 2006). There has been the detriment of the environment for shrimp aquaculture; the removal of mangroves to make way for ponds is a negative aspect. In some Asian countries such as the Philippines and Vietnam where aquaculture is well developed, the highest rates of mangrove loss (70-80%) over the past 30 years have occurred (Primavera, 2006; Casé *et al*., 2008). Mangroves are also important as a means to treat water; as they are known to function as natural biofilters of sewage (Casé *et al*., 2008). The degradation of mangrove forests can be detrimental to those organisms that are dependent on certain conditions in their life history,(e.g. for spawning). The penaeid shrimps are the most affected organisms by mangrove degradation, as the shrimps are estuary-dependent species which need the mangroves as shelter for growth during the post-larvae and juvenile stage (Casé *et al*., 2008). Negative impacts of mangrove removal for aquaculture have been well documented worldwide. Little information, if any, is available in regard to Africa linking the status of mangrove degradation with aquaculture. Due to a lack of information and monitoring, most international shrimp farming industries exploit Africa mangrove areas with little regard to ecosystem health and integrity (World Rainforest Movement (WRM), 2010). Recent studies conducted in the WIO region however indicated that mangroves are under threat from pollution and coastal development, and especially from aquaculture, which remains a concern (United

Nations Environment Programme (UNEP), 2010). These few examples of threats to African mangroves could be used as basis for alerting governments to this issue (WRM, 2010).

The introduction of exotic species or escape of farmed species into the natural environment is one of the adverse impacts of aquaculture that needs to be considered. The consequences of introducing exotic cultured species could be the alteration or impoverishment of native communities and populations of the invaded ecosystem, due to inter-breeding, increased predation and competition for food, space and habitat (Primavera, 2006; Casé *et al*. 2008). The exotic species can cause degradation of the natural environment and,, the alteration of genes in host species. Foreign diseases and parasites that can infect native species are also associated with exotic species (Primavera, 2006). The impact of these foreign diseases can be catastrophic to commercial farmers. According to Primavera (2006) the Yellowhead virus (genus *Okavirus*) in the shrimp *Penaeus japonicus,* originating from Japan, was able to spread to China, Taiwan, Korea, India, the Philippines and tropical America, causing a multimillion dollar loss in revenue ofshrimp farmers.

The introduction of foreign chemicals into the environment is another concern. The excessive use of chemicals such as therapeutants, disinfectants and soil and water treatment compounds in shrimp culture can cause toxicity to non-target populations such as humans, cultured species and wild biota. For example it can result in antibiotic resistance and accumulation of residues (Pullin, 1993; Primavera, 2006). An example is the collapse of shrimp farm production in Taiwan due to the indiscriminate use of antibiotics that led to a high short-term survival and long term resistance among shrimp pathogens (Primavera, 2006). The high resistance to pathogens presents a risk for human health from ingestion of contaminated seafood (Primavera, 2006; UNEP *et al*., 2009).

The construction of ponds for aquaculture is commonly a source of health hazards to the human population in the nearby vicinity. Ponds facilitate the breeding of malaria vectors, especially the mosquito *Anopheles gambiae* (Okorie, 1975, Department of Health and Families, 2006; Volz, 2010). Fishponds may provide the only available surface water to mosquitoes under dry conditions.

The aquaculture infrastructure can affect the water current patterns in estuaries and lagoons resulting in an increase in sedimentation. Heavy loads of silt are responsible for the pollution in inshore water that can threaten coral reefs. (Andren, 1975; Dierberg and Kiattisimkul, 1996; Sahoo, 2005; van Halsema *et al*., 2008). Furthermore, siltation also causes habitat degradation due to sediment deposition from agricultural use, and modification of stream flows, impacting negatively on availability of water for other activities such as irrigation (Western Indian Ocean Regional Assessment and Institutional Analysis (WIORAIA), 2009). Problems related to siltation in Madagascar have been reported where mangrove roots have been smothered (WIORAIA, 2009).

The impact of high loads of suspended solids from aquaculture carry economic losses and reduce farm productivity and profitability, reduce the quality of seafood and losses of artisanal, commercial and recreational fisheries resources and revenues (UNEP *et al.*, 2009). Although there is no certainty of positive contributions made by aquaculture to the environment or any form of environmental rehabilitation (FAO, 2006b), major possible environmental benefits from aquaculture playing the role of decreasing fishing pressure on wild stocks.

5.2 Social Impacts

It is not possible to discuss aquaculture without reference to social impacts, as the main objective of aquaculture is to increase food production, job creation and improve the economy and livelihood of local communities (FAO, 2006a). At the same time it is difficult to deal with social aspects as they cannot be generalised because the tradition and cultures vary from region to region (FAO, 2006a). However, some common points can be found and are highlighted here.

Aquaculture is known as a source of conflicts between the multiple usages at the coast such as artisanal fisheries, recreation and tourism; new sites are needed to increase aquaculture production (FAO, 2006a; Primavera, 2006). Generally, there is a tendency to convert a multiple-use coastline to a single-use resource, leading to conflicts among the social groups (FAO, 2006a; Primavera, 2006). There is an issue of unequal benefits from aquaculture between the involved or affected people. Conflict arises as a result of land degradation and the cost to mitigate the damaged sites or to restore the ecosystem (FAO, 2006a).

Aquaculture activicties can severely affect water quality and habitat degradation, goods and services such as wild catches. As a consequence, social conflicts may start (FAO, 2006a). In India, for example, women were forced to walk longer distances to collect drinking water due to salinisation of nearby waters due to aquaculture pollution (Bunting, 2006). According to Bunting (2006) skin diseases in humans, associated with poor water quality in shrimp farming, have been a concern. Another concern is the sedimentation that causes siltation of irrigation canals. Furthermore, competition for water resources in some cases lead to violence between fishers and fish/shrimp farmers (Emerson, 1999).

Aquaculture also affects the lives of individuals who are not directly engaged in the industry. The best identified social impacts of aquaculture are the effect of pollution and the disturbance of ecosystem that provides goods and services to local communities (FAO, 2009a). Cage culture is usually related to the decline of aesthetics and of returns from recreational fisheries. The declining of recreational fisheries and loss of habitat can bring severe implications for rural economies that receive income from visiting anglers and tourists. Some governments have introduced pollution fees, environmental taxes and tradable permits; however, these regulations are seen as constraints by entrepreneurs as they can be interpreted in different ways (FAO, 2009a). Negative impacts of aquaculture are summarised in Table 2.

Table 2 Summary of the negative impacts related to aquaculture activities (Adapted from Bunting, 2006)

Impact	Consequences	Key Features
Physical	Modified hydrology	Reduction and modification of the flow rates and regimes
	Sedimentation	Reduction of the interstitial water flow and anoxia
Chemical	Pollution	Toxicity of excreted ammonia to invertebrates; eutrophication, antibiotic resistance and negative effect on non-target organisms
	Oxygen depletion Eutrophication	Effect on respiration and exclusion of non tolerant species, caused by an increased Biological Oxygen Demand
Shifting trophic status	Species assemblage changes	Pollution sensitive species are eliminated and the more tolerant increase in abundance and biomass
Escapees	Ecological impacts	Predation and competition cause ecosystem disruption; genetic degradation of native populations
Self- pollution	Reduced production and quality	Fish kills due to anoxic water; disease outbreaks and toxic algal blooms
Restricted amenities	Degradation of water quality and fisheries decline	Water flow restrictions due to sedimentation will affect access of livestock and humans to water; potential source of social conflicts
Reduced functionality	Loss of ecological functions	Loss of habitats and ecosystem degradation; reduction of biodiversity and loss of ecosystem goods and services

6. THE STATE OF AQUACULTURE IN THE WESTERN INDIAN OCEAN REGION

Policies for aquaculture is the most important to promote and expand commercial aquaculture in any country (FAO, 2002). They are viewed as a form of reducing the risks and costs, thereby increasing trust among potential investors (FAO, 2002). In 2002, the FAO secretariat developed a document (General Policy Framework for the Promotion of Sustainable Commercial Aquaculture in sub-Saharan Africa"), which outlined policies for the promotion of sustainable commercial aquaculture based on the "General Policy Framework for the Promotion of Sustainable Commercial Aquaculture in sub-Saharan Africa". The document addressed policies for aquaculture and highlighted that they should be both generalised and specific, depending on the application. The general policies are those which include good governance, a reduction in corruption, political and policy stability (FAO, 2002). The more specific policies are those which cover aquaculture issues including farm issues with the purpose of promoting commercial aquaculture and influencing the price of aquaculture products and quantify inputs needed to attract investors (FAO, 2002).

Capacity building, training and education are needed to ensure that the policies are developed in the region. However, it was noticed that a lack of capital is one of the main constraint hindering aquaculture development (FAO, 2002). The proposed economic policies from FAO includes the loan availability for aquaculture and creation of special funds for aquaculture research and development such as tax exemptions, creation of free trade zones or export processing zones. Other major constraints identified in many countries are the creation of more than one aquaculture department. This reduces the ability to coordinate the sector with other departments responsible for investments, environmental management and other relevant sectors, and this lack of coordination hampers the development of aquaculture on a commercial scale.

The most common constraint in most African countries, including the WIO region, is related to land reforms in aspects such as the nature and duration of land leased as they play a crucial role in facilitating the development of commercial aquaculture and this may delay or encourage development (FAO, 2002). However, some state governments have expanded usage rights by promoting longer lease periods, although within the region their exists a variety of land rights that are not clearly defined, in some cases the process of acquiring land is extensive and fraudulent (FAO, 2002).

In Kenya, for example, the land acquisition imposes some restrictions such as compulsory acquisition where the government may take over a property without consent of the owner aiming at "*general benefit of the community as a whole*". However, compensation is provided, although this practise interferes with the owner's property rights regulated under the sections 75, 117 and 118 of the Constitution as well as Land Acquisition Act cap 295 Laws of Kenya. (Nabutola, 2009). In Mozambique, the land is owned by the state and people have rights only to occupy and use it for a determined period. This is a source of concern among foreign investors as in some cases the land titles are not validated. Freely tradable property is desirable because it offers mobility and incentives and a form of guarantee (Ridler and Hishamunda, 2001; FAO, 2002). Shrimp farms in Madagascar for example are located in Industrial Free-Trade Zones (IFTZ) and the investors can only lease the land. However, the lease period is considered long (20 to 50 years) and the land usage is transferable (Ridler and Hishamunda, 2001; FAO, 2002).

According to FAO (2002), few countries are in the process of reviewing their legislation regarding aquaculture and others have adopted a general aquaculture legislation or legislation for a particular activity. However, some difficulties such as cultural factors which are non-policy variables and are outside of government's control are encountered in establishing the legal framework beneficial to aquaculture (Ridler and Hishamunda, 2001). In Mozambique for example, fishermen argue the need for taking time (6 months or so) feeding fish in aquaculture pond while they can go fishing daily. To solve this issue, the involvement of all stakeholders i.e. the private sector, farmers, investors and communities should be considered. In addition, it is necessary to provide real examples of successful projects in the region to attract investors and financial institutions and increase trust in order to provide financial loans (Ridler and Hishamunda, 2001; FAO, 2002).

It is important to have policies that encourage investors by increasing their confidence and by also creating and encouraging free trade and macroeconomic growth (Ridler and Hishamunda, 2001). For the region, good governance as well as political and social stability are considered the most important determining factors that will facilitate successful investment (Ridler and Hishamunda, 2001).

Sector-specific policies are important to guide aquaculture development as a whole (Ridler and Hishamunda, 2001). The policies can be regulatory/legal, administrative, economic and self-policing to provide a logical development of the sector and can be defined according to existing or perceived issue on the supply or demand side of the industry (Ridler and Hishamunda, 2001). A structured and orderly means of regulating aquaculture by government will reduce negative pressures such as land and water rights conflicts and pollution (Ridler and Hishamunda, 2001).

The principal aspect of aquaculture regulations is the obligation to acquire permits to establish a farm. The purposes of these permits are to regulate the industry in many aspects such as data gathering, stipulation of statistics on technical matters and production (Ridler and Hishamunda, 2001). In Mozambique for example, an environmental impact assessment is required before a permit is granted, however for small sized farms this requirement is not necessary, although negative effects can accumulate or become compounded if the number of farms is extensive for a given region (Ridler and Hishamunda, 2001). Potential investors have been deterred from acquiring environmental licences as the process is considered to be too expensive and time-consuming since it involves different departments (Ridler and Hishamunda, 2001).

Regulations also carry negative aspects such as an inefficiency and bureaucratic rigidity that can hamper development. Inefficiency and bureaucratic rigidity are usually consequences of overlap laws, regulations and jurisdictions that do not clarify responsibilities (Ridler and Hishamunda, 2001). An example is South Africa where prior to 2010 the policies and protocol were fragmented by various Government Departments, inhibiting the development of the aquaculture sector (Department of Water Affairs and Forestry (DWAF) since 2010), 2006). The alternative to circumvent this problem can be the creation of one-stop administrative procedures furnished with all necessary information and with staff from different agencies, avoiding delays when obtaining permits from each department involved in the process. This approach has been implemented in Madagascar (Ridler and Hishamunda, 2001). In South Africa, prior to 2010, there was an attempt to initiate a policy that facilitates coordination between the Departments of Agriculture (DA) and Environmental Affairs and Tourism (DEAT), all the relevant Government Departments as well as stakeholders from the sector (DWAF, 2006). In 2010 due to a restructuring of governmental departments the DA and DEAT were united under the new Department of Agriculture, Fisheries and Forestry (DAFF) (Aquaculture Institute of South Africa (AISA), 2010). It has been well documented that in order for regulations to be successful, they should be easy and cheap to be enforced and monitored as well as the application procedures must be rapid (Ridler and Hishamunda, 2001).

The question has been raised whether governments should or should not intervene at the farm level as the farms are not public enterprises. The answer to this question is not easy because problems that can arise at the farm level, such as pollution, may interfere with other users and cause impacts to the society (Ridler and Hishamunda, 2001). These impacts can be of high cost to society because they are difficult to settle through courts so the government should intervene as a facilitator in conflicts resolution of the aspects such as jobs and social amenities, foreign exchange earnings and tax revenues (Ridler and Hishamunda, 2001). In some WIO countries the government intervenes at farm levels by providing subsidies to farmers in the form of a start up grant and others amend policies to help the expansion of the industry (Ridler and Hishamunda, 2001). For the region as a whole adjustment to the context must be made before the incorporation of these policies and other forms of government intervention. For the purpose of this review an overview of the status of aquaculture in the WIO countries is given below, including their policies and perspectives, cultured species and SWOT analyses.

6.1 Aquaculture in South Africa

Aquaculture in South Africa started more than 100 years ago by the colonial authorities. The main purpose was to stock angling waters and the most cultivated and introduced trout species (Safriel and Bruton, 1984; Rouhani and Britz, 2004). The trout industry faced many difficulties in adapting to local conditions because the production was mainly based on imported technology not supported by local research (Safriel and Bruton, 1984; Rouhani and Britz, 2004). Other species such as oysters *Crassostrea gigas*, waterblommetjies *Aponogeton distachyos* and ornamental fishes (mainly goldfish) were introduced in the 1980s for commercial purposes (Safriel and Bruton, 1984; Rouhani and Britz, 2004).

According to Rouhani and Britz (2004), the South African aquaculture development can be divided into three eras: i) the colonial era, which introduced exotic species for angling purposes; ii) the apartheid era characterised by the development of the private sector in order to encourage commercial aquaculture and iii) the post-1994 democratic era which saw a push towards large scale commercial practices and entrepreneurial development in rural areas. All eras' artefacts/influences are still present and incorporated at different levels in various facilities and projects (Rouhani and Britz, 2004). In the late 1980s to the early 1990s government of South Africa stopped the support of freshwater aquaculture, stunting the development thereof as compared to other countries in the world. During the same period, provincial conservation departments also changed their policy and stopped support of production and stocking of exotic fishes in order to preserve biological diversity in pristine areas (Rouhani and Britz, 2004). The lack of clear guidelines on the use of exotic species retarded the development of aquaculture and according to Rouhani and Britz (2004), the production of native species of low value as a source of animal protein has been unsuccessful. As a result many enterprises shifted their interest to the production of high value species in impoverished parts of the country where the impact of exotic species would be low (Rouhani and Britz, 2004).

The aquaculture industry began as effective commercial enterprises in the 1980s with emphasis on trout, mussel, oyster, catfish and ornamental fish farming (Rouhani and Britz, 2004). During this period, significant initiatives for shrimp farming were attempted at Mtunzini and Amatikulu on the KwaZulu-Natal north coast, however trading stopped (DEAT, 2006) due to high production costs and as a result the farms were not competitive with similar products flooding the market at cheaper prices (Rouhani and Britz, 2004). Amatikulu is currently re-developing the ornamental fish sector on the farm and exports have reached approximately 1 million fish per year (DEAT, 2006). From 1988 to 1998, total production in the sector increased on average by 6.8 % per annum in South Africa, where and according to Moehl (1999), this growth was lower than the average when compared to the rest of Africa (annual average growth of 10.5 %) during the same period; although the period was characterised by a significant increase of aquaculture projects in Africa.

Both freshwater aquaculture and marine (mariculture) are practised in South Africa. However, the freshwater aquaculture is limited in scope, due to South Africa's natural condition of being a semi-arid country where freshwater is scarce (Rouhani and Britz, 2004; FAO, 2006c). The Western Cape Province is the major contributor to the South African aquaculture sector. About 43.8 % of aquaculture producers are located in the Western Cape, followed by Mpumalanga, KwaZulu-Natal and the Eastern Cape with 12.5 % each (Hinrichsen, 2007).

The volume of mariculture production in 2005 was such that the mussel sub-sector produced 48.8 % of the total production, followed by abalone with 27.9 %, oysters 13.6 % prawns 7 % and *Gracilaria* 2.6 %. Abalone is a high value product in comparison with others, constitutes 87.7 % of the total production of cultured species in South Africa (DEAT, 2006). The South African coastline is characterised by high-energycausing limitations for sea-based aquaculture. Due to this natural constraint, sea-based aquaculture is restricted to a small number of sheltered bays and estuaries (DEAT, 2006). Hence a solution is shore-based aquaculture, which has been implemented successfully by abalone farmers (DEAT, 2006).

Freshwater aquaculture in South Africa is also constrained by fluctuation in extreme seasonal temperatures in the interior, limiting the farming of some species (Rouhani and Britz, 2004; FAO, 2006c). Freshwater species cultivated at commercial level are rainbow trout *Oncorhynchus mykiss* and salmon *Salmo solar*. Sharptooth catfish *Clarias gariepinius*, crayfish *Cherax tenuimanus*, tilapia *Oreochromis* spp. with other species presented in section 5.1.2, are also cultivated on small scale basis. Although water scarcity is considered the main constraint to the development of freshwater aquaculture, extreme fluctuations of seasonal temperature are natural barriers that also lead to the high cost of production. To control these seasonal fluctuations, methods in practice are required to either increase or decrease water temperatures, which in turn increase electricity costs and inhibiting the development of aquaculture in rural areas due to needed high capital (Rouhani and Britz, 2004). The uses of recirculation system in areas where water is scarce and where water temperatures need to be consistent are solutions (Rouhani and Britz, 2004).

Another constraint with regard to freshwater aquaculture that needs to be considered is related to the choice of suitable species that have a high market value. According to Rouhani and Britz (2004), most freshwater species have a low market value. However, trout and ornamental fish are the exception.

Services related to aquaculture are fairly well developed in South Africa. These services include feed industry, consultancy services, equipment manufacturing sector and engineering, financial sector for mariculture, tertiary institutions that are dedicated towards aquaculture research and other specialist skills for aquaculture (EFA, 2006). The establishment of industrial development zones (IDZ's) by the South African government is a valuable tool to stimulate and attract investors to aquaculture.

6.1.1 Legal Framework and Institutional Development

The government of South Africa is making considerable efforts at compiling aquaculture regulations. While the existing efforts are significant, policies and legislative frameworks are still incomplete and are not specific to aquaculture practices. Mariculture activities for example fall under the Marine Living Resources Act of 1988; however, a comprehensive policy has yet to be developed (Enviro-Fish Africa (EFA), 2006). The current aquaculture legislation and regulations are adequate from an environmental management perspective, but fails to stimulate the sectorial growth (EFA, 2006). Hirinchsen (2007) states that the development and growth of aquaculture is dependent on successful integration of many aspects such as the use of natural resources, human capacity building, economic resources and a facilitative regulatory environment.

South Africa shares resources with neighbouring countries, not only from WIO region, but also countries from East Atlantic Ocean region. These countries are Namibia and Angola wich share the Benguela Large Marine Ecosystem (BLME). The countries share also regional policies, specific to the countries that share the BLME. Harmonisation was established for the management of protocols. The main issues of the management protocols are regarded to the environmental management (disease control, use of exotic species and others), industry development (technology development, manpower training and products of health certification) (EFA, 2006; DEAT, 2006).

The Department of Environmental Affairs and Tourism (DEAT) created a Mariculture Unit in 2003 with the aim of administering aquaculture licenses, environmental management and research. There are other departments whose mandates indirectly affect mariculture policy and governance (EFA, 2006). They are the Department of Trade and Industry (DTI), the Department of Science and Technology (DST), the Department of Agriculture ((DA) Currently Department of Agriculture, Fisheries and Forestry-DAFF) the Department of Water Affairs and Forestry-DWAF (now Department of Water Affairs-DWA), the provincial governments and local authorities. The research on mariculture sector is conducted mainly by research institutions such as Rhodes University, Stellenbosch University, Council for Scientific and Industrial Research (CSIR) and other public and private institutions (EFA, 2006). A first draft of the Mariculture Sector Plan was produced in 2006 by DEAT. The draft outlines strategies that will enforce practical developmental effects for marine aquaculture and also ensure that good environmental practices are maintained. The Mariculture Sector Plan aims at creating conditions to have a functioning environment which will facilitate contributions to mariculture growth economically within the Accelerated and Shared Growth Initiative for South Africa (ASGISA) framework (DEAT, 2006).

The section 21 of the National Water Act of 1998 makes reference to the multiple water uses for aquaculture; however this section needs a comprehensive and more effective operational policy that is adequate for the purpose of aquaculture as it involves multiple water users and needs authorisation from various departments, making the process of authorisation for water use more complicated. A comprehensive and effective operational plan or draft to support aquaculture regulation regarding the use of water is needed as the multiple water users or uses contradict the primary goal of the act, which aims to simplify and standardise the authorisation process for aquaculture water users in order to facilitate the DWAF (prior to 2010) officials who have limited knowledge on technical aspects of aquaculture water uses (DWAF, 2006). in 2007, due to the expansion of the aquaculture sector DWAF created a "*Guideline for Authorising the Use of Water for Aquaculture*", with the purpose of protecting water resources. The aim of the guideline was to streamline the authorisation process and provided clear procedures that must be followed in applying for water to be used in aquaculture operations (DWAF, 2007).

In the late 1980s the AASA was established with the purpose of contributing towards the development of aquaculture in southern Africa.The non-governmental Aquaculture Association of Southern Africa (AASA) has played a major role since its creation in assisting both government and investors in terms of aquaculture policies for running aquaculture projects.. The association represents the interest of the fledgling aquaculture industry in Southern Africa. In 2003, DA commissioned the AASA to create a proposal for the national aquaculture policy entitled "*Industry contribution to a South African national aquaculture policy; towards sustainable aquaculture development for all"*. The aim of the policy was to facilitate the sustainable and responsible aquaculture development and limit the fragmentation procedures for aquaculture permit between authorities and Government Departments (Rouhani and Britz, 2004). Recently, the aquaculture sector has been united under the new DAFF, after many years of being fragmented in regulation due to the split existence under separate government departments (Aquaculture Institute of South Africa, 2010).

6.1.2 Species Cultivated

Freshwater species are cultivated mainly in the Western Cape, viz., rainbow and brown trout *Oncorhynchus mykiss* and *Salmo trutta*, sharptooth catfish *Clarias gariepinus*, common carp *Cyprinus carpio*, goldfish *Carrasius auratus* and other species, largemouth bass *Micropterus salmoides*, Chinese grass carp *Ctenopharyngodon idella*, marron *Cherax tenuimanus*, tilapia species *Oreochromis* spp.), ornamental fish (various species) and the water hawthorn *Plantae aquaticae* (Hinrichsen, 2007). Trout farming is well established in the Western Cape because there is a favourable environment for growth in winter months with commercialisation accentuated at the end of the winter time. For tilapia species, the best growth occurs in the summer time, creating a good opportunity to alternate cultured freshwater fish species according to the season (Institute for Animal Production (IAP), 2010). The other freshwater species are farmed in regions where higher annual temperatures and rainfall prevail. Total aquaculture production for both freshwater and marine species farmed in South Africa is represented in Table 3.

Marine species cultivated in South Africa are: abalone *Haliotis midae*, the mediterranean mussel *Mytilus galloprovinvialis*, pacific cupped oyster *Crassostrea gigas*, seaweeds species *Gracilaria* spp. and various finfish including cob species *Argyrosomus* spp. (Hinrichsen, 2007; IAP, 2010). Mariculture activities are more developed with emphasis on mussels, oysters, abalone, seaweeds and shrimp. Although the country has a large and well-organised fisheries sector, the mariculture sector is at a low level of development (EFA, 2006). Abalone farming is well established along the Cape south coast between Hermanus and Danger Point, and around

Saldanha Bay/St Helena Bay and is the most established sector where the production reached 515 tonnes in 2003 (EFA, 2006; FAO, 2006c).

Table 3 South African aquaculture production for 1998, 2000 and 2003 (Adapted from DEAT, 2006). Values presented for each year are expressed in tonnes (* *Unit = number of fish*)

Species Scientific names	Common name	1998	2000	2003
Freshwater species				
Aponegeton distachyos	Hawthorne	120	150	170
Carrasius auratus	Goldfish	465000*	805 000*	930 000*
Cherax tenuimanus	Crawfish	4	8	13
Clarias gariepinus	Sharptooth catfish	40	65	240
Cyprynis carpio	Carp	45	55	80
Micropterus salmoides	Bass	5	8	8
Onchorhynchus mykiss	rainbow trout	1 650	1830	1750
Oreochromis mossambicus	Tilapia	45	130	210
Oreochromis spp.	Tilapia spp.	25	45	52
Ornamental fish				
Various spp.	Ornamental fishes	5	7	7
Marine species				
Crassostria gigas	Oysters	175	170	250
Gracilaria spp.	Seaweed	16	40	48
Haliotis midae	Abalone	22	180	515
Mytilus galloprovincialis	Mussels	650	790	900
Penaeus indicus	Shrimp	85	120	130

Oyster farming is most focused on the Pacific oyster *Crassostrea gigas* rather than the native *Striostrea margaritacea* and is limited to the Northern, Western and Eastern Cape coasts. The preference for *C. gigas* could be due its size which is usually larger than S. margaritacea (Haupt *et al*., 2010). The mussel industry for *Mytilus galloprovincialis*, *Choromytilus meridionalis* and *Perna perna* showed a high expansion in the 1980s: however a drop in production occurred in subsequent years due to limited technical expertise, and inadequate administrative and legal support (EFA, 2006).

The seaweeds *Gracilaria* and *Ulva* are cultivated to feed abalone. There were some projects to rear *Gracilaria* for agar production; however, the project ceased due to seasonal nutrient stratification in the water column (EFA, 2006). The water column presented elevated turbidity due to strong wind conditions and wave action which reduced light penetration, affecting the algal production (van Ballegooyen *et al*., 2008)

Prawns farming was initiated in 1970s with the main species targeted being the Indo-Pacific tiger shrimp *Penaeus monodon*, which occurs in South Africa. The culture of tiger shrimp was, however, unsuccessful due to the low quality and availability of wild native broodstock and high temperatures required by this species (Forbes and Demetriade, 2005). A shift was made to the indigenous white prawn *Fenneropenaeus indicus* (EFA, 2006). Thereafter, the shrimp farming declined and in 2004, was declared economically unviable due to cheap imports, unfavourable exchange rate and competition with the local capture fisheries (Sara, J. R., 2010, *Pers. comm.*[1])

European turbot *Scophthalmus maximus* is commercially farmed in the West coast producing small tonnage to supply only the local market. The main constraints on rearing this species are related to local feed unavailability and high production costs (EFA, 2006).

A survey for suitable species for aquaculture indicated that the exotic Atlantic salmon (*Salmo solar*) is one of the favourable species to rear as the species has late maturity thus spends less energy for spawning and has high economic value. Pilot projects were attempted in Gansbaai for this species (EFA, 2006). Marine fish farming has also been experimented and researched with. Examined are the dusky and silver kob *Argyrosomus japonicus* and *A. inodorus*, respectively, yellowtail *Seriola seriola*, white marginated sole *Synaptura marginata*, white stumpnose *Rhabdosargus globiceps* geelbek *Atractoscion aequidens*, and red roman *Chrysoblephus laticeps*. Preliminary results have shown that these species are economically viable and can be produced at commercial level (EFA, 2006; DEAT, 2006).

6.1.3 SWOT analysis of aquaculture in South Africa

South Africa presents both external and internal factors that need to be taken into account when planning the development of the aquaculture sector. According to AUT (2010), internal factors are those related to the strengths and weaknesses and external are usually associated to threats and opportunities presented by a country. A summary of the SWOT analyses of the aquaculture sector in South Africa is presented in Table 4. The major strength in South Africa is a diversified environment suitable for the development of both cold and warm species. A good research base due to existing university programmes is another major strength that places the country at an advantage to establish an ecologically and economically sustainable aquaculture. The weaknesses are a lack of institutional support in terms of development plans, policy and coordination, and poor farm management may be minimised by the good research base that the

[1] Dr Sara, J. R. Aquaculture Research Unit, University of Limpopo, South Africa.

country presents and the involvement of established Aquaculture Producer Associations. Being classified as semi-arid region is another concern that hampers the development of freshwater aquaculture. The country should concentrate its efforts on the development of the mariculture sector as can be seen in Table 4, the list of opportunities and strengths is attractive when compared to other WIO countries.

Table 4 SWOT analysis of freshwater aquaculture and mariculture in South Africa (Adapted from Moodley, 2009; DEAT, 2006; Rouhani and Britz, 2004; FAO, 2006c)

Freshwater aquaculture	**Mariculture**
Strengths: Good research base due to existing Universities programmes. Good infrastructure Potential sites favourable for aquaculture Established Aquaculture Producer Associations Feed manufacturer available Food processing plants Strong currency for export	**Strengths:** Good research base due to existing University programmes. Unpolluted environment Good infrastructure Good sites favourable for aquaculture Established Aquaculture Producer Associations Feed manufacturer Food processing plants Awareness of risk by the private entrepreneurs Strong currency for export
Weaknesses: Lack of institutional support (development plans, policy, coordination Poor farm management Freshwater scarcity Lack of venture capital Lack of adequate policy Low education level of farmers Inadequate training Lack of extension services Lack of functional government hatcheries Ornamental fish farming Lack of marketing	**Weaknesses:** Lack of institutional support (development plans, policy, coordination) Poor farm management Vast open coastal sites that are exposed to the elements as opposed to protected bays. Lack of venture capital Lack of adequate policy Low education level of the farmers Inadequate training Lack of extension services Lack of functional government hatcheries Lack of marketing
Opportunities: Culture based fisheries: mullet, trout Enhanced natural fisheries (stocking of fish) Integrated systems (integrating aquaculture into farm irrigation systems) Tropical and temperate aquaculture	**Opportunities:** Shore-based mariculture Culture based fisheries: mullet, trout Enhanced natural fisheries (stocking of fish) Tropical and temperate aquaculture
Threats: Market factors (limited market, weak currency for import) Susceptibility to Environmental disasters	**Threats:** Market factors (limited market, weak currency for import, competition with industry) Susceptibility to Environmental disasters Coastal development of pristine area

6.2 Aquaculture in Mozambique

The freshwater aquaculture in Mozambique started in the 1950s. Since 1992, there has been a progression in the cultivation of marine organisms (FAO, 2006d). Mozambique's coastline stretches for about 3000 km. This is associated with other natural conditions like a large number of rivers, estuaries and reservoir dams providing great potential for aquaculture in the country (Ribeiro, 1983). In addition to these factors, the tropical and sub-tropical climate plays an important role as it provides an optimal temperature for growth for many warm water aquatic organisms. The level of environmental pollution also plays a relevant role, in that is considered low and thereby a favourable advantage for aquaculture development (Ribeiro, 1983; FAO, 2006d).

Despite its pristine environment, the aquaculture sector is facing huge constraints that need to be addressed as they are hindering the sustainable development of the sector. According to Ribeiro (2007), the main constraints hampering aquaculture development includes a lack of an integrated coastal zone management plan (ICZMP); lack of infrastructure to assist small-scale farming; lack of trained personnel; lack of hatcheries and variability of marketing strategies.

While the capture fisheries encompassing both artisanal and industrial fishing are well developed, the aquaculture sector is still in its infancy and under-developed, with regards to the high potential the country has at becoming a main producer of aquatic organisms, and the needs by the local market for fresh produce (Ministry of Fisheries (MoF), 2007). The aquaculture sector in Mozambique is mainly represented by an industry that produces marine shrimp (2500 ha of land in semi-intensive systems) with production averaging 1 000 metric tonnes (MT) a year (MoF, 2007).

The freshwater aquaculture production is commercialised locally and marine products are mainly for the export market. High valued species such as tiger shrimp *Penaeus monodon* and *Fenneropenaeus indicus* are exported to European and American markets, with small volumes sent to South African and Asian markets (FAO, 2006d). In 2006 the shrimp export was about 800 tonnes and in 2007 it dropped to around 200 tonnes and only 100 tonnes in 2008 as many farms closed due to high production costs associated to the high costs to import feed (oF, 2009). The government of Mozambique considers freshwater aquaculture as the key for small-scale development and mariculture to be better suited for large commercial scale operations. The freshwater aquaculture is operating mostly at subsistence level, although it is usually called small-scale aquaculture (Hanoomanjee *et al*., 2009). The government aims to uplift freshwater farms to a more business orientated operation in order to achieve the Millennium Development Goal which aims at eradicating extreme poverty and hunger (Hanoomanjee *et al*., 2009). Mariculture commenced in the late 1980s and is undertaken on a small-scale basis (Ribeiro, 2007). The mariculture activities are focused on shrimp, fish and seaweed culture, where seaweed farming is more practiced along coastal communities (Ribeiro, 2007). The seaweed farming is well developed because is promoted by NGOs programmes to assist coastal communities; while other mariculture activities are developed by local entrepreneurs without much social integration (Ribeiro, 2007; Omar, 2009).

A large number of ponds have been built countrywide in Mozambique for aquaculture development.The numbers of ponds *per se*, however, are not ideal to determine the level of aquaculture development. Annual production, for example, is a more widely used indicator to evaluate the aquaculture development around the world and Mozambique should incorporate this tool in its evaluation method in addition to number of existing aquaculture ponds (Hanoomanjee *et al*., 2009).

6.2.1 Legal Framework and Institutional Development

Realising the importance of aquatic resources to the economy, food and nutritional security, employment generation and foreign exchange earnings, the Government of Mozambique established the Aquaculture Development Strategy which aims to promote sustainable development of Mozambique's aquaculture sector, and define aquaculture as a feasible alternative for poverty alleviation that could affect presently more than 50% of the population (Ministry of Fisheries, 2007). As part of the "Aquaculture Development Strategy in Mozambique 2008-2017", approved in 2007, the Government of Mozambique created the National Institute for Aquaculture Development (INAQUA) aimed at promoting and managing aquaculture in Mozambique (Hanoomanjee *et al.,* 2009). The strategy also aims to establish a more effective exploitation of the natural resources with aquaculture potential to support the economic growth and reduce poverty levels. To achieve these goals it is important to create a more competitive, sustainable and diversified sector (Hanoomanjee *et al*., 2009).

The relevant advances made regarding aquaculture regulations and legislation culminated with the production of the following documents (Omar, 2009):

- Aquaculture regulation (2001);
- Aquaculture development strategy (2008-2017)- To guarantee that natural resources

with potential to aquaculture are sustainably exploited and contribute to poverty alleviation;

- Heavy metals and antibiotics control and monitoring plan (2007);
- Institute of Aquaculture Development (2008) which lead the promotion, extension and management of aquaculture in Mozambique ;
- Environment contaminants control & monitoring plan (2008);
- Reviewed the code of investment incentives (2009);
- Shrimp research and training laboratory (2009);
- Protocols for cooperation with universities; and
- Review of the legal framework (2009 under revision).

6.2.2 Species cultivated

The most cultivated freshwater species are *Tilapia* spp. whilst mariculture has focused mainly on semi-intensive shrimp production *Penaeus* spp. and seaweeds *Kappaphycus* spp. (FAO, 2006d). The feed for shrimp farming is imported from South Africa and Seychelles or from Asia, increasing production costs (FAO, 2006d). The ponds are located near mangrove forests on the bank of estuaries and farmers treat their effluents by using settlement ponds and mangrove as biofilters.

Tilapia farming is practiced in earthen ponds that vary from small ponds (200-400 m^2) to large ponds (1.5 ha). The most implemented system is extensive. Broodstocks are collected from the wild or from other farmers and are fed only with agriculture by-products and livestock manure. The growth is not satisfactory for the desired market size as farmed tilapia species reach only an average of 150 g in a period of six months due to inappropriate feeding and high populations densities. The expected growth rate of tilapia in a period of 6 months should be around 500 g (FAO, 2006d). The annual aquaculture production is estimated on 0.8 tonnes/ha (FAO, 2006d). At a commercial level, the facilities usually include raceways for fingerling production. Cages are also common, being constructed with locally available raw material such as bamboo and plastic bottles used as buoys.

The system used in coastal areas to farm the seaweeds *Eucheuma denticulatum* and *Kappaphycus alvarezii* consists of poles that are placed in shallow waters near the shore. The mariculture of fish is still in its infancy with species such as the milkfish, *Chanos chanos*, being the most farmed species which is reared in polyculture with tilapia (Ribeiro, 2007). The water supply of ponds is limited to tidal flow. Projects for culturing mud crab (*Scylla serrata)* are planned. In 2009 a pilot project of finfish culture was started in the northern part of Mozambique rearing the species dusk kob *Argyrosomus japonicus* and cobia *Rachycentron canadum*. The juveniles are reared in tanks and transferred to cages offshore (Omar, 2009).

A survey of suitable species for marine culture has been conducted. The identified species include the penaeid shrimps *Penaeus monodon*, *Fenneropenaeus indicus*, *Metapenaeus monoceros* and *Penaeus japonicus*, the bivalve *Perna perna*, and other mussels such as *Modiolus philippinarum*. In terms of clams, the species *Eumarcia paupercula* and *Meretrix meretrix* were considered as potential species because of their high commercial value. Fishes also included in the survey were mullet *Mugil cephalus* and other finfish of high commercial value such as *Epinephelus* sp., the seabream *Rabdosargus* sp., and the snapper *Lutjanus* spp. (Ribeiro, 2007).

6.2.3 SWOT analysis of aquaculture in Mozambique

Mozambique presents good opportunities to develop both freshwater and marine aquaculture. Good water quality, land availability, political stability, improved legislation, regulation and sector plans and high biodiversity are some of the main strengths that the country presents to boost the aquaculture sector and attract new investments (Table 5). Poor infrastructure, absence of hatchery facilities and seed availability are the first barriers in the establishment of a sustainable aquaculture in the country. There is also lack of trained personnel and extension services, poor coordination between relevant institutions which increase significantly the list of constraints. However, the country present also opportunities to improve build capacity, and build infrastructure as well as to harmonise aquaculture projects and integrate better environmental management. Lack of funds constitutes a threat in the sector as the country is highly dependent on external aid. A summary of the SWOT analysis of the aquaculture sector is provided in Table 5.

Table 5 SWOT analysis of freshwater aquaculture and mariculture in Mozambique (Adapted from Ribeiro, 2007; Hanoomanjee *et al.,* 2009; Omar, 2009)

Freshwater aquaculture	Mariculture
Strengths:	**Strengths:**
Good water quality, pollution free and land availability	Good water quality, pollution free and land availability
Political stability	Political stability
Legislation, regulation and sector plans improved	Legislation, regulation and sector plans improved
High biodiversity	High biodiversity
New aquaculture institution created	New aquaculture institution created

Freshwater aquaculture	Mariculture
Government priority Satisfactory interest from local communities and farmers Willingness by government to develop High annual temperatures	Government priority Satisfactory interest from local communities and farmers Willingness by government to develop High annual temperatures Long shore line for mariculture
Weaknesses: Lack of infrastructure and logistic aspects Absence of hatchery facilities Seed availability Lack of trained personnel and extension services Poor coordination among the relevant institutions Lack of investment Few incentives High tax rates High level of losses and poor quality certification Low skills Expensive feed cost (lack of local feed factory) Absence of market strategy	**Weaknesses:** Lack of infrastructure and logistic aspects Absence of hatchery facilities Seed availability Lack of trained personnel and extension services Poor coordination among the relevant institutions Lack of investment Few incentives High tax rates High level of losses and poor quality certification Low skills Expensive feed cost (lack of local feed factory) Lack of a clear strategy for mariculture development Absence of market strategy
Opportunities: Build capacity and train for involved stakeholders (on the way) Build infrastructure Harmonise aquaculture projects and integrate environmental management Review tax regimes and land acquisition rates Develop applied research on high valued species and technologies Implement best management practices and avoid losses Improve local fish market Development of demonstration sites and improved extension networks Job creation Better coordination between NGOs and GOs institutions Construct a feed plant by using local feed ingredients	**Opportunities:** Build capacity and train for involved stakeholders (on the way) Build infrastructure Harmonise aquaculture projects and integrate environmental management Review tax regimes and land acquisition rates Develop applied research on high valued species and technologies Implement best management practices and avoid losses Improve local fish market Development of demonstration sites and improved extension networks Job creation Better coordination between NGOs and GOs institutions Construct a feed plant by using local feed ingredients
Threats: Lack of funds Theft and vandalism Susceptibility to natural disasters (cyclones, floods, erosion and droughts) Lack of capacity for disease management Poor environmental management Bureaucracy	**Threats:** Lack of funds Theft and vandalism Susceptibility to natural disasters (cyclones, floods and erosion) Lack of capacity for disease management Poor environmental management Bureaucracy

6.3 Aquaculture in Tanzania

Tanzania has got a vast unexploited potential for aquaculture, however the history of aquaculture is not well documented. Aquaculture began in the early 1950s, starting with tilapia culture in Tanga and Mwanza regions (FAO, 2006e), using small sized ponds, water reservoirs and irrigation channels. In the 1970s the aquaculture started to gain a high input in terms of policies as it was given some importance in the Fisheries Policy, although at very low level of priority (FAO, 2006e). The small scale fish farming comprises mainly the species *Oreochromis mossambicus,* and Zanzibar tilapia *Tilapia hornorum* and the commercial culture of the rainbow trout *Onchorhynhus mykiss*.

Both freshwater and mariculture are practiced although the level of production is very low due to poor management, rudimentary technology and environmental conditions such as droughts and land availability (FAO, 2006e). In 2004, the freshwater aquaculture production was estimated at 1.5 tonnes for tilapia and 7.0 tonnes for rainbow trout. Fish production is aimed only at the local market, except for rainbow trout which is exported to neighbouring countries (FAO, 2006e). Mariculture started in 1989 with seaweed farming in Zanzibar and in 1995 on the mainland. The cultured species are *Eucheuma denticulatum* and later *Kappaphycus alvarezii* (FAO, 2006e; Msuya and Mmochi, 2007). In Tanzania the farming of seaweed, in 2008, reached a total production of about 9000 tonnes, making Tanzania the third largest producer worldwide at the time. The seaweed product was exported to Denmark and the United States of America (USA) (Semesi, 2009).

According to Msuya and Mmochi (2007) the method used for seaweed farming has reached maximum carrying capacity as all suitable areas are used. For this reason, new methods of farming are needed. Msuya and Mmochi (2007) suggested a method of deeper water farming to increase production. Previously Rice *et al*. (2006) suggested the floating raft method that is currently used by few farmers for seed stock and maintenance during the rainy season. However, the availability of bamboo and other materials constitute a barrier for the implementation of floating raft culture on a commercial scale.

Many experiences have been developed in marine finfish and shrimp farming. In 1995 the Institute of Marine Science (IMS) and the Western Indian Ocean Marine Science Association (WIOMSA) started research on farming marine organisms in Tanzania. The species studied were rabbit fish *Siganus* spp., milkfish *Chanos chanos*, mullet *Mugil cephalus* and tilapia *Oreochromis* spp. In terms of shellfish the attention was on the black pearl oysters, *Isognomon* sp., blue mussels *Mytilus edulis* and *Anadara* sp. (Msuya and Mmochi, 2007).

Tanzania has a good potential for mariculture development. A survey was conducted in 1996 to identify the potential for mariculture. The results showed that the potential is very high for shrimp farming in areas ranging from the northernmost region of Tanga to the southernmost region of Mtwara (FAO, 2006e). The aquaculture industry in Tanzania is still considered as a part-time activity, characterised by operations at subsistence level and owned by households who often have a low level of education. The number of woman involved is higher than the number of men at a ratio of 70:30 (FAO, 2006e). According to FAO (2006e), the impact of aquaculture on the country's economy and poverty alleviation is still insignificant at present; however, it has contributed towards the supply of animal protein in rural areas where fisheries captures are nonexistent; aquaculture has also as increased employment and income opportunities in rural areas.

6.3.1 Legal framework and Institutional Development

The aquaculture sector is under the control of the Tanzanian Fisheries Department. The department formulates and ensures the implementation of policies and regulations. Aquaculture is guided under the Fisheries Policy of 1997, the Fisheries Act No. 6 of 1970, which was amended to the Act No. 22 of 2003, in order to better incorporate aquaculture, and the Principal Fisheries Regulations of 2004 (FAO, 2006e). The amended Fisheries Act No. 22 of 2003 provides tools for eco-labelling and quality certification of aquaculture products. The regulations are related to the protection of the environment, producers and also provide the warranty of aquaculture products. Tanzania ratified the Aquaculture Section of FAO Code of Conduct for Responsible Fisheries (FAO, 2006e).

The mariculture sector is under the jurisdiction of Fisheries Act of 2003 and the Fisheries Regulations of 2005. The regulations are focused on the permit requirements, exotic species translocations and sector specific regulations to control farming activities (Shipton and Hecht, 2007). For commercial operations, the National Environmental Management Council (NEMC) is involved in mariculture activities as an Environmental Impact Assessment (EIA) is required and approval by the Tanzanian Investment Centre (TIC) before a permit can be issued (Shipton and Hecht, 2007). Permits for subsistence operations are issued at District Fisheries Officer (DFO). The DFOs are responsible for the monitoring of subsistence operations. A mariculture guideline is available to facilitate the process of permit issues.

6.3.2 Species Cultivated

Fish farming is dominated by tilapia species with *Oreochromis niloticus* being the most preferred species for farming. Another fish freshwater species cultivated is the catfish *Clarias gariepinus*. The trout *Onchorhynhus mykiss* is commercially farmed, however, on very small scale; there is only one fish farm in Arusha (FAO, 2006e). There are records that affirm that the rainbow trout was introduced into rivers during the colonial era for fishing sports (FAO, 2006e).

Species used in marine fish farming comprise milkfish *Chanos chanos* and the grey mullet *Mugil cephalus*. Shellfish culture includes penaied shrimp (*Penaeus monodon*), molluscs, mud crabs *Scylla serrata*, the pearls oysters *Pinctada margaritefera* and *Pinctada penguin (*FAO, 2006e; Shipton and Hecht, 2007). Cultivated seaweed species are *Eucheuma spinosum, Kappaphycus cottonni* and *Eucheuma striatum*.

A survey of potential species for aquaculture farming has been undertaken and the following organisms were identified as potential candidates: ornamental fish, corals culture, serranid species, sea cucumber *Holothuria* spp. and *Artemia* spp. (Shipton and Hecht, 2007). The most used aquaculture systems are earthen ponds, small tanks and single raceways. For seaweeds fixed off-bottom and raft methods are used.

6.3.3 SWOT Analysis of Aquaculture in Tanzania

Similar to Mozambique, Tanzania also has a great potential for developing both freshwater aquaculture and mariculture; however, the preference seems to be mariculture. Water quality and high research capacity are the major strengths that the country may use to improve their aquaculture status. The country also has a good opportunity to improve the policies related to aquaculture the current absence of a Aquaculture Strategic Plan may prevent large investments in the sector. The government of Tanzania supports aquaculture initiatives and this strength should be used also to attract investors in the country. SWOT analyses of the aquaculture sector in Tanzania are outlined in Table 6. The constraints and strengths presented are similar to those found in South Africa and Mozambique.

Table 6 SWOT analysis of freshwater aquaculture and mariculture in Tanzania (Adapted from Shipton and Hecht, 2007)

Freshwater	Mariculture
Strengths: Good water quality High research capacity	**Strengths:** Good water quality High research capacity

Freshwater	Mariculture
Governmental support Suitable areas available Well established NGOs	Governmental support Suitable areas available Large biodiversity Well established NGOs
Weaknesses: Lack of a Aquaculture Strategic Plan Poor extension capacity Poor aquaculture facilities and hatcheries Low involvement of the private sector Poor management practices Poor feed formulation	**Weaknesses:** Lack of a Aquaculture Strategic Plan Poor extension capacity Poor aquaculture facilities and hatcheries Low involvement of the private sector Poor management practices Poor feed formulation
Opportunities: Improvement of guidelines Development of demonstration sites to improve extension services Greater NGOs participation Development of a Sector Plan	**Opportunities:** Improvement of guidelines Development of demonstration sites to improve extension services Greater NGOs participation Development of a Sector Plan
Threats: Governance constraints Vandalism and theft Poor monitoring	**Threats:** Overexploitation of juveniles for culture Governance constraints Vandalism and theft Poor monitoring

6.4 Aquaculture in Kenya

Aquaculture in Kenya has some similarities with many African countries: it is characterised by a period of rapid growth and then by stagnation (FAO, 2006f). In the early 1900s, fish farming was introduced by the colonialists and it was focused mainly on sport fishing. Fish were cultured in static water ponds; and the main reared species were tilapias followed by sharptooth catfish *Clarias gariepinus* and common carp *Cyprinus carpio*. Later, trout species were introduced to stock rivers for sport fishing (FAO, 2006f).

The stagnation in the aquaculture sector was due to poor extension services and inadequate reporting and documentation that led to poor perception of aquaculture (FAO, 2006f; Mbugua, 2008). The Department of Fisheries believes that aquaculture will eradicate poverty and hunger and encourage the development of private commercial aquaculture, research and training (FAO, 2006f). Furthermore, the Government identified aquaculture as a priority area for funding and this is expressed in the Poverty Reduction Strategy Paper created in 2000 (FAO, 2006f).

Kenya has a great potential for aquaculture in the agricultural rural areas. Poverty and a deficiency in dietary proteins is prevalent in communities living in areas with a relative high number of lakes and rivers. Efforts are being made to produce more food, uplift communities and ensure food security through aquaculture initiatives (Mbugua, 2008). The Aquaculture Collaborative Research Support Programme (ACRSP) financed by United States Agency for International Development (USAID) demonstrated that it is possible to change the custom of rural communities by introducing commercial fish farming practices. The results of ACRSP demonstrated that aquaculture can be a very lucrative business; however, more collaboration with the farmers is needed to make it more economically and ecologically sustainable (Mbugua, 2008).

Mariculture in Kenya was introduced in the late 1970s and a pilot shrimp farm project was established by the Department of Fisheries at Ngomeini Prawn Farm (FAO, 2006f; Mirera, 2007). This project was not environmentally viable as large areas of mangrove forest were degraded (Mirera, 2007). The shrimp production was not at satisfactory levels to be self sustainable as the project was dependent on international donor funds to operate. Later in the 1990s more organisms were introduced for culture such as oysters and seaweeds. According to Mirera (2007) the oyster culture flourished initially reaching more than 10 million farmed oysters (the largest success in Africa); however, the project failed due to a lack of an established market and equipment theft. Pearl oyster farming of the species *Crassostrea cucullata* was introduced by the Kenya Marine and Fisheries Research Institute (KMFRI) with the aim of disseminating seed for culture to the communities if successful (Mirera, 2007).

The Government of Kenya established aquaculture and fisheries as priority areas for poverty alleviation and has been developing facilities throghout the country to be used for research centres, for training of farmers and fisheries personnel, for demonstration sites and for source of fingerlings to farmers (Mbugua, 2008). In parallel, there is an improvement on capacity building of technical staff of the aquaculture sector, diffusion of information through periodical magazines, aquaculture brochures and manuals. One of the positive outcomes of government efforts is the manufacture of 30% protein content tilapia feed to supply tilapia producers, making imports no longer necessary (Mbugua, 2008).

6.4.1 Legal Framework and Institutional Development

The aquaculture in Kenya is regulated under the Fisheries Act of 1991 (cap 378). However, the act is not specific to aquaculture and deals more with species transfer from one catchment area to another. The Government is planning to create a legal framework and policies for aquaculture development (FAO, 2006f). Revisions of the Fisheries Policy are undertaken to include some aspects of aquaculture into the act as the fisheries are geared more towards control than development (FAO, 2006f; Shipton and Hecht, 2007). The Department of Fisheries is responsible for permit issuing for mariculture activities. An Environmental Impact Assessment (EIA) is required for small-scale aquaculture activities; however, aquaculturists lobby for exemption of EIA for small size operations (Shipton and Hecht, 2007).

The Forestry Department plays an important role in mariculture due to an interest in promoting sustainable and environmental responsible mariculture to protect the mangrove forests (Shipton and Hecht, 2007). Other Acts that deal indirectly with aquaculture activities are the Local Authority and Planning Act 6 of 1996 which is related to land based operations; the Water Act 8 of 2006, the Maritime Authority Act of 2006 and the Kenya Ports Authority Act 391 of 1978, which is focused on sea based mariculture activities (Shipton and Hecht, 2007).

6.4.2 Species Cultivated and Systems Used

Three categories of aquaculture can be described in Kenya: warm freshwater aquaculture, cold freshwater aquaculture and marine water aquaculture (mariculture) (Mbugua, 2008). Tilapia is the most farmed species warm water fish in polyculture with sharptooth catfish *Clarias gariepinus*. Cold freshwater fish species involves rainbow trout *Oncorhynchus mykiss*, cultivated at intensive levels in tanks and raceways (Mbugua, 2008).

The aquaculture systems practiced are the extensive, semi-intensive and intensive. The most used farming system in Kenya is the extensive to semi-intensive, using earthen ponds, attaining the size of 1000 m^2. Floating cages in lakes, rivers, dams or water reservoirs and various types of tanks are other systems used to stock cultured species. Intensive tilapia culture is also present; it has begun recently and is also done in cages (FAO, 2006f). Circular concrete ponds and raceways are also used for stocking fishes. Aquaculture in semi-intensive systems contributes to more than 70% of the Kenyan total aquaculture production (FAO, 2006f).

Increased fishing effort to support tourist hotels and export markets caused a decrease of some natural populations of mud crab (Mirera, 2009). The mud crab *Scylla serrata* is the most cultivated species and is known to have a great potential for development as alternative livelihood for the people. However, the survival and growth rates of the larvae are too low to ensure an economic return for the investment and effort to rear the crabs (Mirera and Mtile, 2009). Other species that are cultivated in Kenya are the penaeid shrimps *Penaeus monodon* and *Fenneropenaeus indicus*, oysters *Crassostrea cucullata*, seaweeds *Eucheuma denticulatum* and

Kappaphycus alvarezii, and milkfish *Chanos chanos* (Mirera, 2009).

According to Mbugua (2008) candidate species for aquaculture in Kenya are the finfishes *Oncorhynchus mykiss*, *Oreochromis niloticus*, *Clarias gariepinus*, *Cyprinus carpio*, and *Micropterus salmoides*. The candidate molluscs include *Crassostrea* spp. while the candidate aquatic flora includes *Porhphyra* spp., *Laminaria* spp. and *Alaria* spp. Milkfish has been cultivated by the communities in the last seven years and the results showed that this species has a significant potential to improve the community livelihood (Mirera and Ngugi, 2009).

6.4.3 SWOT Analysis of Aquaculture in Kenya

The enthusiasm of the Government of Kenya in supporting the aquaculture sector is a valuable open door that should be used as a reference to catch the attention of potential investors on aquaculture. Community commitment may be used on the development of small-scale aquaculture, however, a good research base and capacity building is recommended to reduce the environmental degradation and high mortality present and minimise the weaknesses presented in the SWOT analysis of aquaculture in Kenya (Table 7). Kenya has a potential to develop both freshwater and marine aquaculture.

Table 7 SWOT analysis of freshwater aquaculture and mariculture in Kenya (Adapted from Shipton and Hecht, 2007)

Freshwater aquaculture	Mariculture
Strengths: Committed governments and communities Research capacity at KMFRI Government enthusiasm	**Strengths:** Good water quality Committed governments and communities Research capacity at KMFRI Government enthusiasm High biodiversity Support of silviculture by Forestry Department
Weaknesses: Lack of aquaculture guidelines and supporting policies Poor extension capacity Poor understanding of farm-made feeds Seed stocks availability Lack of funding Lack of appropriate technology Networking and information dissemination Marketing Lack of solid research base High mortality rates Environmental degradation	**Weaknesses:** Lack of aquaculture guidelines and supporting policies Poor extension capacity Conflict on access and use of the resources Poor understanding of farm-made feeds Seed stocks availability Lack of funding Lack of appropriate technology Networking and information dissemination Marketing Lack of solid research base High mortality rates

Freshwater aquaculture	Mariculture
	Environmental degradation
Opportunities: Government and /or bilateral support NGO involvement Expansion of demonstration facilities Develop a sector plan Improve the capacity building Fish feeds manufacturing	**Opportunities:** Government and /or bilateral support NGO involvement Expansion of demonstration facilities Develop a sector plan Improve the capacity building
Threats: Land availability Theft and vandalism	**Threats:** Conflict with tourism Land availability Theft and vandalism High soil porosity in coastal zone

6.5 Aquaculture in Madagascar

Small scale experimental fish farms and the subsistence culture of fish in Madagascar were started in the 19050s. The main purpose of farming was to increase the fish stock of natural water bodies for fishing and also to find alternatives to animal protein sources (Woynarovich, 1980). Aquaculture was developed in reservoirs and dams using cages or pens. The species farmed were the silver carp *Hypophtalmichthys molitrix* and bighead carp. *Aristichthys nobilis* The Nile tilapia *Oreochromis niloticus* was also stocked in a restricted number of ponds (Woynarovich, 1980).

The country possesses a variety of biotopes (e.g. long coastline, mangroves in abundance and lagoons) (Ministry of Agriculture Livestock and Fisheries, 2005). Shrimp farming has been developed quite well. In 2007 and the country was considered the African leader in terms of shrimp production with an annual output of 6000 tonnes (Brummett *et al*., 2008). Shrimp production is seen as an alternative means of reducing the pressure on the natural resource because the export thereof is the main source of foreign currency. Although shrimp farming is well developed, the mariculture sector as a whole is still in its infancy. Many efforts in terms of training and infrastructure development are being conducted for seaweed, spirulina *Arthrospira* spp., artemia *Artemia* spp. and brackish water tilapia *Oreochromis* spp. farming (Shipton and Hecht, 2007). Furthermore, the farmers are making efforts to harvest products such as shrimp that can be eco-labelled as "sustainable".

The main constraints that hinder the aquaculture development in Madagascar are the lack of adequate infrastructure such as hatcheries, nurseries, feed factory and processing plants. To solve these constraints, investments on large scale industrial operations (having their own available capital and expertise), can be a viable alternative (FAO, 2001a).

According to Shipton and Hecht (2007) aquaculture extension services in Madagascar are limited. In the past, the extension services were undertaken by large bi-lateral Donor/NGO programmes. The programmes included brackish water tilapia farming, developed by USAID, the small-scale prawn culture developed by the Japanese International Cooperation Agency (JICA) and seaweed farming developed by the Norwegian Agency for Development Cooperation (NORAD). To date only the seaweed culture remains functional. The mariculture research is currently undertaken by the Institute Hallequite de Science Marine, Tulear University in Madagascar and the Department of Biology of the National Centre of Applied Research and Rural Development (FOFIFA). Aquaculture research bone at the University of Antananarivo is focused on *Holothuria scabra*, spirulina *Arthrospira* spp., mussels *Modiolus auriculatus* and *Mytilus edulis*, oyster *Crassostrea cucullata* and brackish water tilapia *Oreochromis* spp. International research partners are Belgian and French universities and donor groups (Shipton and Hecht, 2007).

Aquaculture companies in Madagascar are striving toward the enhancement of their business and the welfare of their employees while at the same time reducing the environmental footprint of their activities (Gruzen, 2005). Initiatives such as community development programmes, town planning infrastructure development and environmental education by these companies are conducted in an attempt to enhance the welfare of their employees and surrounding towns. These initiatives are in partnership with government agencies, NGOs and community associations (Gruzen, 2005).

6.5.1 Legal Framework and Institutional Development

Aquaculture falls primarily under the Fisheries and Aquaculture Ordinance of 1993 (Ordinance No. 93-022). The Ordinance proposed that aquaculture establishments be located on state owned land and require prior authorization of land use, when the use of public water is involved (FAO, 2001a). The concession is delivered by the Ministry of Agriculture Livestock and Fisheries and the Ministry of Environment. The 1993 Ordinance provide some central elements of a permit system; however, some aspects such as a comprehensive Code for Aquaculture to encourage sustainable commercial aquaculture are not covered, making it necessary to examine and refine the Ordinance (FAO, 2001a). The 1993 Ordinance does not repeal early provisions made by 1960 Act. The 1960 provision (Arrêté No. 1794 du 22.10.1960) made rules that govern the culturing of shellfish which conflicted with the 1993 Ordinance. Consequently, it is unclear the continuity and validity of the Arrêté No. 1794 du 22.10.1960, leaving the 1993 Ordinance as the only source for granting the right to undertake such aquaculture operations.

The Ministry of Agriculture Livestock and Fisheries (MAEP) together with the FAO created a master plan for fishing and aquaculture development (2004-2007, supporting documents, 1,2, 3, 6, 15, 16) (Shipton and Hecht, 2007) to improve aquaculture legislation and technical capacity at the MAEP. MAEP/FAO created protocols to promote sustainable small-scale commercial and family based shrimp faming; the identification of suitable culture and biosecurity and technologies. However, the protocols have not been implemented yet due to insufficient political interest or insufficient funds to support the process (Shipton and Hecht, 2007).

According to Grazen (2006), it is clear that unwritten laws must be respected by aquaculture companies in Madagascar to avoid costly and violent social conflicts. Communications with local communities to understand local culture are critical to establish a social stability and sustainability. Aquaculture companies recognise that respect for the environment and cultures of local communities are necessary step for the survival of the shrimp industry in Madagascar.

The 1993 Ordinance (Supporting Document 14) establishes the frameworks for mariculture development and the Ministries of Agriculture Livestock and Fisheries and of the Ministries of Environment and Forestry are the responsible authorities for permit grant to mariculture activities (Shipton and Hecht, 2007). EIA is requested prior to authorisation to undertake mariculture activities. The Department of Fisheries acts as a "one stop shop" for the issuing of mariculture permits and also creates incentives programmes for the industry. The incentives include, the export zone and tax concessions on investments for larger commercial operations (Shipton and Hecht, 2007).

6.5.2 Species Cultivated and Systems Used

The most important species cultivated is *Penaeus monodon* due to its abundant occurrence in the Indian Ocean. The farms are established far away from anthropogenic pressure, providing an advantage in terms of a reduction in water pollution, shrimp and human diseases and theft of the products (Gruzen, 2005). Hi-tech *Penaeus monodon* hatcheries were successfully established between 2003 and 2006, with production reaching 6 million post larvae (PL) per annum (Shipton and Hecht, 2007). However, due to global economic crisis, records points that shrimp farming is also in crisis and the production is decreasing, obligating some farms to closure (Iltis, 2009).

Red algae species *Kappaphycus alvarezii* and *Eucheuma denticulatum* are cultivated at fringing reef and subtidal and intertidal zones. Some farmers are propagating alga for research purpose while others, for carrageenan export and coastal community income improvement (Iltis, 2009). Hatchery techniques and farm testing have been done for the species *Holothuria scabra*. Other farmed species in Madagascar are *Crassostrea cucullata* (in mangroves and intertidal zones), *Modiolus auriculatus* and *Mytilus edulis* (at coastal lagoons). The farming of spirulina is mainly done on the species *Arthrospira platen*sis and *Arthrospira paracas* and the main purpose of farming these organisms is to fight against malnutrition, create jobs, and also incorporation into animal feeds (Iltis, 2009).

Prospects for farming the mud crab *Scylla serrata* is underway and pilot projects started in 2008 with only one farm in operation. *Artemia salina* production has stopped in the private sector and is currently pursued at research level (Iltis, 2009). Projects are planned for 2010 are eel farming, with selected species being *Anguilla mossambica* and *Anguilla marmorata*. Shipton and Hecht (2007) identified the following species to be suitable for farming in Madagascar: *Chanos chanos*, *Oreochromis* spp., *Rachycentron canadun*, *Seriola* spp. and serranid spp.

6.5.3 SWOT Analysis of Aquaculture in Madagascar

Madagascar has favourable environmental conditions such as good water quality to develop aquaculture. Although freshwater aquaculture is present in the country, mariculture is more developed. The research undertaken in Madagascar in collaboration with other institutions abroad is more focused on rearing marine species. A summary of the SWOT analysis findings is presented (Table 8). The current unclear sector plan constitutes a weakness for the sector and poor farm management is one of the threats. However, the willingness to develop the aquaculture sector from government and communities associated with the research support could be used to improve the sector plan and enforce best management practice for aquaculture.

Table 8 SWOT analysis of freshwater aquaculture and mariculture in Madagascar (Adapted from FAO, 2001a; Gruzen, 2005; Shipton and Hecht, 2007; Iltis, 2009)

Freshwater aquaculture	Mariculture
Strengths: Research support in country and abroad Bilateral donor agreements Willingness to develop the aquaculture sector from government and communities Excelence in training Land availability Private investment	**Strengths:** Good water quality Research support in country and abroad Bilateral donor agreements Willingness to develop the aquaculture sector from government and communities Well established private prawn industry Excelence in training High biodiversity with potential to culture

Freshwater aquaculture	Mariculture
	Land availability Private investment
Weaknesses: Unclear sector plan Poor extension services Funds availability	**Weaknesses:** Unclear sector plan Poor extension services Funds availability
Opportunities: Good relationship between government NGOs Good NGOs involvement Potential to develop research centre for the development of new species culture Hands-on training of trainers in Madagascar	**Opportunities:** Good relationship between government and NGOs Good NGOs involvement Potential to develop research centre for the development of new species culture Hands-on training of trainers in Madagascar Pioneer in sea cucumber ranching in WIO
Threats: Poor farming management Theft and vandalism Resource conflicts Biosecurity issues for small prawn farms	**Threats:** Poor farming management Theft and vandalism Resource conflicts Biosecurity issues for small prawn farms

6.6 Aquaculture in Mauritius

Aquaculture in Mauritius started in the French colonisation period. The fingerlings of marine finfish were collected in lagoons and stocked with the purpose of fattening (Ministry of Agro-Industry and Fisheries, 2007; Shipton and Hecht, 2007). Various species of tilapia were introduced during 1953-1957 and reared using supplemental feed and fertilisation. Due to the prolific breeding behaviour of tilapia species, an explosion population followed, limiting the growth size and consequently reducing market value. Escaped cultured species to natural environments are now considered pests in Mauritius (Shipton and Hecht, 2007). Freshwater shrimp aquaculture was introduced in 1970s through *Macrobrachium rosenbergii* which was introduced from Hawaii.

According to the Ministry of Agro-Industry and Fisheries (2007), three species of Chinese carps and another three species of Indian carps were introduced in 1975 in the private sector for commercial purpose. The carp farming was done in association with the freshwater prawns (camaron); however, the culture was forced to stop due to low demand for these species. Red tilapia from Malaysia was also introduced in 1990 and sex reversal was implemented to maximise the growth. Late, in 1996, Australian crayfish was introduced by the private sector; however, the production was discontinued for the same reasons as for carps (Ministry of Agro-Industry and Fisheries, 2007).

Mauritius is an oceanic island and its endemic freshwater fauna is limited (Shipton and Hecht, 2007). A scarcity of land close to the sea is visible, resulting in a very narrow mangrove area, the most appropriate site for aquaculture. However, the area with lagoons is extensive and enough for coastal aquaculture development. The country presents a considerable potential for the increase in fish production for export, thereby contributing towards the economy. The introduction of cage culture in 2002 seems to be a good alternative for increasing fish production; however, some conditions such as suitable species and appropriate technology must be provided and suitable environmental conditions available to make this system successful (Ministry of Agro-Industry and Fisheries, 2007).

Mariculture activities began in late 1980s in Barachois with the Japanese International Cooperation Agency (JICA) collaboration, starting with sea bream culture and two species of marine shrimp for the replenishment of the coastal water stock. The development of mariculture requires high capital investment. The lack of good sites deters any serious development by the private sector. Government hatcheries are the only source of juvenile shrimps to enhance and restock the lagoons (Ministry of Agro-Industry and Fisheries, 2007). To overcome this situation, experiments to acclimatise species from marine to freshwater environments were undertake; however, the results were discouraging. Other experiments were done for mud crab seed production; unfortunately the results were not satisfactory (Ministry of Agro-Industry and Fisheries, 2007). Promising results were obtained when rearing the red drum *Sciaenops occellatus*, sea bream *Pagrus pagrus* and rabbit fish *Siganus* spp. farmed in the deep channel in the lagoon of the South-East coast of the country.

The farming techniques used in Government hatcheries were clear water and green water technologies which were also transferred to the private sector (Ministry of Agro-Industry and Fisheries, 2007; Shipton and Hect, 2007). Freshwater scarcity halted production in 2002 and most of the private farmers abandoned the activity due to high production costs. During these times, fingerlings were provided from Government hatcheries to supply the medium and small scale farmers (Ministry of Agro-Industry and Fisheries, 2007).

Due to the crisis faced in some sectors such as the textile and the sugar sector, the Government of Mauritius is encouraging the introduction of new projects. The first choice is mariculture as the country presents a good potential for finfish culture and other marine organisms and efforts are underway to attract investments for marine aquaculture projects (Ministry of Agro-Industry and Fisheries, 2007). The focus area for mariculture production in Mauritius is the Barachois region, were since 2002, the Ferme Marine Mahebourg Ltd is farming goldmine sea bream *Rhabdosargus sarba*, the red drum *Scianops ocellatus* and is also planning to rear cobia

Rachycentron canadum (Shipton and Hecht, 2007).

The country is now aware that it has mariculture potential and only recently attempts to develop the sector started. A Master Plan for Aquaculture was drafted in 2007 and policies were also formulated to implement aquaculture projects in conjunction with the eco-tourism development (Ministry of Agro-Industry and Fisheries, 2007; Shipton and Hecht, 2007). A draft pertaining to the Aquaculture Business Activities Act was also developed in 2007. Furthermore, the Government is planning to lease identified/demarcated sites to investors with sustainable and environmentally friendly aquaculture practices (Ministry of Agro-Industry and Fisheries, 2007).

6.6.1 Legal Framework and Institutional Development

The Fisheries Act of 1998 regulates freshwater aquaculture activities and mariculture. The Act presents some provisions that allow the Minister to grant permits and exemptions to individual farmers. The Act is not clear in terms of policy guidelines, enforcing interested individuals to apply for such a permit or exempt them from doing so, depending on the interests of the applicants (Shipton and Hecht, 2007). The lack of clear policies constitutes a constrain for potential investors as they do not have legal rights regarding any specific land; and are not able to prevent the access of other resource users in the area (Shipton and Hecht, 2007). To solve this problem, amendments to the Fisheries Act of 1998 were approved by parliament in 2008, through the Bill of Finance (2008), to enable the development of the aquaculture sector (Chellapermal, 2008). The Section 8C of the Bill presents some changes related to concession areas for aquaculture. With the Bill, portions of the lagoons and sea can be leased for a period of 20 years then be renewed for periods of 10 years in consecutive years for aquaculture projects. The Finance Bill also serves as an incentive for mariculture development because it applies low corporate taxation and tax breaks (Chellapermal, 2008). The amendment brought discussion among the society as the traditional users such as fishermen, boaters, divers and water sports practitioners saw their access to these areas denied, and in case of violation, they will be punished by fines or imprisonment (Chellapermal, 2008).

The research regarding mariculture is conducted at Albion Research Centre where extension and research facilities are available; although most of the facilities are underutilised due to the lack of funds. The centre aims to ensure that aquaculture projects are environmentally presenting baseline studies such water quality and pollution. Furthermore, Certification protocols for exporting aquaculture products are also being developed (Shipton and Hecht, 2007). According to Lesperance (2009), the recommended mariculture sector plan of 2007, was successfully developed in 2008 to improve the regulatory and institutional framework.

The Government strategy aims to develop the seafood industry and aquaculture. Sites for aquaculture and potential investors have been identified (Ministry of Agro-Industry and Fisheries, 2007). A Master Plan for aquaculture was drawn to create a good environment for investors. Although the Master Plan gives privilege to the already farmed species, the Government strategy encourages the investor to introduce farming of high-valued species (Lesperance, 2009).

Permits for fish farming are applied in conformity with the First Schedule of the Fisheries and Marine Resources Act 2007 as amended by the Finance Act of 2008. The Ministry of Agro Industry, Food Production and Security, Prime Minister's Office, Ministry of Environment and the Board of Investment, are the authorities involved in the process of permit granting for fish farming (Bourgeois, 2009).

6.6.2 Species Cultivated and Systems Used

The main cultivated and candidate species are the red drum *Sciaenops ocellata,* cobia *Rachycendron canadum*, Nile tilapia *Oreochromis niloticus*, cordonnier *Siganus Sutor*, barramudi *Lates Calcarifer*, yellowtail kingfish *Seriola lalandi* and Almaco Jack *Seriola rivoliana* (Ministry of Agro-Industry and Fisheries, 2007).

The aquaculture system mostly used is the extensive system. The unavailability of agricultural and fishery products for feed production makes the supplementation of feed in ponds difficult. Algae and invertebrates are collected from the lagoon and used in few farms to supplement the fish diet (Shipton and Hecht, 2007). Fingerlings are collected from the lagoon or entry directly through pond the gates during high tides while crabs are collected during the night using nets and lights. Oyster seeds for stocking are obtained from natural beds and a culture of imported fast-growing species such as *Crassostrea virginica*, *C. gigas* and *Ostrea edulis*, was attempted as these species showed a better growth than the local oyster *Crassostrea cucullata* (Shipton and Hecht, 2007). However, high mortality rates were observed because these species require an environment with high phytoplankton productivity, low temperatures and salinities, conditions not found in local waters (Shipton and Hecht, 2007).

Four marine shrimps were identified as having good potential for aquaculture during a survey done in 1984. The species are shrimps *Penaeus monodon*, *Penaeus latisulcatus*, *Penaeus canaliculatus* and *Metapenaeus monoceros*; however, the availability for breeding stock only appeared with *P. latisulcatus* and *M. monoceros*. Recent 2008 studies carried out during the Regional Programme for the Sustainable Management of the Coastal Zones of the Countries of the Indian Ocean (ReCoMap) shows that seaweed farming and sea-cucumber ranching may have some potential (ReCoMap, 2009). Freshwater prawn faming is undertaken at small and medium scale and seeds are provided by the Government hatcheries. Strains of hybrid tilapia are also farmed at low level (Ministry of Agro-Industry and Fisheries, 2007). Red drum *Sciaenops ocellata* in association with other finfish species is cultivated in floating cages since 2002.

6.6.3 SWOT Analysis of Aquaculture in Mauritius

Unpolluted waters, existence of an aquaculture sector plan and government commitment are the main strengths that Mauritius has to develop its aquaculture sector. The SWOT analysis (Table 9) shows that the country has a great opportunity to develop commercial mariculture. Poor extension services, high feed costs and lack of research at academic level at the main university are the principal factors found to slow down aquaculture development in the country.

Table 9 SWOT analysis of freshwater aquaculture and mariculture in Mauritius (Adapted from Ministry of Agro-Industry and Fisheries, 2007, Shipton and Hecht, 2007; ReCoMap, 2009)

Freshwater aquaculture	Mariculture
Strengths: Unpolluted waters Governmental commitment Good research and monitoring capacity Support from the Bureau of Investments	**Strengths:** Unpolluted waters Existence of a Sector Plan Governmental commitment Good research and monitoring capacity Support from the Bureau of Investments
Weaknesses: Poor extension capacity Difficulties on selection of suitable species Seed availability High cost of supplemental feed Low funding availability No research at academic level at the main university	**Weaknesses:** Poor extension capacity Difficult access to the coast Difficulties on selection of suitable species Seed availability High cost of supplemental feed Low primary production Low funding availability Intentions to restrict mariculture to large scale developments No research at academic level at the main university
Opportunities: Increased governmental and /or bilateral support Greater NGOs involvement	**Opportunities:** Commercial mariculture development Increased governmental and /or bilateral support Greater NGOs involvement
Threats: Seasonal increase of water temperature leading to disease outbreak Establishment of products at a competitive price	**Threats:** Conflicts among marine environment users Vulnerability to cyclones Seasonal increase of water temperature leading to disease outbreak High land completion with other development

	areas along the coast Limited access to the Barachois region Establishment of products at a competitive price

6.7 Aquaculture in Seychelles

There have been many attempts to develop aquaculture in the past, however, most of the attempts failed, due to poor coordination, poor planning of the procedures and lack of proper framework, to guide and develop the sector (Lesperance, 2009). There are some conflicts and disagreements amongst key statutory role players in recognising the potential of the aquaculture sector on the inner and outer islands. For example the Department of Agriculture and Natural Resources and Seychelles Fishing Authority recognise the overfishing and the depletion status of most demersal fish stocks and agree on the development of the aquaculture sector. There are opinions from the Island Development Company that there is no potential to develop the sector on the inner islands due to user conflicts (Shipton and Hecht, 2007). An assessment of aquaculture opportunities can be a valuable tool to provide Seychelles with information to take rational decisions, whether to commit or not to commit with the development of the sector. Efforts in assessment of aquaculture requirements were made in 2004 (Shipton and Hecht, 2007); however, the assessment was elementary and failed to provide a clear future scenario for promotion and development of the aquaculture sector (Shipton and Hecht, 2007).

6.7.1 Legal Framework and Institutional Development

Aquaculture is regulated by the Fisheries Act of 1991 jurisdiction Chapter 82 (Supporting Document 1). The Fishing Authority has a responsibility to manage, administer and develop aquaculture, and to conduct appropriate research for purpose of facilitating the development of the sector (Shipton and Hecht, 2007). The Fisheries Policy of 2005 (Supporting Document 8) states that aquaculture research and development will be a valuable tool to facilitate new breeding techniques for suitable species. Furthermore, the Government should promote research development for aquaculture to ensure a sustainable use of resources and an ecologically sustainable aquaculture, while minimising the adverse impacts on the environment (Shipton and Hecht, 2007).

A scoping study of mariculture opportunities was conducted in 2009 and a Mariculture Master Plan was recommended to ensure that the development of the sector will be sustainable socially and environmentally (ReCoMap, 2009). According to the ReCoMap (2009) a Master Plan should consider a review of relevant legislation and investments incentives. A bio-physical assessment of the marine environment should also be considered to identify suitable sites as well as potential species. With a successful implementation of master plan, the mariculture sector will contribute significantly to fish production and ensure the food security.

According to the Environmental Protection Act (Supporting Document 12) new mariculture activities are subjected to an EIA. Mariculture in Seychelles is limited due to narrow mangrove forest available for this activity. Any mariculture in mangroves is regulated by the Forestry Reserves Act of 1967 (Chapter 185) is to be considered and applied. Other relevant Acts are the National Parks and Nature Conservancy Act of 1969 (Chapter 141), for mariculture activities in marine parks; the Town and Country Planning Act of 1972, for land based mariculture and the Maritime Zones Act, No. 2 of 1999 for sea based mariculture (Shipton and Hecht, 2007).

The capacity of the Seychelles Fisheries Authority is limited, consisting on only one scientist (MSc level) and 2 technicians, who attended short courses in China. The Seychelles Centre for Marine Research and Technology actively facilitates research initiatives of foreign organisations and academic institutions (Shipton and Hecht, 2007).

6.7.2 Species Cultivated and Systems Used

Mariculture in the Seychelles is dominated by shrimp farming with the tiger shrimp *Penaeus monodon* being the most farmed species (Shipton and Hecht, 2007). Shrimp farming is most developed on Coetivy Island (De Muylder, 2000; Shipton and Hecht, 2007). Black oyster pearls *Pinctada margaritifera* and giant clams *Tridacna maxima* culture are also reared at a significant level.

Research suggested the following species to be potential candidates for aquaculture in Seychelles, these are: *Epinephelus fuscoguttatus, Epinephelus polyphekadion, Epinephelus tukula, Epinephelus lanceolatus, Epinephelus tauvina, Epinephelus polyphekadion, Seriola rivoliana, Lutjanus sebae, Lutjanus argentimaculatus, Trachinotus blochii, Rachycentron canadum* and *Lutjanus gibbus* (Lesperance, 2009).

Shipton and Hecht (2007) and Lesperance (2009) noticed that the country has a potential for sea cucumber ranching in the lagoons. Additionally, there is potential for crab culture at small and medium scale and also a need for upgrading the prawn farming at Coetivy or for finding alternative sites (Lesperance, 2009).

6.7.3 SWOT Analysis of Aquaculture in Seychelles

The Seychelles present a great potential to develop mariculture. No data were found related to freshwater aquaculture in this country. This may be due to the severe freshwater scarcity in the country. In terms of mariculture, Table 10 present an list of important qualities such as excellent water quality, high level of institutional support, and as well established feed factor that the country has developed for the sector. However, the weaknesses such as poor legislative and regulatory framework and lack of scientific data and information are very strong issues and need to be dealt with seriously; so may compromise the growth of mariculture.

Table 10 SWOT analysis of freshwater aquaculture and mariculture in Seychelles (Adapted from Shipton and Hecht, 2007; Lesperance, 2009, ReCoMap, 2009)

Freshwater aquaculture (No information available)	**Mariculture**
Strengths:	**Strengths:** Excellent water quality Outside cyclone belt Perception by the fishermen of resources depletion High level of public institutional support Recognition of future potential Good international research relationship and research cooperation Attractive investment incentives Suitable sites for cage culture Well established feed factory Raw material locally available
Weaknesses:	**Weaknesses:** Low capacity building Lack of comprehensive assessment opportunities Poor understanding of the future fisheries scenarios Lack of scientific data and information Poor legislative and regulatory framework
Opportunities:	**Opportunities:** Contribute to GDP through sea cucumber ranching Pearl culture expansion Upgrade the existent farms to a larger commercial level Development of finfish cage culture Aquarium fish and crustacean culture for export
Threats:	**Threats:** Lack of consciousness of the government of future fish supply and demand scenarios Competition for space with other sectors such as tourism

7. DISCUSSION

There are some common constraints that hamper the aquaculture development and investors attraction in the region. Most of them are associated with bad governance, and lack of political and policy stability (FAO, 2002). To encourage investment in the sector, policies such as rights to land usage and an appropriate exchange rate are needed. Some countries have started administrative reforms and the results are encouraging. The reforms must avoid over-regulations that are detrimental to the industry and that are highly costly (FAO, 2002).

Research development, extension services in the private sector and producer associations need some improvements. Developing research could be advantageous as the finding can be internalised to all members, giving an incentive to contribute to research funds. It was noted that many government stations in the evaluated countries were abandoned after the donor agencies left (FAO, 2002). Due to these phenomena, many expert have recommend that governmental stations be divested of their role as seed producers, fish feed suppliers and demonstration centres, being the responsibility of fingerling production attributed to the private sector (FAO, 2002). Well-managed and accountable producer associations are encouraged to be used as marketing agents and as monitors for environmental self-policing (FAO, 2002; Rouhani and Britz, 2004).

7.1 Legal Framework

Specific aquaculture regulations are needed in the region to avoid uncertainties among investors. However, all WIO countries are making considerable efforts at compiling aquaculture regulations. South Africa united recently the Department of Agriculture and the Department of Environmental Affairs and Tourism, creating a new department, the Department of Agriculture, Fisheries and Forestry (AISA, 2010). This initiative will solve the problem of fragmentation of regulation, making a valuable contribution to the aquaculture sector, for example in terms of procedures for aquaculture permits. The government of Mozambique on its Aquaculture Developement Strategy established in 2008 the National Institute for Aquaculture Development (INAQUA) to promote aquaculture and also to establish a more sustainable use of natural resources with potential to aquaculture (Hanoomanjee *et al*., 2009). The establishment of INAQUA can be considered as a very important step for aquaculture development as the country has a governmental institution dealing exclusively with tasks related to aquaculture. However, coordination between INAQUA and institutions such as the Ministry for Coordination and Environmental Affairs (MICOA) is still needed, because large scale aquaculture operations require Environmental Licences (E L), and MICOA is the authority responsbale for issuing. Furthermore, coordination between the Ministy of Tourism is also necessary to avoid competition for space, especially along the coast.

In Tanzania, changes have been made to the current Fisheries Act of 2003, to better incorporate aspects related to aquaculture (FAO, 2006e). Similar to other WIO countries, an EIA is required for permit issue in Tanzania. Coordination among institutions has not yet been well addressed. For example, permit for commercial operations must be curried out under supervision of the National Environment management Council but an approval from the Tanzanian Investment Centre is also required, before permit grant (Shipton and Hecht, 2007). Important steps made by Tanzania are the establishment of eco-labelling and quality certification of aquaculture products, and the ratification of the Aquaculture Section of FAO Code of Conduct for Responsable Fisheries, which may need from farmers more responsibility regarding environmental protection.

Positive progress in aquaculture is expected to occur in Kenya as revisions of the Fisheries Policy were conducted to include specific aquaculture regulations. The aim of the Government of Kenya in relation to aquaculture include the promotion of a more sustainable and environmental aquaculture (Shipton and Hecht, 2007). This is a positive signal that awareness regarding environmental protection is present. The most important step that Kenya did is the improvement on capacity building of technical staff of the aquaculture sector. Madagascar made also positive progress by creating a Master Plan to improve aquaculture legislation and technical capacity at the Ministry of Agriculture Livestock and Fisheries and establish the ‘one-stop-shop’ (Shipton and Hecht, 2007). The creation of a “one-stop-shop”, which facilitate the swift issuing of permits and decision making whereby efforts are concentrated on attracting new investments in the sector (DEAT, 2006; FAO, 2006).

Similar to other WIO countries, in Mauritius an environmental compliance is required for permit granting in aquaculture acticities. Protocols for exporting aquaculture products were developed as well as a Master Plan to create a good environment for investors (Lesperance, 2009). The country has a mariculture research centre (Albion Research Centre) which ensures that aquaculture projects are environmental friendly.

According to ReCoMap (2009), a Master Plan is required for the Seychelles to incorporate aspects such as investments incentives and the environment protection. A Centre for Marine Research and Technology was created in the Seychelles to facilitate research initiatives for foreign organisations and academic institutions, thus, increasing the needed capacity buiding for the sector. An EIA is also required for mariculture activities.

7.2 SWOT analysis of the WIO countries

A summary of the common issues found in the SWOT analyses is graphically presented below. The SWOT analyses demonstrate that the WIO region presents some strength and opportunities for aquaculture development and promotion of which could improve the status and provide means of livelihood. The main identified strengths, with regards to aquaculture development in the region, are represented in Figure 3. It is noticeable that the most powerful strengths within the region are water quality followed by Government's commitment and research base support aspects considered important when planning the development of aquaculture in a country.

Lack of extension services and adequate aquaculture policies (Figure 4) are the main weaknesses of the aquaculture sector in the region, followed by lack of feed factories and of investments/funds.

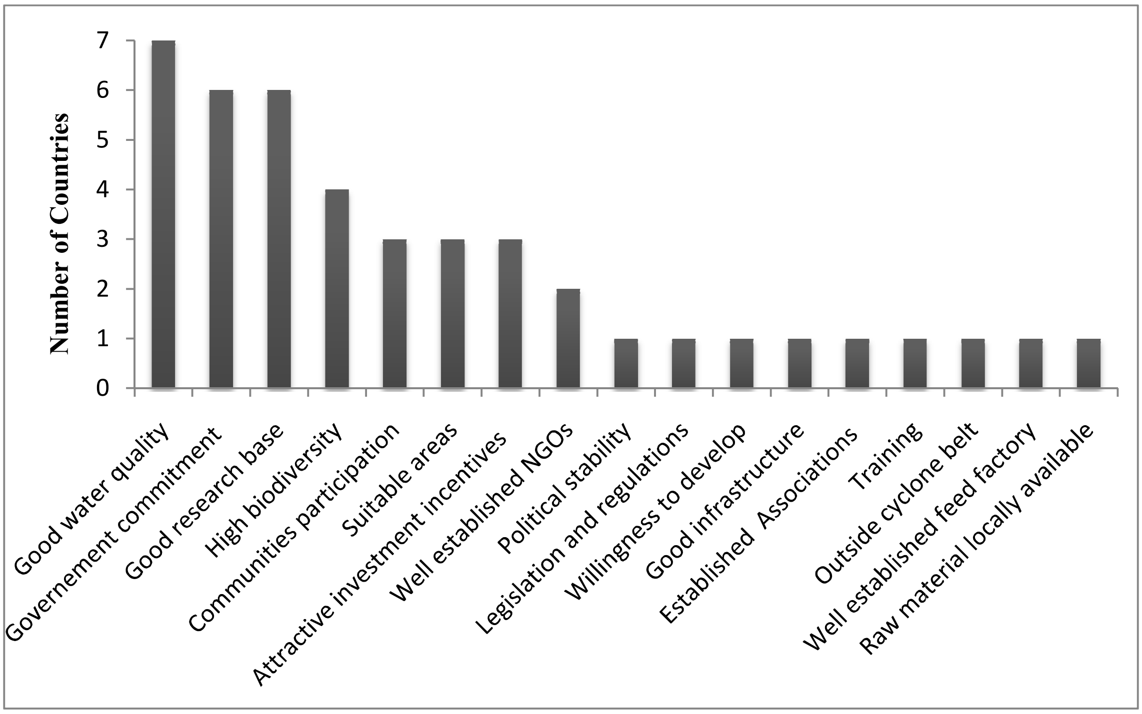

Figure 3 Summary of the major aquaculture strengths in the Western Indian Ocean region

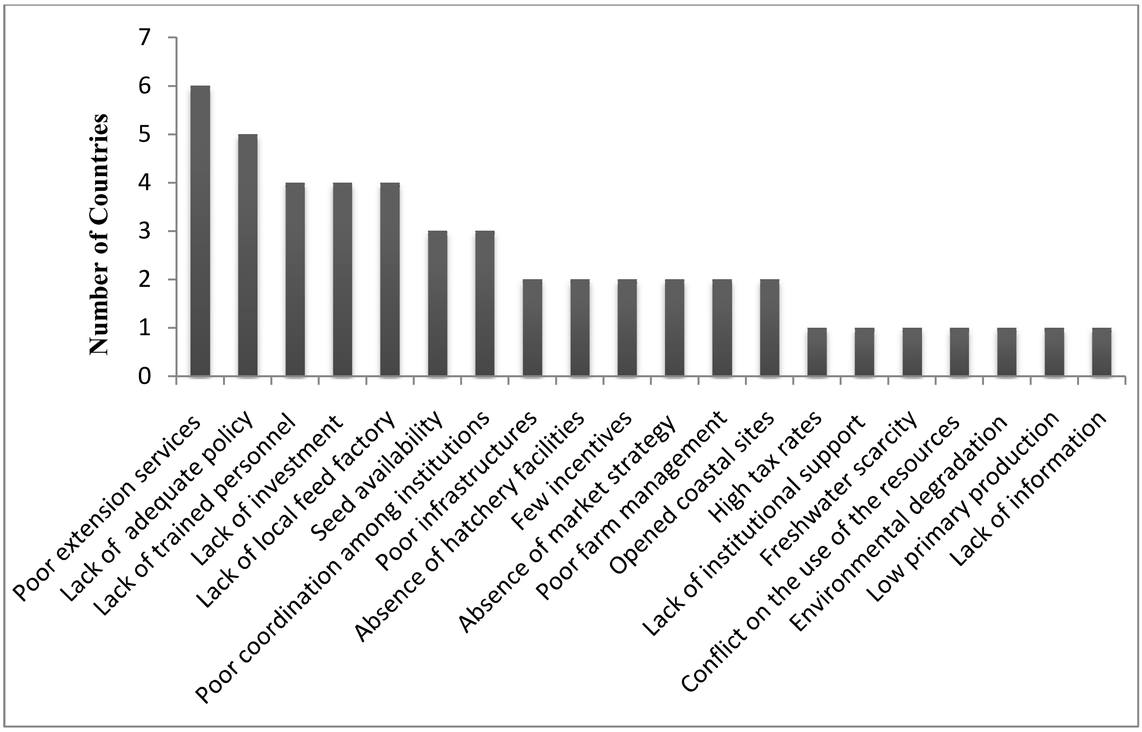

Figure 4 Summary of the major aquaculture weaknessess in the Western Indian Ocean region.

Although a large list of constraints inhibiting aquaculture in the region exists, there are a reasonable number of (Figure 5) that are valuable for aquaculture development. The region presents good opportunities to improve the coordination between institutions to avoid duplications and handling time for all the necessary documentation for new applicants seeking permits. The lack of capacity building and training of the involved stakeholders is relevant weaknesses that need to be transformed into opportunities to further the development of aquaculture in the region. There is a common interest to develop research capacity and technologies that can produce positive results for the sector.

The major threats that have been identified in the region are theft and vandalism, susceptibility to natural disasters and the poor environmental management (Figure 6). Conflict among resource users is another concern that threatens the aquaculture sector and is considered as being one of the main sources of social conflicts caused by aquaculture activities.

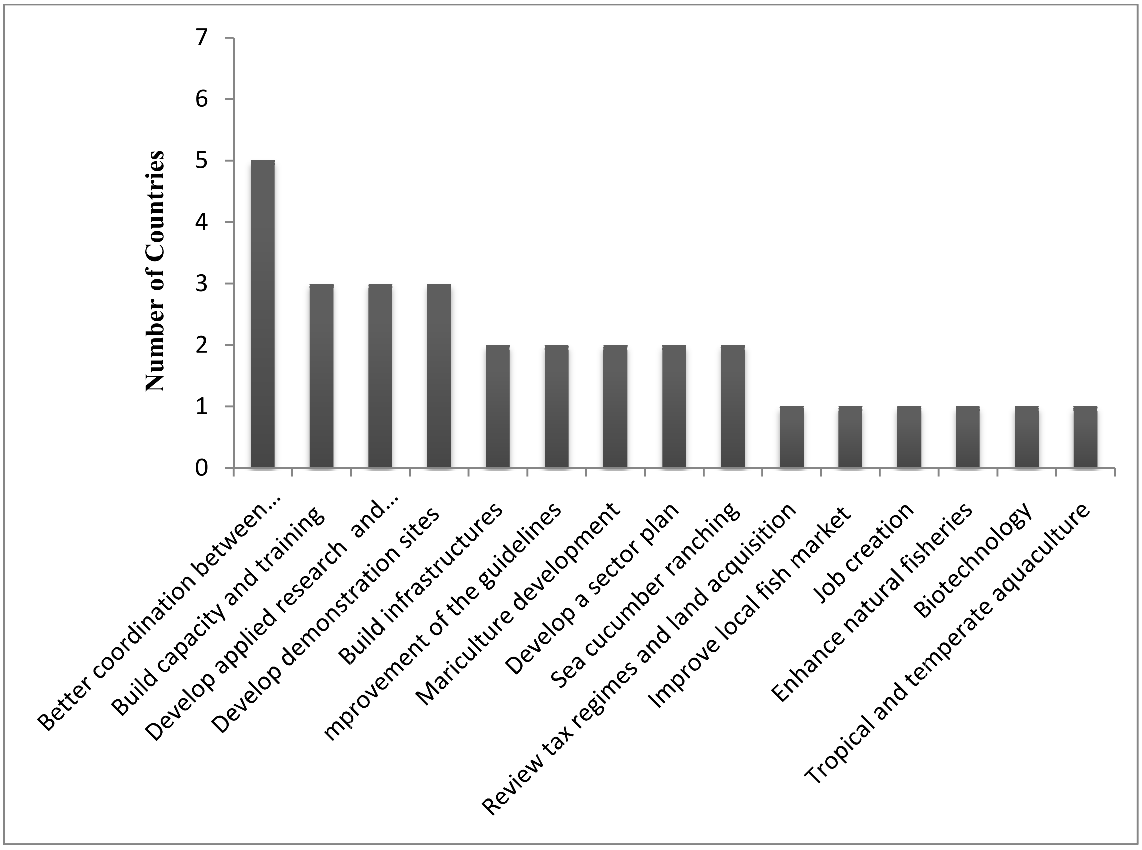

Figure 5 Summary of the major aquaculture opportunities in the Western Indian Ocean region

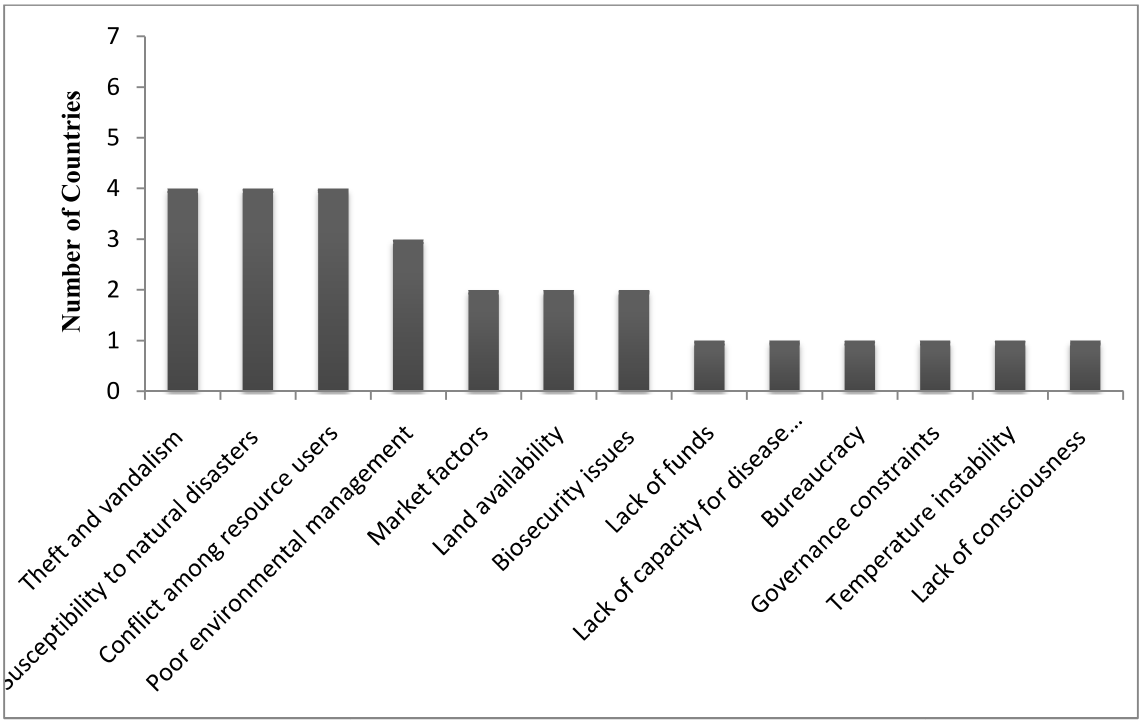

Figure 6 Summary of the major aquaculture threats in the Western Indian Ocean Region

7.3 Cultured species and candidate species to aquaculture

Certain species are common in the region, however the only species that is, or has been farmed in all countries evaluated in this review is the shrimp *Penaeus monodon* (Figure 7; Appendix A). Figure 7 shows the most cultured species in the WIO region. After tiger shrimp *P. monodon*, tilapia species *Orecochromis niloticus*, *Artemia* spp. and sharptooth catfish *Clarias gariepinus* are the most cultured species in the region. Mud crab *Scylla serrata* was recently introduced in the region (cultured mainly in Kenya), however, studies are still needed to evaluate the potential of this species to aquaculture. Appendix A shows species cultured in each WIO country and the species considered candidate to aquaculture. The reason for the preference for this species in all countries could be because *P. monodon* is considered one of the most economically important species in aquaculture, it shows good growth rates in tropical waters and has the ability to spawn twice or more times per year in the tropics (Mukherejee and Mandal, 2009).

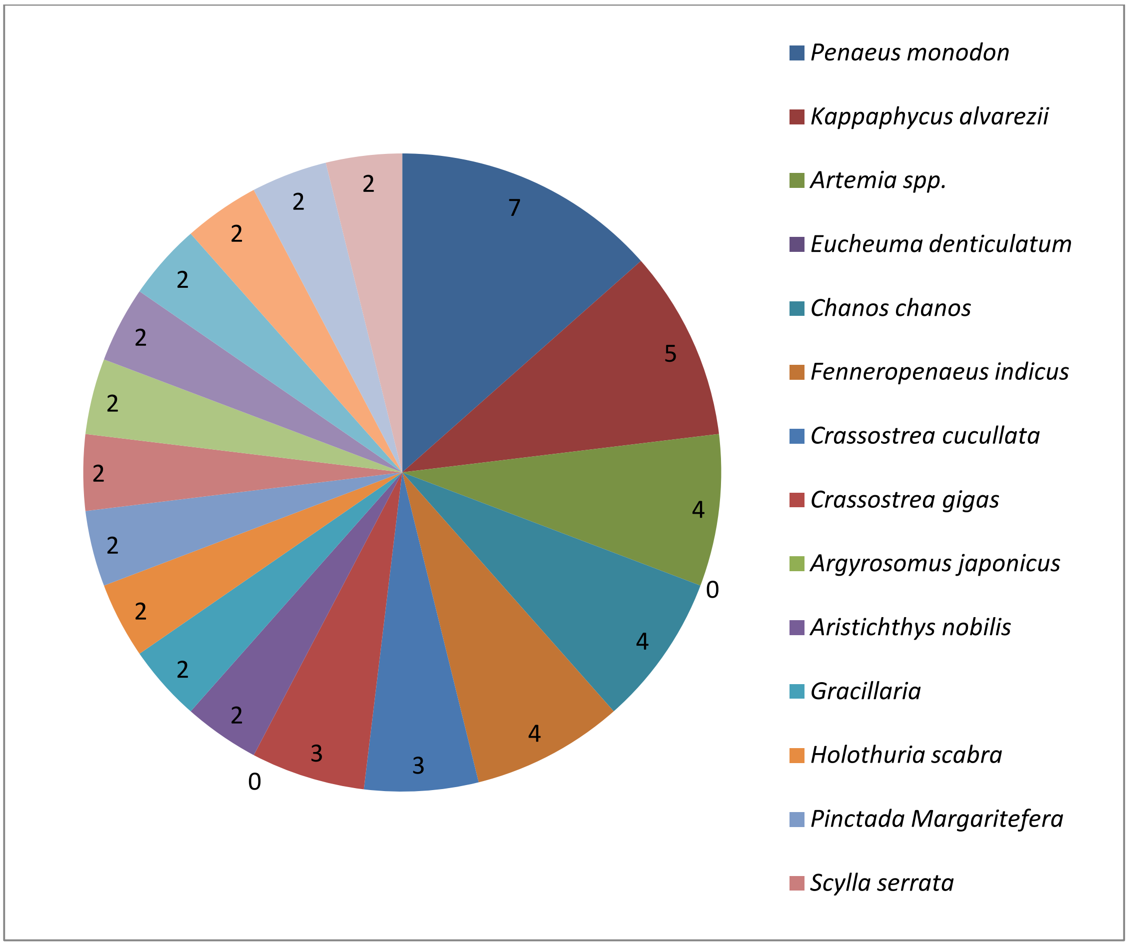

Figure 7 The most cultured species in the Western Indian Ocean region. The numbers in the pie indicate the number of countries where the species is cultivated

Candidate species with a good potential for aquaculture were identified in the review (Figure 8, AAppendixes A, B and C). It was noticed that the WIO countries are willing to develop the mariculture sector as most of the species recommended as potential are marine species. The species *Rachycentron canadum* is the most recommended followed by *Lutjanus* spp., *Metapenaeus monocerus*, *Scylla serrata* and *Seriola rivoliana*. The preference for *Rachycentron canadum* may be due to its rapid growth, high fecundity, good feed ratio conversion and high selling price (Colburn *et al.*, 2008; Chen *et al.*, 2009). Furthermore the species can be propagated artificially with huge success and can reach 4 to 6 kg within 1 year (Colburn *et al.*, 2008; Chen *et al.*, 2009).

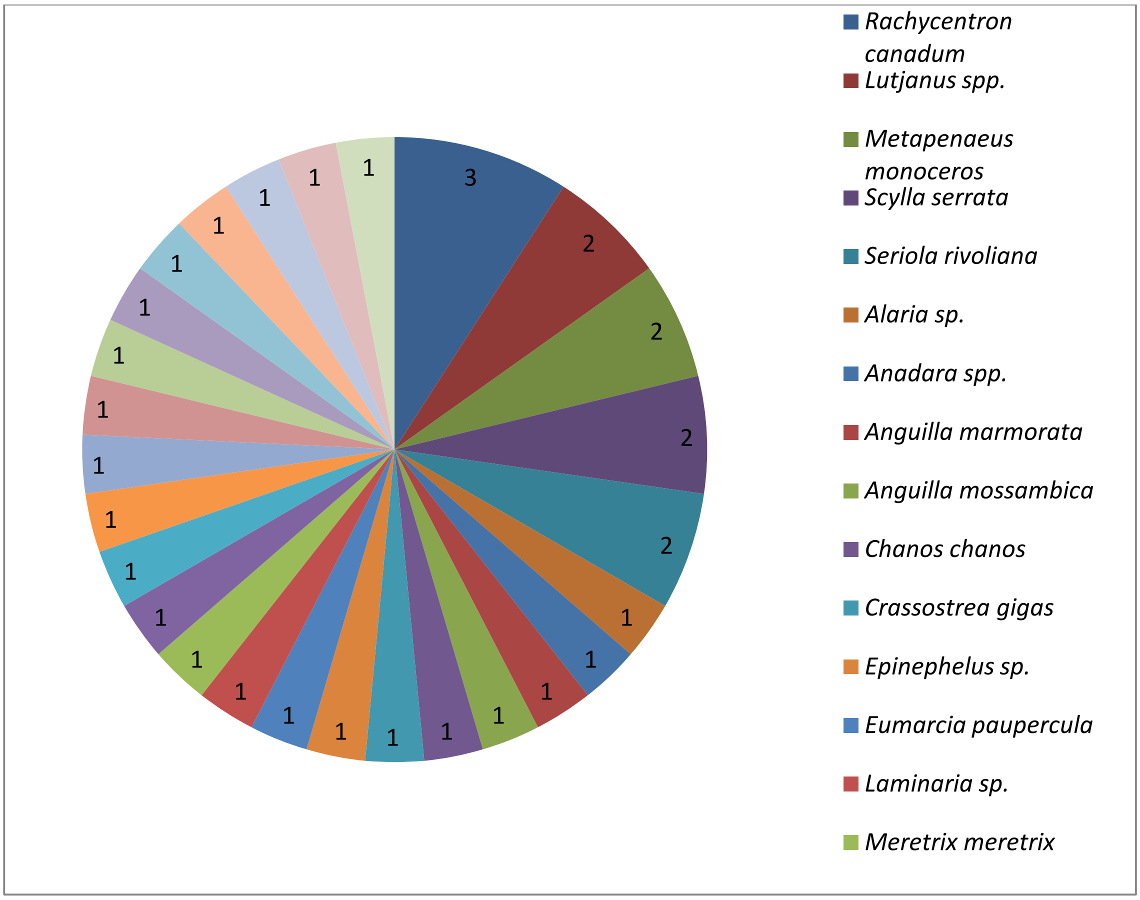

Figure 8 The candidate species with potential for aquaculture in the Western Indian Ocean region. The numbers in the pie indicates the number of countries where the species are considered as candidates for aquaculture.

A description of species in terms of biology and ecology as well as environmental interactions and factors inhibiting growth, is provided in order to facilitate the decision in the selection of suitable species for aquaculture, according to the characteristics of each country (see Appendix

B for freshwater species and Appendix C for marine species). The countries' characteristics should comprise climate conditions, water availability and origin of the species. Appendices B and C also present informative contents regarding species disease diagnosis and treatment necessary, that may be of interest to specialists of farm disease control.

8. RECOMMENDATIONS FOR FUTURE AQUACULTURE DEVELOPMENT

Weaknesses and threats that constrain aquaculture in the WIO region were identified in the previous section (Summary of the Major Issues for Aquaculture in the WIO Region). Although processes for developing aquaculture in Africa have started (Coche *et al*., 1999), the continent is still in an early stage of development, compared to other regions of the world (Coche *et al*., 1999; Primavera, 2006). A more holistic approach is required for aquaculture to achieve the promise of food security and poverty alleviation without compromising the environment and the socio-economy (Primavera, 2006). The FAO highlighted important initiatives to further the development of the sector. These initiatives included the engagement of many stakeholders, such as fishers and fisher communities to avoid too much focus on the aquaculture sector and/or farms (Coche *et al*., 1999). Additionally, the initiatives suggest greater responsibility of the private sector on all production aspects such as feed, seed and technology as well as redefinition of the role of many governments. Instead of acting as the manager and the investor in the sector, the governments could focus their efforts by facilitating and monitoring aquaculture projects. The governments are also called upon to support research initiatives and provide information to achieve better results (Coche *et al*., 1999). Producers' commitment at managing the sector was also pointed to be a vital tool to further the development of the sector. Better statistical information could be obtained if the farmers could organise themselves into associations and be active at supplying reliable information, (Coche *et al*., 1999). Issues identified using SWOT analysis and the recommendations proposed are based on lesson learnt from other countries that have a well established, profitable and vibrant aquaculture sector. More alternatives to mitigate or reduce the main constraints that hamper the development of aquaculture in the WIO region are described below

8.1 Extension Services

Aquaculture extension services in Africa were initiated in the 1950s and incorporated in the 1960s through technical assistance to fish farmers by extension agents (Machena and Moehl, 2001). The extension agents, usually employed by the government, were responsible for introducing and monitoring the country's aquaculture programmes, made the aquaculture extension more expensive due to the logistic support of distant fish farmers. As a consequence, the extension services were weak or non-existent (Machena and Moehl, 2001). Brummett *et al*. (2004) identified key issues that should be considered to improve the extension services for aquaculture in the sub-Saharan Africa. These key issues prioritise access to more accurate and updated information on aquaculture technology, as information and technologies are considered to be crucial components. For example, the current extension material used in many African countries can be updated by introducing more illustrations for better understanding, to achieve better results for farmers (Brummett *et al*., 2004). Furthermore, the research component must incorporate both extension agents and farmers to ensure that the research is relevant to farmer's needs and that valuable information and technology is also available to them (Aguilar-Manjarrez and Nath, 1998; Mohel, 1999; Brummett *et al*., 2004; Ifejika *et al.,* 2008; Ravisankar *et al.,* 2009).

According to Brummett and Williams (2000), a shift is required toward a more flexible and efficient structure to meet producer's needs. A shift may be warranted to establish complete reforms for extension services that include remuneration packages and rewards to extension agents in the field. A reward incentive could allow, for example, promotion within the field rather than move them up the ranks and further away from contact with farmers (Brummett *et al*., 2004). According to Brummett *et al.* (2004) in-service or overseas training have made insignificant changes on the improvement of aquaculture extension. Moreover, progress based on restructuring of the relationship between research, extension and farmers has been verified in several countries (Brummett *et al*., 2004). Madagascar is one of the countries where attention has focused on small groups who have had some experience in aquaculture, education and capital assets and who have a will to assist their fellow farmers. The method for assisting small groups has proved to be more effective than assisting a large number of farmers. The number of extension agents could be effectively reduced (Brummett *et al*., 2004).

8.2 Improvement of Aquaculture Policies

The establishment of comprehensive aquaculture policies and appropriate aquaculture legislation is needed to promote a sustained growth of the aquaculture sector in Africa (Machena and Moehl, 2001). The role of governments in providing legislation, such as aquaculture policies and development plans in consultation with relevant stakeholders, is essential to prevent or reduce the negative impacts caused by aquaculture (Brummett and Williams, 2000; Primavera, 2006). This can be achieved, for example, through the establishment of regulations and standards for water quality, acceptable level of emissions and the enforcement of EIA and specific laws (Primavera, 2006). The governments should also create environmental policy programmes and introduce penalties and taxes, based on the Polluter Pays Principle, to mitigate or reduce the environmental and socio-economic damages caused by aquaculture activities. These taxes can be used for rehabilitation of mangroves and other damage caused to the environment and to finance alternative water supplies in case of salt-water intrusion and compensation of local people, for the loss of their livelihoods (Primavera, 2006).

According to Brummett and Williams (2000), policies and planning are a question of "political will". If the political will is strongly present, formulation of appropriate policies and plans will be achieved in the region. The support of national policies and programs and capitalisation by local and international development agencies is required if aquaculture is to succed in Africa. A sentiment is shared by the NEPAD (2005). The NEPAD also recommends a review of international lessons and evaluation of their implications into African context. Furthermore, NEPAD (2005) suggests an establishment of regional networks of aquaculture policy practitioners to accelerate the development of aquaculture strategies integrated into wider economic strategies at national level (NEPAD, 2005).

Aquaculture cannot be seen as an isolated sector, but as one of the many agricultural activities for which countries must cater. Madagascar and Mozambique have made positive progress, and currently, appropriate aquaculture policies and legal frameworks are being developed and awareness for the importance of relevant policies is increasing (Machena and Moehl, 2001). According to NEPAD (2005), aquaculture should be linked to investors at all national and regional initiative programs and the lessons and experiences of public-private partnership from other sectors and regions must be reviewed. Furthermore, the reviewed policies and legal frameworks must support further private sector opportunities, research, training and technology development.

The region in general has started to develop some of the policies that can promote aquaculture. Worldwide implemented policies for promoting aquaculture are summarised in Table 11 (FAO, 2002). The list is not exhaustive with regard to the WIO region, however constitutes a good base research to improve the current aquaculture policies in the region; the main issues found in the SWOT analysis of the WIO countries are presented. Some additional expenditure to be practicable in each country in the region may be needed. In addition, Table 11 indicates whether the impact is immediate, medium-term or long-term.

Table 11 List of policies from worldwide that could be used as a reference to promote commercial aquaculture in the Western Indian Ocean region. *Short (within one year), medium (1-5 years) and long (more than five years) (Source: FAO, 2002).

Constraint/Issue	Policy instruments			
	Involving Additional Outlays	**Impacts**	**Not Involving Additional Outlays**	**Impacts**
Duplication of administrative procedures	Lead agency Sectoral plan	Long Medium	Legislative framework for aquaculture	Medium
Permit acquisition			Improve access to regulations	Medium
			Accelerate processing of applications	Medium
Encourage environmental sustainability			Land/water legislation	Long
			Legislation on imports of alien species	Long
			Environmental Impact Assessment	Long
			Self policing	Medium
			Economic incentives	Medium
			Zoning	Long
Feed availability	Subsidise feed mills	Long	Attract a large companies with a demand for feed	Long
			Encourage livestock companies to diversify	Medium
			Encourage domestic production with tariffs	Medium
Seed availability	Use of government fish stations	Short	Shift of stations to the private sector	Medium
Cost of feed/seed	Subsidies and Cash grants	Short	Exemption from sales taxes/custom duties on inputs	Medium
Promotion of investment	Start-up grant	Short	Tax holidays	Medium
	Export subsidies	Medium	Tax relief on imports	Medium
Research	Increase research intensity	Long	Increase demand driven research	Medium
	Improve diffusion, and networks	Long	Increase private sector funding	Medium
Training and extension	Extension based on model farmers	Medium	Training/extension provided by the companies supplying inputs	Medium
	Training at colleges/ professional schools	Long	Training/extension provided by the producer associations	Medium
			Use of technical assistance paid for by producers	Medium

8.3 The Plight and Role of Women in Aquaculture

An assessment of traditional inequalities between gender relations of men and women in aspects such as labour and income in sub-Saharan Africa needs to be fully understood as usually women are allocated unpaid family and community work, while men are given productive and remunerated tasks (Rutaisire *et al.*, 2009,). The role of woman in aquaculture in the sub-Saharan Africa is generally limited to seaweed farming, processing, packaging and marketing functions

(Anetekhai *et al*., 2004; Rutaisire *et al*., 2009). There is a need to encourage and promote women to play a more active role in aquaculture; usually women are also not featured in policies and programmes (Rutaisire *et al*., 2009,). Furthermore it is important to improve gender awareness among all stakeholders in order to establish gender-sensitive approaches to developing, training and transfer technology. This can be achieved through enabling access to means of production, especially, land and funds (Anetekhai *et al*., 2004). Moreover, there will have to be a cultural change whereby men do not fear their women counterpart who may excel and earn similar to or higher wages than them.

8.4 Capacity Building

Aquaculture research has been highly developed worldwide, however, in Africa the restricted access to current knowledge and technologies is still impeding research development (Machena and Moehl, 2001). There is a need to improve communication systems that can subscribe to current technical literature through libraries, universities and other institutions (Machena and Moehl, 2001). According to NEPAD (2005) it is necessary to identify available technologies that fit into the regional context and strengthen the capacity of relevant institutions to provide science and training services and links with private sector initiatives. Research on the main factors that affects the aquaculture production such as fish feed, quality fingerlings and pond preparation are key elements for the success (Anetekhai *et al*., 2004). In 2007 Mozambique made a step forward in the development of sustainable marine resource by establishing a National Centre for Aquaculture that enables training and provide expertise needed to support the sector.

8.5 Establishment of Local Feed Factories

It is necessary to provide nutrition of adequate quality and quantity to the farmed organisms in order to increase production (Machena and Moehl, 2001). The agricultural development of the country is correlated to the production of commercial fish feed; meaning that well established agricultural systems often increase the capacity of providing fish feed that can meet the demand of the industry (Machena and Moehl, 2001). In South Africa for example, the private sector has got the capacity to supply the feed requirements of the industry. However, in many countries rations and pelleted feeds are still not available and have to be imported, thus increasing production costs (Machena and Moehl, 2001).

According to Brummett and Williams (2000), there remains a need to promote and facilitate the private sector's production of feed and seed stock. Hasan *et al*. (2007) proposed alternatives, such as, training public and private sector nutritionists on pelleting, on-farm feed formulation and manufacture; also small-scale feed manufacturing, design and development of low cost feed drying technologies and on appropriate storage facilities. Furthermore, in terms of research, Hasan *et al*. (2007) suggest an evaluation of alternate feed ingredients and quantification of demand for animal manure in aquaculture. The role of the governments should be in providing incentives for the development of animal feed industries including aquafeeds and also review their legislation with respect to the feed industry (Hasan *et al*., 2007).

8.6 Coordination Among Institutions Involved In Aquaculture

The promotion of collaboration, coordination and exchange of information between institutions will be a valuable tool in reducing time spent in the acquisition of licences, permits or aquaculture certifications (Brummett and Williams, 2000). The integration of communities in the management of resources should be considered since they are the usual managers of these resources (Primavera, 2006; Ribeiro, 2007). Integrated coastal zone management (ICZM) should be delineated for fisheries, aquaculture, tourism and other uses, based on the concept of ecological footprint, which incorporates aspects, such as, feed and seed stock and also outputs, such as, effluent treatment (Primavera, 2006; Ribeiro, 2007).

8.7 A Creation of "One-Stop-Shop" for Interested Investors

The current process of licensing and granting aquaculture permits in the WIO countries is considered time consuming and gigantic obstacle for the harmonious development of aquaculture, due to the weaknesses of lack of the regulation by various government departments (FAO, 2006). It is necessary to call for coordination among different authorities or departments that share regulatory responsibility, in order to avoid the duplication of efforts, with regard to the use of resources, and thereby, halt the delay in issuing aquaculture permits. The creation of a "one-stop-shop" should facilitate the swift issuing of permits and decision making whereby efforts are concentrated on attracting new investments in the sector (DEAT, 2006; FAO, 2006).

8.8 Aquaculture Infrastructure and Hatchery Facilities

Transport infrastructure is a key factor in aquaculture development (Machena and Moehl, 2001). It was verified that most of the countries in the WIO region present poor transport infrastructure; some roads are accessible only during the dry season while others are only accessible using four-wheel driven vehicles (Machena and Moehl, 2001). These factors have a negative effect on the distribution of fry and the export of harvested products to the markets. Governments, donors and development agencies should make every effort to invest in marketing infrastructure such as roads, retailing facilities and ice plants (Brummett *et al.,* 2008).

Numerous unsustainable aquaculture hatcheries and stations built for research, fry production and training were operated and sustained through donor funding (Machena and Moehl, 2001). Expensive and unsustainable aquaculture infrastructure should be reduced, especially the government fish stations (Brummett and Williams, 2000). Government stations should be used only for research and maintenance of broodstock that can ensure satisfactory operations (Machena and Moehl, 2001).

Hatcheries as the reliable sources for producing large quantities of seed stock are an essential prerequisite for any aquaculture enterprise. Although hatcheries may be expensive to establish, sustainable technologies for hatchery seed production need to be developed in the WIO region in order to guarantee the supply of seed, stimulating the growth of the aquaculture sector specially for emerging small-scale farmers. Hatcheries may be used as training centres increasing consequently the capacity building of farmers and relevant aquaculture players (DEAT, 2006). In the case of South Africa where government hatcheries no longer produce fingerlings for stocking rural aquaculture projects or water bodies, there is a need to re-assess the role of existing hatcheries in terms of fingerling supply (Rouhani and Britz, 2004). The assessment should consider the involvement of the private sector as the private sector is considered essential for sustainable growth of rural aquaculture.

8.9 Aquaculture Investments, Incentives and Market Strategies

The lack of capital investment is one of the factors which hamper the development of commercial aquaculture. To support commercial aquaculture development financially, special financing mechanisms should be established that include loan insurance schemes (FAO, 2002). According to FAO (2002), the establishment of financial institutions that provide loans and banking services should help on the expansion of aquaculture even for small-scale aquaculture initiatives.

The creation of incentives for medium and large-scale producers is necessary to promote aquaculture in Africa (Brummett and Williams, 2000; Primavera, 2006). The establishment of taxes, credits, penalties for effluent disposal, groundwater extraction and the use of foreign chemical could be more effective in the induction of behavioural changes towards the environment and also for generating revenues (Primavera, 2006). Good market mechanisms can provide financial incentives for the aquaculture industry. For example, the industry can modify its production process and incorporate consumer boycotts and eco-labelling (Primavera, 2006). The compliance with the eco-labelling process could be rewarded through premium prices. In addition, certification of the products and regular monitoring of farms should be provided by the government (Primavera, 2006).

Information flow on markets, prices and standards to enterprises and investors in the region need to be improved. The improvement should be through an assessment of options for public-private partnership for management and financing of the aquaculture sector based on experiences of other regions (NEPAD, 2005). Furthermore, encouraging an establishment of a regional aquaculture industry association should facilitate coordination, market development, research and development.

8.10 Farm Management

To improve on the sustainability of aquaculture, an improvement on farm management is required, especially with regard to feed, water, effluents and diseases. An adoption of codes of conduct and best management practices such as the 1997 FAO Code for Responsible Fisheries-Aquaculture Development could be appropriate (Primavera, 2006). Water quality standards should be applied for effluents and ponds and a good management of the cultured organisms, feed, water and soils should be considered as the first defence against diseases outbreaks. To manage diseases outbreaks, a combination of good husbandry and good feed with the use of prophylactic agents may be created in order to reduce to a minimum the use of chemicals. The chemicals must be used only in extreme cases the environmental conditions, nutrition and hygiene has been optimised. Any chemical/substance used should be safe to the cultured organism, farm staff, environment and the consumer (Primavera, 2006).

According to Brummett *et al*. (2008), there is a need to establish standards for EIA for cages in lakes and other waterbodies. Closed and semi-closed systems that allow for the recycling of water can be practical means of reducing waste discharge and also can minimise the introduction of diseases to the environment (Primavera, 2006). The growth of mangrove seedlings must be promoted as mangroves act as bio-filters by treating effluents and reducing the level of solids, organic matter and nutrients that leads to eutrophication in the surrounding environment (Primavera, 2006).

8.11 Integrated Aquaculture

Integrating aquaculture with agriculture, livestock and small-scale irrigation systems can be a valuable tool for increasing the productivity of farms, and thereby contributing significantly to food security (NEPAD, 2005; Brummett *et al*., 2008). Examples of integrated successful aquaculture are available in Southern Africa, e.g. Malawi; where integrated systems are used such that the effluent water of fishponds is utilised to irrigate crops, produces almost six times the yield that would otherwise be generated by the typical smallholder. However, to make integrated systems work, approaches need to be assessed and adapted to a country's natural environment (NEPAD, 2005; Brummett *et al*., 2008).

8.12 Aquaculture and Climate Change (Susceptibility to Natural Disasters)

Climate change is a relatively new concern that may threaten the sustainability of aquaculture development. The changes are due to gradual global warming and associated physical changes that can lead to extreme weather events (FAO, 2009a). For example, in Tanzania the Western Indian Ocean Regional Assessment and Institutional Analysis (2009) reported impacts of climate changes observed in seaweed farming; seaweed stocks died due to rising water temperatures related to climate changes.

It is difficult to predict the magnitude of future impacts of climate change on aquaculture dependent communities as the magnitude of the impacts depend on the vulnerability of each community, its exposure to the impacts, as well as its adaptive capacity (De Silva and Soto, 2009; FAO, 2009a). To minimise negative impacts, a better understanding and promotion of adaptive strategies by both public and private sectors will be required; also so are the mainstreaming of cross-sectoral responses into governance frameworks (FAO, 2009a). Recognition of climate-related vectors and processes and their interactions and the availability of information for decision-making may be needed (FAO, 2009a). According to FAO (2009), cooperation and coordination between government and all relevant stakeholders will be required for policy-making and action planning in response to climate change. The FAO (2009) suggests a review on existing aquaculture management plans, to ensure that the plans will cover potential climate change impacts, mitigation and adaptation responses.

There are gaps in knowledge in relation to the response and adaptation of both marine and freshwater resources and ecosystems to climate changes, meaning that planning for the unexpected needs to become a priority (FAO, 2009a). Aquaculture activities should respond to these changes by relocating farms or alternately farming more tolerant and resistant species to climate changes (De Silva and Soto, 2009). In the development of adaptive measures, the interactions between temperature and salinity must be taken into account as it may vary between farmed organism (De Silva and Soto, 2009). Furthermore, examples of past management practices such as conservation of key ecosystems, strategies for flood, droughts and coastal management (Magrin *et al.,* 2007) in response to climate variability and extreme events must provide valuable lessons as how to deal with unpredicted impacts of climate change (FAO, 2009a). A Geographical Information System (GIS) based assessments of aquaculture related vulnerability to climate change should also be conducted (NEPAD, 2005).

8.13 Ornamental Fish Farming

The African continent features a huge diversity of ornamental fish particularly cichlids, cyprinids and catfishes. South Africa has shown a greater potential of ornamental fish culture in the region where, 21 tonnes were exported in 2003 (FAO, 2006). An increase of interest in ornamental fish and plants (excluding seaweeds) for non-food purpose was observed Ornamentals fish are not bred for consumption but for the hobbyist, they provide a solid means to generate income.

8.14 Species Selection

The interest for rearing finfish species, both in cold and warm waters, has increased for the aquaculture development and growth (Francois *et al*., 2010). The selection of species must be well thought-out decision. Different aspects, such as, species diversification, different approaches to species selection and demand from local and international markets, must be considered in the selection of suitable species for aquaculture. Priority should be given to species that grow fast, are tasty, with high disease resistance, efficient in food conversion rate and inexpensive to rear (Mann, 1984). Good market value of final products, and climate and environmental adaptations aspects should also be assessed before species selection (Northern Aqua Farms, 2010). In addition, reliable rearing techniques must be established for the intended species and the natural life cycle should be well known.

The use of indigenous species reduces some environmental concerns, and may facilitate broodstock and hatchery management at the farm level (Brummett, 2007). However, in order to improve the quality of currently farmed species it will be necessary to create selective breeding and realistic options, such as, the importation of alien species/strains, with high commercial value (Brummett *et al*., 2008). In the WIO region, there is a need for rearing high-quality fingerlings to be more competitive as many tilapia producers worldwide uses selectively bred or improved strains that grow faster than wild stocks (Brummett *et al*., 2008). However, the environmental concerns related to the impact on biodiversity may limit the importation of species with faster growth. Breading programs for indigenous species may be a solution to reduce the environmental risk brought by the importation of alien species or strains (Brummett *et al*., 2008). Appendices A, B and C provides essential species information on biology, aquacultural characteristics and environmental interactions which provide technical information that may be of reference in the field of aquaculture in terms of species selection.

9. CONCLUSIONS

Aquaculture in the WIO region presents a common historical background, characterised by a period of rapid development funded largely by external donors, followed by a period of stagnation. Lack of political stability and adequate policies such as land acquisition and water uses in relation to aquaculture were found to be the major constraints that hamper the aquaculture development and which retracted new investments in the region (FAO, 2002, DWAF, 2006; Nabutola, 2009). Most of the WIO countries have started reforms on their current regulations in order to better address the aspects related to aquaculture; and the results are encouraging.

The SWOT analyses showed that the main potential strengths of the region are the availability of suitable sites for aquaculture development, governments' commitment and improved research base. These strengths are the key factors for a successful aquaculture development planning and may be used as opportunities to attract more investments in the sector. The identified strengths may be associated with the major opportunities presented by the region such as the improvement of coordination between institutions, capacity building and training of involved stakeholders. If the governments are committed to the development of the sector, they may act as facilitators on the link between different institutions that play roles in aquaculture, thereby, avoiding duplications and handling time applications for aquaculture permits within a reasonable timeframe. South Africa made the first step most recently through merging two government departments that dealt with aquaculture regulations after many years of being fragmented (Aquaculture Institute of South Africa, 2010).

Foreign investments have been made in Africa for the development of the aquaculture sector during 1978 to 1984, however, due to the lack of knowledge in the field, associated to the lack of institutional structure support, few advantages of these investments were apparent (FAO, 2006a; Brummett *et al*., 2008). As a consequence, many aquaculture projects failed after funding ceased or abandonment of foreign expertises, as the local technical capacity to continue with the projects was limited and in some cases non-existent. Currently, improvements are made in terms of capacity building and training of the involved stakeholders in the WIO region. This makes a great difference compared to the last 40 years; and could be used as an opportunity to show that the region now is in the process of becoming furnished with the needed capacity to manage aquaculture entrepreneurs.

Theft, vandalism, susceptibility to natural disasters and the poor environmental management, constitute the main threats for aquaculture development in the WIO region. Minimising the identified weaknesses such as poor capacity building and training and using the opportunities such as coordination between government institutions and all relevant stakeholders, the region will be in a better position to respond to the different aspects related to natural disasters and environmental management. The governments will have a opportunity to include on their existing and future aquaculture development plans aspects that will cover the potential impacts of climate change and proposed mitigation and adaptation responses (FAO, 2009a).

Conflict among resource users is considered as one of the main sources of social conflicts caused by aquaculture activities. With the reforms to the current regulations that are being undertaken in many countries of the WIO region, this concerns could be better addressed by creating clear planning for delineation of the spaces according to priority needs.

Analysis of most suitable species for aquaculture shows that the species *Penaeus monodon* is the most widely farmed in the WIO region; and its farming continues to be recommended as the species is economically viable and the tropical environment of the WIO region is suitable to rearing it. Most recommended aquculture species in the countries surveys were marine species, meaning that the WIO countries are interested in developing the mariculture sector (Appendice A, B and C). The species *Rachycentron canadum* followed by the species *Lutjanus* spp., *Metapenaeus monocerus*, *Scylla serrata* and *Seriola rivoliana* were the main recommended species.

Categories of aquaculture system and practices were described accordin to stocking densities and fertilisation input. Environmental problems associated with aquaculture were also presented. The most common problems are related to water quality, ecosystems degradadion and social impacts.

10. REFERENCES

Aguilar-Manjarrez, J. and Nath, S.S. 1998. A Strategic Reassessment of Fish Farming Potential in Africa. CIFA Technical Paper No. 32. Rome, FAO. 170p.

Andren, L.E., 1975. Pollution and Degradation of Environment Affecting Aquaculture in Africa. FAO, Rome (Italy). Fisheries Dept, FAO/CIFA Symposium on Aquaculture in Africa, Accra (Ghana). 16 p.

Anetekhai, M.A., Akin-Oriola, G.A., Aderinola, O.J. and Akintola, S.L., 2004. Steps ahead for aquaculture development in sub-Saharan Africa- the case of Nigeria. *Aquaculture*. Vol. 239 (1-4), 237-248.

Aquaculture Institute of South Africa, 2010. South African aquaculture legislation. www.ai-sa.org.za (Retrieved 28 October 2010).

AUT University, 2000. S.W.O.T. Analysis. Product Brief Development Tools. http://www.ciri.org.nz/downloads/SWOT%20Analysis.pdf (Retrieved 28 July 2010).

Begum, M., Shah, M.M R., Mamun, A.A. and Alam, M.J., 2009. Comparative study of mud crab (*Scylla serrata*) fattening practices between two different systems in Bangladesh. Journal of Bangladesh Agricultural University. 7(1), 151–156.

Benetti, D.D. and Orhun, R., 2002. Aquaculture of pelagic fish: Cobia (*Rachycentron canadum*). Global Aquaculture Alliance. Technical Magazine 5(1), 61-62.

Beveridge, M.C.M. and Phillips, M.J., 1993. Environmental impact of tropical inland aquaculture. In: R.S.V. Pullin, H.Rosenthal and J.L. Maclean (Eds), Environment and Aquaculture in Developing Countries. ICLARM Conf. Proc., 31, 213-236.

Biao, X., Ding, Z. and Xiaorong, W., 2004. Impact of the intensive shrimp farming on the water quality of the adjacent coastal creeks from Eastern China. Marine Pollution Bulletin 48, 543–553.

Bourgeois, O.A., 2009. Opportunities for cage farming of Ombrine/Red Drum (*Sciaenops ocellatus*) in south-east Mauritius. A Report to the Fishermen Investment Trust. Regional Programme for the Sustainable Management of the Coastal Zones of the

Countries of the Indian Ocean (ReCoMaP). Mauritius. 36 p.

Brummett, R.E. and Williams, M.J**.,** 2000. The evolution of aquaculture in African rural and economic development. Ecological Economics, 33 (2), 193-203.

Brummett, R.E., 2007. Indigenous species for African aquaculture development, in: Bert, T. M. (ed.), Ecological and genetic implications of aquaculture activities. Springer, pp 290-245.

Brummett, R.E., Lazard, J. and Moehl, J., 2008. African aquaculture: Realizing the potential. Food Policy 33, 371–385.

Brummett, R.E., Pouomogne, V. and Coche, A., 2004. Aquaculture extension in sub-Saharan Africa. Fisheries Circular 1002, Food and Agriculture Organization of the United Nations, Rome. 64pg.

Bunting, S.W., 2006. Low impact aquaculture. Centre for Environment and Society. Occasional Paper 3, University of Essex, Colchester UK.16 p.

Burford, M.A., Constanzo, S.D., Dennison, W.C., Jackson, C.J., Jones, A.B., McKinnon, A.D., Preston, N.P. and Trott, L.A., 2003. A synthesis of dominant ecological processes in intensive shrimp ponds and adjacent coastal environments in NE Australia. Marine Pollution Bulletin 46, 1456–1469.

Cambray, J.A., 2003. The need for research and monitoring on the impacts of translocated sharptooth catfish, *Clarias gariepinus*, in South Africa. African Journal of Aquatic Science, 28: 2, 191 — 195.

Casé, M., Lec, E.E., Leitão, S.N., Schwamborn, R. and Moraes, A.T., 2008. Plankton community as an indicator of water quality in tropical shrimp culture ponds. Marine Pollution Bulletin 56, 1343–1352.

Catacutan, M.R., 2002. Growth and body composition of juvenile mud crab, *Scylla serrata*, fed different dietary protein and lipid levels and protein to energy ratios. Aquaculture 208, 113-123.

Chellapermal, P., 2008. Mauritius: The introduction of aquaculture. Reproduced from the Sea

Grant Network listserve. WIO Mariculture Forum.

Chen, G., Wang, Z., Wu, Z. and Gu, B., 2009. Effects of Salinity on Growth and Energy Budget of Juvenile Cobia, *Rachycentron canadum* Cobia. Journal of the World Aquaculture Society. 40, (3) 374–382.

Chinabut, S., Somsiri, T., Limsuwan, C. and Lewis, S., 2006. Problems associated with shellfish farming. Review of Science and Technology Off. International Epizootics 25 (2), 627-635.

Coche, A., Moehl, J. and Sagua, O. and V., 1999. Africa Regional Aquaculture Review. FAO Aquaculture Newsletter, No 23.

Colburn, H.R., Walker, A.B. and Berlinsky, D.L., 2008. Factors Affecting Survival of Cobia, *Rachycentron canadum*, during Simulated Transport. Journal of the World Aquaculture Society 39 (5), 678–683.

De Graaf, G.J., 1994. Artificial reproduction and the farming of the African catfish (*clarias gariepinus*) in the lake basin area. Report of a Mission to the Project for the Development of Small Scale Fish Farming in the Lake Basin Area. FAO/UNDP/BSF-KEN/86. 27 p.

De Muylder, E., 2000. Aquaculture on the Seychelles Islands. Oral presentation at World Aquaculture Conference. Nice, France.

De Silva, S.S. and Soto, D., 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation, in: Cochrane, K., De Young, C., Soto D. and Bahri, T. (eds.), Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper, Rome, 530, 151-212.

Department of Environmental Affairs and Tourism (DEAT) (), 2006. Draft marine aquaculture sector Development plan. Vol. 1, South Africa, 24 p.

Department of Health and Families, 2006. Guidelines for Preventing Mosquito Breeding Sites associated with Aquaculture Developments in the NT. Northern Territory Government. Darwin. 14 p.

Dierberg, F. and Kiattisimkul, W., 1996. Issues, impacts, and implications aquaculture in thailand. Environmental Management 20 (5), 649-666.

Dorward, P., Shepherd, D. and Galpin, M., 2007. Participatory farm management methods for analysis, decision making and communication. FAO, Rome, 48 p.

Department of Water Affairs and Forestry (DWAF), 2006. Operational Policy:Use of Water for Aquaculture Purposes. Directorate Water Abstraction and Instream Use, Sub-directorate Environment and Recreation. Pretoria, South Africa. 22 p.

Department of Water Affairs and Forestry (DWAF), 2007. Guideline for Authorising the Use of Water for Aquaculture. Directorate Water Abstraction and Instream Use, Sub-directorate Environment and Recreation. 38 p.

Edwards, P., 1990. Environmental issues in integrated agriculture-aquaculture and waste water-fed fish culture systems. Conference on environment and third world aquaculture development, Rockefeller Foundation, Bellagio, Italy.

Emerson, C., 1999. http://www.csa.com/discoveryguides/aquacult/overview.php (Retrieved 28 November 2009).

Enviro-Fish Africa, 2006. A Review of Aquaculture Policy and Institutional Capacity in the Benguela Large Marine Ecosystem (BCLME) Region with Recommended Regional Policy Options. BCLME Project LMR/MC/03/01. South Africa, 52 p.

Food and Agriiculture Organization (FAO), 2001a. Promotion of sustainable commercial aquaculture in sub-Saharan Africa, FAO, Rome, 1 (408). 16 p.

Food and Agriiculture Organization (FAO), 2001b. The Bangkok declaration and the strategy for aquaculture development beyond 2000: Aquaculture Concepts as Addressed in the Bangkok Declaration.

Food and Agriiculture Organization (FAO), 2002. Policies for the Promotion of Sustainable Commercial Aquaculture in sub-Saharan Africa. FAO Fisheries Report, 671, 46 p.

Food and Agriiculture Organization (FAO), 2004. Aquaculture extension in sub-Saharan Africa. Fisheries Department, Inland Water Resources and Aquaculture Service, Rome.

Aquaculture extension in sub-Saharan Africa, FAO Fisheries Circular, 1002, 64 p.

Food and Agriiculture Organization (FAO), 2006a. State of world aquaculture 2006, Inland Water Resources and Aquaculture Service Fishery Resources Division FAO Fisheries Department, 128 p.

Food and Agriiculture Organization (FAO), 2006b. Regional review on aquaculture development for sub-Saharan Africa – 2005, by T. Hecht, J.F. Moehl, M. Halwart and R. Subasinghe. FAO Fisheries Circular, 1017/4. Rome.

Food and Agriiculture Organization (FAO), 2006c. National Aquaculture Sector Overview. South Africa. National Aquaculture Sector Overview Fact Sheets. in: FAO Fisheries and Aquaculture Department. Rome. http://www.fao.org/fishery/countrysector/naso_southafrica/en (Retrieved 10 May 2010).

Food and Agriiculture Organization (FAO), 2006d. National Aquaculture Sector Overview. Mozambique. National Aquaculture Sector Overview Fact Sheets. In: *FAO Fisheries and Aquaculture Department*. Rome. http://www.fao.org/fishery/countrysector/naso_mozambique/en (Retrieved 10 May 2010).

Food and Agriiculture Organization (FAO), 2006e. National Aquaculture Sector Overview. United Republic of Tanzania. National Aquaculture Sector Overview Fact Sheets. Text by Mushi, V.E. In: FAO Fisheries and Aquaculture Department. Rome. http://www.fao.org/fishery/countrysector/ naso_tanzania/en (Retrieved 29 January 2010).

Food and Agriiculture Organization (FAO), 2006f. National Aquaculture Sector Overview. Kenya. National Aquaculture Sector Overview Fact Sheets. in: FAO Fisheries and Aquaculture Department. Rome. http://www.fao.org/fishery/countrysector/naso_kenya/en. (Retrieved 10 May 2010).

Food and Agriiculture Organization (FAO), 2007. Cultured Aquatic Species Information Programme. Chanos chanos. Cultured Aquatic Species Information Programme. Text by Nelson, A.L.; Marygrace C.Q. In: FAO Fisheries and Aquaculture Department. Rome. http://www.fao.org/fishery/culturedspecies/Chanos_chanos/en (Retrieved 13 July 2010).

Food and Agriiculture Organization (FAO), 2008. Cultured Aquatic Species Information Programme *Rachycentron canadum* (Linnaeus, 1766). Cultured Aquatic Species Fact Sheets. FAO Fisheries and Aquaculture Department. Rome. http://www.fao.org/fishery/culturedspecies / *Rachycentron_ canadum* /en (Retrieved 13 July 2010).

Food and Agriiculture Organization (FAO), 2009a. The world state of fisheries and aquaculture 2008. Fisheries and Aquaculture Department. Rome. 196 p.

Food and Agriiculture Organization (FAO), 2009b. Cultured Aquatic Species Information Programme *Cyprinus carpio*. Cultured Aquatic Species Fact Sheets. Text by Peteri, A. In: *FAO Fisheries and Aquaculture Department*. Rome.

Food and Agriiculture Organization (FAO), 2009c. Cultured Aquatic Species Information Programme *Eucheuma* spp. Cultured Aquatic Species Fact Sheets. Text by Gavino C. Trono Jr. In: *FAO* Fisheries and Aquaculture Department. Rome. http://www.fao.org/fishery/culturedspecies /Cyprinus_carpio/en (Retrieved 13 July 2010).

Food and Agriiculture Organization (FAO), 2009d. PROSPECTUS: FAO Expert Workshop on Indicators for Assessing the Contribution of Small-Scale Aquaculture (SSA) to Sustainable Rural Development. Tagaytay, Philippines).

Food and Agriiculture Organization (FAO), 2010. Cultured Aquatic Species Information Programme. *Clarias gariepinus*. Cultured Aquatic Species Information Programme . Text by Pouomogne, V. In: *FAO* Fisheries and Aquaculture Department. Rome.

Fielder, D.S. and Bardsley, W., 1999. A preliminary study on the effects of salinity on growth and survival of mulloway *Argyrosomus japonicus* larvae and juveniles. Journal of the World Aquaculture Society 30 (3), 380–387.

Foong, L.M., 2007. Understanding of SWOT Analysis. http://www.TQMCaseStudies.com (Retrieved 11 November 2010).

Forbes, A.T. and Demetriades, N.T., 2005. A review of the commercial, shallow water penaeid prawn resource of South Africa: status, fisheries, aquaculture and management. Specialist Report. Ezemvelo KZN Wildlife. 64 p.

Fourie, J.J., 2006. A practical investigation into catfish (*Clarias gariepinus*) farming in the Vaalharts irrigation scheme. Submitted in fulfilment of the requirements for the degree Magister Scientiae. University of the Free State. 112 p.

Francois, N.R., Jobling, M., Carter, C. and Blier, P., 2010. Finfish aquaculture: species selection for diversification. 704 p.

Gerung, G.S. and Ohno, M. 1997. Growth rates of *Eucheuma denticulatum* (Burman) Collins et Harvey and *Kappaphycus striatum* (Schmitz) Doty under diferent conditions in warm waters of Southern Japan Journal of Applied Phycology 9, 413–415.

Gruzen, R., 2005. Shrimp aquaculture and urban growth in Madagascar: sustaining societies and conserving coasts? New Haven: Yale University School of Forestry & Environmental Studies, 23 p.

Gupta, M.V. and Acosta, B.O., 2004. Inland aquaculture : Tilapia farming: A global review of tilapia farming practices. WorldFish Center, Penang, Malaysia.

Gyllenhammar, A. and Håkanson, L., 2005. Environmental consequence analyses of fish farm emissions related to different scales and exemplified by data from the Baltic--a review. Mar Environ Res. 60(2) pp.211-43.

Hanoomanjee, S., Mapfumo, B. and Russell, D., 2009. Small Scale Aquaculture Development Plan for Mozambique. INFOSA. Windhoek, Namibia. 107 p.

Hasan, M.R., Hecht, T., De Silva, S.S. and Tacon, A.G.J., 2007. Study and analysis of feeds and fertilizers for sustainable aquaculture development. FAO Fisheries Technical Paper. 497. Rome, 510 p.

Haupt, T.M.L., Griffiths, C., Robinson, T., Tonin, B., Antonio, F.G., and De Bruyn, P.A., 2010. The history and status of oyster exploitation and culture in South Africa. Journal of Shellfish Research. Report 7084.

Hempel E., 2006 African aquaculture. Article from EUROFISH Magazine, Issue 6. www.globefish.org/?id=3497 - 24k (Retrieved 18 February 2010).

Hinrichsen, E., 2007. Introduction to Aquaculture in the Western Cape: Edition. Division of

Aquaculture, Stellenbosch University Report. Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town, 9 p.

Hopkins, J.S., Sandifer, P.A., De Voe, M.R., Holland, A.F., Browdy, C.L. and Stokes, A.D., 1999. Environmental impacts of shrimp farming, special reference to the situation in the Continental United States. Estuaries, 18 (1A), 25-42.

Ifejika, P.I., Ayanda, J.O., Nwbeze, G.O and Obetta, N.C., 2008. Contribution of information channels to adoption of aquaculture technologies among fish farmers in anambra state and implication for training. Journal of Agriculture and Social Research, 8, (2). 6 p.

Iltis, J. 2009. Mariculture activities in Madagascar. Mariculture in the WIO region challenges and prospects Workshop. WIOMSA. Zanzibar, Tanzania.

Institute for Animal Production, 2010. Potential of Aquaculture: Aquaculture in Western Cape. South Africa. http://www.ai-sa.org.za/news-events/index.asp (Retrieved 29 October 2010).

International Union for Conservation of Nature (IUCN), 2007. The advantages and isadvantages of culturing Fish. In "Guidelines for the Sustainable Development of Mediterranean Aquaculture". Málaga, Spain.

Jackson, C., Preston, N., Thompson, O.J. and Burford, M.A., 2003. Nitrogen budget and effluent nitrogen components at an intensive shrimp farm. Aquaculture, 218, 387-411.

Jonsson, B., 2006. Invasive alien species fact sheet – *Oncorhynchus mykiss*. From: Online Database of the North European and Baltic Network on Invasive Alien Species – NOBANIS www.nobanis.org, (Retrieved 15 May 2010).

Kaiser, J.B. and Holt, G.J., 2005. Species profile: Cobia. Southern Regional Aquaculture Center. Publication 7202, 6 p.

Kaliba, A.R., Osewe, K.O., Senkondo, E.P., Mnembuka, B.V. and Quagrainie, K.K., 2006. Economic Analysis of Nile Tilapia (*Oreochromis niloticus*) Production in Tanzania. . Journal of the World Aquaculture Society. 37 (4). 64-73.

Keenan, C.P. and Blackshaw, A., 1999. Mud crab aquaculture and biology. Proceedings of an international scientific forum held in Darwin, Australia, ACIAR Proceedings 78, 216 p.

Landesman L., 1994. Negative Impacts of Coastal Tropical Aquaculture Developments. World Aquaculture 25(2), 12-17.

Larsson, B., 1994. Three overviews on environment and aquaculture in the tropics and sub-tropics. ALCOM Field Document, 27. FAO, Rome. 46 p.

Lesperance, A., 2009. Mariculture in the Seychelles and WIO countries – An Overview. Mariculture in the WIO region challenges and prospects Workshop. WIOMSA. Zanzibar, Tanzania.

Liao, I.C., Huang, T-S., Tsai, W-S., Hsueh, C-M., Chang, S-L. and Leaño, E.M., 2004. Cobia culture in Taiwan: current status and problems. Aquaculture 237, 155-165.

Lin, D.T. and Fong, P., 2008. Macroalgal bioindicators (growth, tissue N, d15N) detect nutrient enrichment from shrimp farm effluent entering Opunohu Bay, Moorea, French Polynesia. Marine Pollution Bulletin 56, 245–249.

Machena, C. and Moehl, J., 2001. Sub-Saharan African aquaculture: regional summary, in: R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur (eds.) Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, pp. 341- 355.

Magrin, G., García, C.G., Choque, D.C, Giménez, J.C., Moreno, A.R., Nagy, G.J., Nobre, C. and Villamizar, A., 2007. Latin America Climate Change: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds.), Cambridge University Press, Cambridge, pp. 581-615.

Masterson, J., 2007. *Scylla serrata*. Smithsonian Marine Station at Fort Pierce.

Mazzola, A., Mirto, S., La Rosa, T., Fabiano, M. and Danovaro, R., 2000. Fish-farming effects on benthic community structure in coastal sediments: analysis of meiofaunal recovery. ICES Journal of Marine Science 57, 1454–1461.

Mbugua, M., 2008. Opportunities in fish farming for employment and sustainable livelihood in Kenya. Ministry of Fisheries Development. Kenya, 10 p.

Meserve, N. 2005. Aquaculture in America Is it worth it? Benefits, Costs and the Future. Duke University, Biology, Spring, 217 p.

Ministry of Agriculture Livestock and Fisheries, 2005. Fisheries and Aquaculture in Madagascar.

Ministry of Agro-Industry and Fisheries, 2007. Potential for Sustainable Aquaculture Development in Mauritius. Board of Investments, 12 p.

Ministry of Fisheries, 2007. Estratégia para o Desenvolvimento da Aquacultura em Moçambique (2008 – 2017). Government of Mozambique.

Ministry of Fisheries. 2009. Conselho Coordenador, Manica. Government of Mozambique.

Mirera, D.O. and Mtile, A., 2009. A preliminary study on the response of mangrove mud crab (*Scylla serrata*) to different feed types under drive-in cage culture system. Journal of Ecology and Natural Environment 1(1), 007-014.

Mirera, D.O. and Ngugi, C.C., 2009. Sustainability and income opportunities of farming milkfish (*Chanos chanos*) to local communities in Kenya: assessment of initial trials of earthen ponds. EC FP7 Project, SARNISSA. 21 p.

Mirera, D.O., 2007. An inventory of small-scale mariculture activities in kenya. The Sustainable Coastal Communities and Ecosystems (SUCCESS) Program. WIOMSA. Zanzibar, Tanzania. 27 p.

Mirera, D.O., 2009. Mud crab (*Scylla serrata*) culture: understanding the technology in a silvofisheries perspective. Western Indian Ocean Journal of Marine Science. 8 (1), 127-137.

Moehl, J., 1999. Developments in Africa, FAO Aquaculture Newsletter 21, 34 p.

Moffitt, C.M., 2006. Environmental, economic and social aspects of animal protein production and the opportunities for aquaculture. economic growth forum. Fisheries 30 (9) 29-38.

Moodley, G.K., 2009. Applied Marine Biology (Aquaculture, Marine Pollution and Marine Biotechnology) Biol 343. Universtiy of KwaZulu-Natal, Durban.

Moyo, N.A.G. and Sara, J.R., 2010, pers. comn. November 2010. Aquaculture Research Unit.University of Limpopo. Turfloop Campus.

Msuya, F.E. and Mmochi, A.J., 2007. Inventory of small-scale Mariculture in Tanzania. The Sustainable Coastal Communities and Ecosystems (SUCCESS) Program. WIOMSA. Zanzibar, Tanzania, 33p.

Mukherejee, K. and Mandal, N., 2009. A microsatellite DNA marker developed for identifying disease-resistant population of giant black tiger shrimp, *Penaeus monodon*. Journal of the World Aquaculture Society 40 (2), 274–280.

Muñoz, J., Freile-Pelegrín, Y. and Robledo, D., 2004. Mariculture of *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae) color strains in tropical waters of Yucatán, México. Aquaculture 239 pp. 161–177.

Nabutola, W., 2009. Compulsory purchase and land acquisition in Kenya. 7th FIG Regional Conference. Hanoi, Vietnam 22 p.

New Partnership for Africa's Development (NEPAD), 2005. The NEPAD Action Plan for the Development of African Fisheries and Aquaculture. NEPAD-Fish for All Summit Abuja, Nigeria.

Nguyeni, T.N. and Davis, D.A., 2009. Evaluation of alternative protein sources to replace fish meal in practical diets for juvenile tilapia, *Oreochromis* spp. Journal of the World Aquaculture Society 40 (1), 113–121.

Okorie, O.O., 1975. Environmental constraints to aquaculture development in Africa. FAO, Rome (Italy). Fisheries Dept, FAO/CIFA Symposium on Aquaculture in Africa, Accra, 7 p.

Omar, I., 2009. Overview of mariculture in Mozambique. Mariculture in the WIO region challenges and prospects Workshop. WIOMSA. Zanzibar, Tanzania.

Palmer, RM., 2008. The feasibility of stock enhancement as a management tool for dusky kob

(*Argyrosomus japonicus*) in South Africa. Submitted in Fulfilment of the Requirements of the Degree of Master of Science. Rhodes University. 165 p

Partridge, G.J., Lymbery, A.J. and George, R.J., 2008. Finfish Mariculture in Inland Australia: A Review of Potential Water Sources, Species, and Production Systems. Journal of the World Aquaculture Society. 39 (3), 291-310.

Perelberg, A., Ronen, A., Hutoran, D., Smith, Y. and Kotler, M. 2005. Protection of cultured *Cyprinus carpio* against a lethal viral disease by an attenuated virus vaccine. Vaccine 23, 3396–3403.

Primavera, J.H., 2006. Overcoming the impacts of aquaculture on the coastal zone. Ocean & Coastal Management 49, 531–545.

Pullin, R.S.V., 1993. An overview of Environmental Issues in Developing Country Aquaculture, in: Pullin, R. S. V., Rosenthal, H. and Maclean, J.L. (eds.). Environment and Aquaculture in Developing Countries. ICLARM Conference Proceedings. 31, 359 p.

Radheyshyam, R., 2001. Community-based aquaculture in India - strengths, weaknesses, opportunities and threats, in: Gupta, M. V. (ed.), aquaculture section of the network of tropical aquaculture. Naga, The ICLARM Quarterly 24 (1-2), 9-12.

Ravisankar, V.D.D., Mahalakshmi, P.T., and Kumaran, M., 2009. e-Sagu Aqua: An innovative information and communication technology model for transfer of technology for aquaculture. Research & farming techniques 14 (4), 23-25.

Regional Programme for the Sustainable Management of the Coastal Zones of the Countries of the Indian Ocean (ReCoMap), 2009. Opportunities for cage farming of Ombrine/Red Drum (*Sciaenops ocellatus*) in south-east Mauritius. Board of Investment & Fisheries Division/FMM. Mauritius.

Ribeiro, F., 2007. Inventory of Small-Scale Mariculture in Mozambique. The Sustainable Coastal Communities and Ecosystems (SUCCESS) Program. WIOMSA. Zanzibar, Tanzania. 12 p.

Ribeiro, F., 1983. Guia prático de piscicultura. Boletim de Divulgação 4. Instituto de

Investigação Pesqueira. Maputo, 15 p.

Rice, M.A., Mmochi, A.J., Zuberi, L. and Savoie, R.M., 2006. Aquaculture in Tanzania. World Aquaculture 50-57.

Ridler, N. and Hishamunda, N., 2001. Promotion of sustainable commercial aquaculture in sub-saharan africa. Policy Framework. FAO Fisheries Technical Paper 408 (1). 67 p.

Rothlisberg, P.C., 1998. Aspects of penaeid biology and ecology of relevance to aquaculture: a review. Aquaculture 164, 49–65.

Rouhani, Q.A., and Britz, P.J., 2004. Contribution of Aquaculture to Rural Livelihood in South Africa: A baseline study. Water Research Commission Project No. 1466. Report No: TT 235/04. South Africa, 95 p.

Rutaisire, J., Kabonesa, C., Okechi, J.K. and Boera, P.N. 2009. Lake Victoria Basin: Gender Issues in Fish Farming. IDRC Bulletin. Document(s) 8 of 11.

Safriel, O and Bruton, M.N., 1984. Aquaculture in South Africa: A cooperative research programme. South African National Scientific Programmes. Report No. 89. Foundation for Research Development Council for Scientific and Industrial Research. Pretoria, South Africa. 75 p.

Sahoo, D., 2005. Integrating seaweed cultivation into brackish water aquaculture - Chilika Model. PICES 14th Annual Meeting Book of Abstracts. 70 p.

Sales, J., 2004. Abalone. Species. Aqua Feeds: Formulation & Beyond 1 (3), 23-26.

Sara, J.R., 2010. Pers. comm., November 2010. Aquaculture Research Unit.University of Limpopo. Turfloop Campus.

Semesi, S., 2009. Seaweed Farming in WIO. Mariculture in the WIO region challenges and prospects Workshop. WIOMSA. Zanzibar, Tanzania.

Shipton, T. and Hecht, T., 2007. Coastal mariculture assessment - final report. Regional Programme for the Sustainable Management of the Coastal Zones of the Indian Ocean Countries (ReCoMaP). 9. ACP.RSA.020. 61 p.

Silberschneider, V. and Gray C.A., 2008. Synopsis of biological, fisheries and aquaculture-related information on mulloway *Argyrosomus japonicus* (Pisces: Sciaenidae), with particular reference to Australia. Journal of Applied Ichthyology 24, 7–17.

Simon, C.A., Kaiser, H. and Britz, P.J., 2004. Infestation of the abalone, *Haliotis midae*, by the sabellid, *Terebrasabella heterouncinata*, under intensive culture conditions, and the influence of infestation on abalone growth. Aquaculture 232, 29-40.

Smith, S.J.F. and Briggs, M.R.P., 1998. Nutrient budgets in intensive shrimp ponds: implications for sustainability. Aquaculture 164, 117-133.

Sousa, O.V., Macrae, A., Menezes, F.G.R., Gomes, N.C.M., Vieira, R.H.S.F. and Mendonça-Hagler, L.C.S., 2006. The impact of shrimp farming effluent on bacterial communities in mangrove waters, Ceará, Brazil. Marine Pollution Bulletin 52, 1725–1734.

Sung, H.H., Li, H.C., Tsai, F.M., Ting, Y.Y. and Chao, W.L., 1999. Changes in the composition of *Vibrio* communities in pond water during tiger shrimp (*Penaeus monodon*) cultivation and in the hepatopancreas of healthy and diseased shrimp. Journal of Experimental Marine Biology and Ecology 236, 261-271.

Taylor, M.D., 2006. Environmental Impact of Stocked Mulloway (*Argyrosomus japonicus*) in New South Wales Estuaries. University of New South Wales. PhD Thesis. 177 p.

Thirumaran, G. and Anantharaman, P., 2009. Daily Growth Rate of Field Farming Seaweed *Kappaphycus alvarezii* (Doty) Doty ex P. Silva in Vellar Estuary. World Journal of Fish and Marine Sciences 1 (3), 144-153.

United Nations Environment Programme (UNEP), 2010. Southern Africa and coastal and marine environments, in: Cleveland C. J. (ed.) Encyclopedia of Earth http://www.eoearth.org/article/Southern_Africa_and_coastal_and_marine_environments (Retrieved 24 October 2010).

UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009. Regional synthesis report on the status of pollution in the Western Indian Ocean region. UNEP, Nairobi, Kenya, 116p.

van Ballegooyen, R., Carter, R. and Monteiro, P., 2008. Port of Saldanha expansion of iron-ore handling facilities: Phase 2 Environmental Screening Study - Marine Risks, CSIR Report No CSIR/NRE/ECO/ER/2008/0119/C, 29 p.

van Halsema, G.E., Wood, A., Kumar, R. and Nguyen-Khoa, S., 2008. Agriculture in tropical river basins – impacts on aquatic lagoon and estuary ecosystems, in: Wood, A.; van Halsema, G. E. (Eds.). Scoping agriculture-wetland interactions: towards a sustainable multiple-response strategy. FAO Water Reports 33, Rome, pp. 87-95.).

Volz, S.J., 2010. How to Eliminate Mosquitoes in Backyard Ponds. at http://www.ehow.com/how_6188986_eliminate-mosquitoes-backyard-ponds.html#ixzz15GfUcoQ7 (Retrieved 14 November 2010).

Welcomme, R.L. and Barg, U., 1997. Aquaculture development. Series title: FAO Technical Guidelines for Responsible Fisheries 5, 40 p.

Western Indian Ocean Regional Assessment & Institutional Analysis, 2009. Ecosystem Services for Poverty Alleviation: Marine & Coastal Situational Analysis Appendix 2.

Woynarovich, E., 1980. Technical assistance for inland fish culture (carp) and fishery improvement, (Madagascar). Inland fisheries and aquaculture development project. FAO, Rome , 114 p.

World Rainforest Movement (WRM) (), 2010. Africa: The huge value of mangroves for communities, Bulletin 151, http://www.wrm.org.uy/bulletin/151/Africa.html (Retrieved 26 October 2010).

APPENDICES

APPENDIX A: Summary of cultured species and candidate species suitable for aquaculture in the Western Indian Ocean Region (Fw= freshwater species, M= marine species and Sw= seaweed).

	Countries													
Species	South Africa		Mozambique		Tanzania		Kenya		Madagascar		Mauritius		Seychelles	
	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate
Alaria sp. (M)								X						
Anadara spp. (M)						X								
Anguilla marmorata (M)										X				
Anguilla mossambica (M)										X				
Aponogeton distachyos (M)	X													
Argyrosomus inodorus (M)	X													
Argyrosomus japonicus (M)	X		X											
Aristichthys nobilis									X					
Artemia spp. (M)	X		X		X				X					
Arthrospira platensis (M)									X					
Arthrospira paracas (M)									X					
Atractoscion aequidensI (M)	X													
Chanos chanos (M)			X		X		X			X				
Choromytilus meridionalis (M)	X													
Chrysoblephus laticeps (M)	X													
Clarias gariepinus (Fw)	X		X		X		X							

Species	Countries													
	South Africa		Mozambique		Tanzania		Kenya		Madagascar		Mauritius		Seychelles	
	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate
Crassostrea cucullata (M)									X		X			
Crassostrea gigas (M)	X							X			X			
Crassostrea margaritacea (M)	X							X						
Crassostrea virginica(M)											X			
Crayfish (maron) (M)	X													
Cyprinus carpio (Fw)			X					X						
Epinephelus sp. (M)				X										
Eucheuma denticulatum (Sw)			X		X		X		X					
Eucheuma spinosum (Sw)					X									
Eucheuma Striatum (Sw)					X									
Eumarcia paupercula (M)				X										
Fenneropenaeus indicus (M)	X		X				X							
Gracillaria (Sw)	X								X					
Haliotis midae (M)	X													
Holothuria scabra (M)									X			X		
Hypophtalmichthys molitrix (Fw)									X					
Isognomon sp (Sw)					X									
Kappaphycus alvarezii (Sw)			X		X		X		X					
Laminaria sp. (M)								X						
Lates Calcarifer (M)												X		
Lutjanus spp. (M)				X										X

Species	Countries													
	South Africa		Mozambique		Tanzania		Kenya		Madagascar		Mauritius		Seychelles	
	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate
Meretrix meretrix (M)				X										
Metapenaeus monoceros (M)				X								X		
Micropterus salmoides														
Modiolus auriculatus (M)									X					
Modiolus philippinarum (M)				X										
Mugil cephalus (M)				X	X									
Mytilus edulis (M)								X	X					
Mytilus galloprovinciali (M)	X													
Oncorhynchus mykiss (Fw)					X		X							
Oreochromis mossambicus (Fw)	X		X		X					X				
Oreochromis niloticus (Fw)			X		X		X		X			X	X	
Penaeus monodon (M)	X		X		X		X		X		X		X	
P. latisulcatus (M)												X		
P. canaliculatus (M)												X		
Perna perna(M)	X			X										
Pinctada Margaritefera (M)					X								X	
Pinctada penguin (M)					X									
Pinctada spp. (M)													X	
Porhphyra sp. (Sw)								X						
Rachycentron canadum (M)			X							X		X		X

	Countries													
Species	South Africa		Mozambique		Tanzania		Kenya		Madagascar		Mauritius		Seychelles	
	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate	Cultured	Candidate
Rhabdosargus globiceps (M)	X			X										
Rhabdosargus sarba (M)											X			
Salmo solar (M)	X													
Scophthalmus maximus (M)	X													
Sciaenops Ocellata (M)												X		
Scylla serrata (M)				X	X		X			X				
Seriola lalandi (M)												X		
Seriola rivoliana (M)												X		X
Seriola seriola (M)	X									X				
Siganus Sutor (M)												X		
Synaptura marginata (M)	X													
Tilapia rendalii (Fw)			X											
Tilapia hornorum (Fw)					X									
Tridacna maxima (M)													X	
Ulva (Sw)	X													

APPENDIX B: Assessment of the main freshwater species with potential for aquaculture in Western Indian Ocean region

Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
Sharptooth catfish *Clarias gariepinus*	The species *Clarias gariepinus* is distributed throughout Africa and parts of Middle East. It has a capacity to use atmospheric oxygen through their branchial organs (De Graaf, 1994). The species is strongly recommended for aquaculture due to its high growth rate, omnivorous habits. They shows a high resistance to adverse water quality and poor environmental conditions and also tolerate high densities, being relatively easy to rear in captivity (De Graaf, 1994). The use of dry feed is recommended to reduce the production cost. Dry feed can be supplemented by live zooplankton for optimal performance of the juveniles. A good feed conversion is reached when the use of dry and live feed is optimal. A feed ratio conversion (FRC) of 1.05 has been reported in *C. gariepinus*; however, this is dependent on the nutritional value of specific dry feed consumed (Fourie, 2006). This species is generally a bottom feeder eating a large variety of organisms such as crabs, plankton, insects, fish, amphibians and fruits (Cambray, 2003). The species is a voracious predator and can survive in extremely adverse conditions (Cambray, 2003).	Escapees of this species from aquaculture to natural water bodies where the species is alien are responsible for loss of native biodiversity. The species may cause negative ecological effects by alterations of ecological communities in terms of ecological functions and ecosystem health (Cambray, 2003). The translocation of *C. gariepinus* may also facilitate the spread of parasites, and in severe cases cause extinction of indigenous species due to their low resistance to these new parasites (Cambray, 2003).	Although *C. gariepinus* is disease resistant, white spot disease caused by the myxobacteria which is characterised by white spots on skin and around the mouth and gills is common in catfish (Fourie, 2006; FAO, 2010). Other diseases such as Motile Aeromonas Septicaemia caused by the bacteria *Aeromonas* spp. and Water Mould caused by the fungi *Saprolegnia* spp. which also affects eggs may influence the health and growth of *C. gariepinus*. Infections from gill parasites such as *Trichodina maritinkae* are also common and may cause lethargy, weaknesses and loss of appetite.

Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
Common carp *Cyprinus carpio*	The species is generally a bottom dweller, but it can be found in the middle and upper layers of water bodies. The common carp inhabit in a broad ecological spectrum, tolerating cold temperatures, low oxygen concentration and high salinity up to 55‰. Optimal growth is obtained between 23^{o}C and 30^{o}C (FAO, 2009b). *C. carpio* is omnivorous and can feed on insects, zooplankton, worms, molluscs, and leaves and seeds of aquatic and terrestrial plants. The species is used in aquacultures because this feed and utilise a large variety of food provided by farmers. In polyculture this species may reach 0.6 to 1.0kg body weight in one season. Males mature	This species may impact negatively the water quality and may also destroy aquatic vegetation by uprooting (Cambray, 2003). *Cyprinus carpio* is considered a strong competitor for food compared to other benthos-feeding fish.	Lethal diseases have been reported regarding this species. Diseases such as Carp Nephritis Gill Necrosis Virus (CNGV) or koi herpes virus (KHV), caused by an unclassified large DNA virus have caused large economic losses (Perelberg *et al.,* 2005). Infestations caused by the nematode *Contracaecum* spp., have been reported as causing roundworms in heart and body cavity an internal blood loss (FAO, 2009b). Gill hyperplasia and secondary infections may be caused by the species *Ergasilus* spp. The parasite *Argulus* spp. causes lethargy, small haemorrhages and fin erosion. White spot disease caused by *Ichthyophthirius multifiliis* is also common and the principal symptom of this infection is gill damage and increase gill beat rate as well as white spots on fins, eyes, gill and skin. Other diseases that may affect *C.*

Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
			carpio are bacterial diseases caused by *Flavobacterium branciophyla,* Columnaris disease cause by *Flexibacter columnaris* as well as ulcer disease Branchyomycosis. Variations in factors such as temperature, oxygen and genetic modifications may interfere in the growth of the common carp.
Rainbow trout *Oncorhynchus mykiss*	It is a cold-temperate species and presents an optimal growth between 15^o to 18^{o}C. Critical temperatures vary from 24^o to 26^{o}C. This species require less potassium inputs compared to other species, which is an advantage to aquaculture (Partridge et al., 2008). Furthermore, the rainbow trout is easy to spawn, fast growing (can achieve 7-10 kg within 3 years) and tolerate handling and adverse environmental conditions. However, they cannot spawn naturally in culture systems, making it necessary to obtain the juveniles by artificial spawning or by collecting eggs in the wild (FAO, 2007). This is primarily a freshwater species, although some populations have been recorded in some sea waters. The species shows preference to clean and well oxygenated environment. Their reproduce sexually	It is suspected that this species establishes negative effects on native fish populations, invertebrates and amphibians as it is a good predator and feed competitor. They also destroy eggs of native trout and salmon when they spawn in the same areas. Other impacts include hybridisation and disease transmission. Massive production leads to environmental pollution such as eutrophication (FAO, 2007). According to Cambray (2003) this species may impact aquatic communities by displacing indigenous species through competition and predation (Cambray, 2003).	Diseases and parasites may affect the health of rainbow trout in aquaculture. Good hatchery sanitation is important to prevent the outbreak of diseases. The most common whirling disease is caused by protozoan *Myxobolus cerebralis* that can result in fish losing the orientation ability. Other pathogens that threat rainbow trout are Furunculosis, Vibriosis, Bacterial kidney disease (BKD) Infective Pancreatic Necrosis, Infective Haematopoietic Necrosis, Viral Haemorrhagic Septicaemia

Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
	and the eggs are fertilised externally. The females excavate a hollow to release and hold between 700 to 4000 eggs and the male fertilise the eggs and cover with a layer of gravel. The maturity is reached around 2 to 4 years and at this stage the fish migrate to spawn in tributaries. *O. mykiss* feed on zooplankton, zoobenthos and fish (Jonsson, 2006, FAO, 2007).		White spot, Hexamitaisis Octomitis Costiasis, Fluke and Trematodal parasite (FAO, 2007).
Mozambique tilapia *Oreochromis mossambicus*	Mozambique tilapia may be found in a widely dispersed environment. The species has been introduced in many tropical and subtropical waters in many parts of the world as well as in some warm temperate regions (Cambray, 2003). This is a freshwater species and lives in warm environment, but can be found in both estuarine and coastal lakes. The species presents mainly diurnal habits and can survive in a temperature range from 8° to 42°C. This species was introduced to many tropical and subtropical to temperate regions of the world (Gupta and Acosta, 2004). The species is listed in the IUCN Red List as Near Threatened due to high level of hybridisation with the species *Oreochromis niloticus*. The females are usually mouth breeders and wait until the eggs are fertilised in the nest. They keep the larvae and small fry protected inside of her mouth	This is a omnivorous species and eats a large variety of organisms, from algae to insects (Cambray, 2003). The species *O. mossambicus* is classified as an invasive species and may cause a decline of indigenous species. This species can survive in very adverse environmental conditions such as low temperatures, high salinity and poor water quality (Gupta and Acosta, 2004) Generally, tilapia species cause negative impacts on flora and fauna as they compete for food, causing disruptions in the ecological balances. The species may also increase water turbidity as they fond of digging. Increased turbidity will consequently reduce the light penetration, affecting the photosynthetic organisms	This species is known as being attacked by many parasites in aquaculture and aquariums. Streptoccoccosis has been reported as causing health problems to tilapia species and death in severe cases (Cambray, 2003). Columnaris disease caused by the bacteria *Flavobacterium columnaris* is another concern for farmed tilapia and aquarium tilapia as this disease is contagious and can cause death of the species in 48-72 hours after infection cases (Cambray, 2003).

Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
	after hatch and release only after 10-14 days. The species is omnivorous and feeds on anything from algae to insects, small crustaceans and fishes. *O. mossambicus* tolerate a large range of salinity, being found in estuaries and coastal lakes Gupta and Acosta, 2004). The species is a filter feeder and can filter plankton out of the water and can adapt its diet according to environmental conditions and feed availability The *species O. mossambicus* is classified as an invasive species and may cause a decline of indigenous species This species is common in aquacultures due to its easy growth and attractive white and mild flesh. The species has been used by the fish farming industry for hybridisation, however concerns on deterioration of genetic qualities are increasing among small-scale producers (Gupta and Acosta, 2004).	(Gupta and Acosta, 2004)	.
Nile tilapia *Oreochromis niloticus*	Nile tilapia is the most preferred freshwater species for aquaculture due to its fastest growth rate, short food chain, efficient food conversion, high fecundity, high tolerance to adverse environmental conditions and the good quality flesh (Kaliba *et al*., 2006; Nguyeni and Davis, 2009). The species is a mouthbreeder and the female keeps	See *Oreochromis mossambicus*	See *Oreochromis mossambicus*

Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
	the eggs and inhabits various different freshwater environments as well as brackish conditions. It feeds on phytoplankton and benthic algae and there are records of this species be used to reduce the amount of aquatic weeds.		

APPENDIX C: Assessment of the main marine species with potential for aquaculture in the Western Indian Ocean region

Group	Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
Crustaceans	Black tiger shrimp *Penaeus monodon*	*P. monodon* is one of the most economically important species of shrimps used in aquaculture (Mukherejee and Mandal, 2009). In the Indo-Pacific tropical environment they spawn twice a year. The larvae present three stages (nauplius, zoea and mysis) and each stage has 6 sub-stages with different morphologies, swimming and feed behaviour. Nauplius feeds on yolk reserves, zoea are herbivorous and mysis carnivorous; however they are all opportunistic feeders. The post larvae move into estuaries and coastal grounds in cohorts. High densities of prawns affect negatively the growth. Temperature and lunar cycles also have influence on growth and reproduction. Usually the prawns peak few days after the new and full moons. Juveniles and adults feed on plant material and microinvertebrates such as gastropods, bivalves, crustaceans and	Shrimp farming impacts negatively the coastal environment due to nutrient enrichment. Eutrophication of estuaries by shrimp effluents, when shrimp discharges exceed the natural carrying capacity of the receiving environments. Salination and land use transformation are also pointed as environmental constraints caused by shrimp farming (Hopkins et al., 1999; Smith and Briggs, 1998). Wetland areas are often devastated for shrimp ponds construction, leaving many organisms without a spawning ground, including the shrimp, and the land degradation is usually irreversible. Environmental friendly culture systems are needed to minimise the negative effects of shrimp farming. Soil and water are the most affected elements and also affect the farm performance through self pollution (Hopkins et al., 1999; Smith and Briggs, 1998). The shrimp farming is responsible for ecological	High economic losses have been registered in *P. monodon* because of the white spot syndrome virus (WSSV). The WSSV affects the post larval and adult shrimps, reducing in this way the production (Mukherejee and Mandal, 2009). The major shrimp disease is caused by secondary opportunistic pathogens where the environment is poorly managed. Shrimp do not grow in unhealthy environments. Poor quality environments increase the susceptibility to the viral disease yellowhead (YBV) (Smith and Briggs, 1998). Bacteria septicemia and *Vibrio* spp. are also recognised as the major agents causing diseases on shrimp (shell disease and localised infections) (Sung *et al.*, 1999).

Group	Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
		polychaetes, in most cases depending on the availability in the wild (Rothlisberg, 1998).	disturbance of native species through shrimp diseases and chemical that are spread on adjacent estuarine ecosystems (Hopkins *et al*., 1999. The mangrove forests are important to protect the land against waves and storms and other environmental catastrophic events such as tsunamis (Chinabut *et al*., 2006)	
	Mud crab *Scylla serrata*	The mud crab, *Scylla serrata* is widely distributed in the Pacific and Indian oceans. It is available in brackish coastal waters and estuaries, has less aggressive behaviour, high value and has a great potential for aquaculture due to its high meat yield and delicate flavour, although crab "seed" for stocking continue to be the main constraint (Begum *et al.,* 2009). This species is associated with mangrove swamps and nearby intertidal and subtidal habitat (Keenan and Blackshaw, 1999). The carapace length is used as reference for reproductive maturity. Within the first year of life the carapace can reach 90 mm. The females hold the eggs and migrate offshore where the eggs hatch.	It has been reported that the growth of mud crab industry is contributing to mangrove forest degradation and overexploitation due to wild stock caught for stocking (Keenan and Blackshaw, 1999)	Diseases and pathogens can cause mass larvae mortality. They are usually infested by ectoparasites such as *Zoothamnium* sp., *Epistylis* sp., *Lagenidium* sp., *Lagennorphris* sp. and *Vorticella* sp. Three species of vibrio were identified to be pathogenic to larvae, namely namely *V. carcharie*, *V. alginolyticus* and *V. parahaemolyticus*. Mud crab are also very sensitive to luminous bacteria such as *V. harveyii* (Keenan and Blackshaw, 1999) The molting death syndrome (MDS) is associated to high larval mortality where the larvae

Group	Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
		The larval development period to megalopa stage is between 20 to 26 days at 25°C and can be reduced on higher temperatures. Salinity is an important factor on larval survival; lower salinities (15ppt) can cause 100% of mortality. The adults are eurythermal and eurohaline while larvae show a narrower tolerance. *S. Serrata* is mainly carnivorous and preys on small invertebrates and on small quantities of detritus and plant material and fish (Masterson, 2007). They present nocturnal habits, remaining buried at day and emerging at night to feed (Catacutan, 2002, FAO, 2010).		are unable to do metamorphosis to megalopa and to juvenile crab (Catacutan, 2002).
Fishes	Kob, mulloway *Argyrosomus japonicus*	*Argyrosomus japonicus*, also known as mulloway (Australia) and kob (South Africa) is a large estuarine fish, member of the Sciaenidae family. This species is also found in fresh and coastal marine waters and is highly desired for commercial and recreational purposes as well as for aquaculture due to its high fecundity, fast growing and a good food conversion ratio (Silberschneider and Gray, 2008). The species is distributed on Pacific and	If reared for stock enhancement they can increase competition and competition in the surrounding ecosystem causing adverse interaction with the wild species (Taylor, 2006). In captivity the most used system is cage culture and this can bring some environmental concerns such as eutrophication due to faecal and uneaten feed wastes. Sediment pollution is also common and this	Infections by *Amyloodinium ocellutum* are common. Salinity manipulations (lowering) seem to be effective on treatment of variety infectious diseases (Fielder & Bardsley, 1999). Protozoans and trematodes also cause epidemic diseases and have killed juveniles and adults species of *A. japonicus*.

Group	Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
		Indian Ocean waters along the southeast African coast from the Cape of Good Hope to Southern Mozambique and in the northern part of Indian Ocean on Pakistan and northwest coast of India (Fielder & Bardsley, 1999). In the field of aquaculture, a significant advance has been achieved on the development of techniques to induce fish reproduction (Mittelmark and Kapuscinski, 2008). Fishes can be spawned spontaneously using hormones and pellets implants or subjected to specific temperature and light conditions (Palmer, 2008). Another alternative could be a strip spawn method, where the eggs are collected and mixed with sperm in a bowl (Palmer, 2008). The size at maturity can reach 920 mm for males and 1070 mm for females. The species presents delayed maturity and prolonged longevity.	affects benthic communities. The cages are more susceptible to escapes and in this case escapes may cause genetic alterations on wild populations or losses on the biodiversity due to competition.	
Fishes	Cobia, black kingfish, black salmon, ling,	It is a carnivorous species widely distributed along tropical and subtropical environments and warm temperate waters. It is a migratory pelagic fish. Although this species is commonly used	Outbreaks of diseases are common in fish culture and most of them are due to lack of good management of the culture sites (Liao et al., 2004). There is little information available	Studies have shown that salinity can affect significantly food conversion (Chen et al., 2009). Cobia is susceptible to parasites, bacteria and virus infections. The

Group	Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
	lemonfish *Rachycentron canadum*	worldwide for recreational fish, *R. canadum* show a high potential to aquaculture due to its rapid growth, high fecundity, good food ratio conversion and high selling price. Furthermore the species shows success in artificial propagation and larval production and can reach 4 to 6 kg within 1 year (Colburn et al., 2008; Chen et al., 2009). The range of temperature that this species can tolerate varies from 16.8^o to 32.2^{o}C and salinity between 22.5 and 44.5 ppt. They release the buoyant eggs that float freely until hatching. The larvae are planktonic. The reproductive maturity is reached at 2 years for males and females at 3. They can do up to 20 individual spawns in one season with intervals of one to two weeks. The eggs can reach 80 g in two months and 8 kg in one year. More than 60% of total body weight can be used for fillets (Benetti and Orhun, 2002). The species presents active behaviour and requires high levels of dissolved oxygen to respond to their high metabolic rates. On other hand, cobia is less resistant to stressors.	regarding the types and quantities of waste produced in cobia culture.	bacterial diseases are pasteurellosis, vibriosis and streptococcosis. The viral include lymphosystis and the parasites (*Myxosporidea*, *Trichodina* and *Neobedenia*). *Amyloodinium* is the parasite that causes more problems to this species as it is capable of cause death within few days is left untreated (Kaiser and Holt, 2005). Other parasites that need to be considered are variety of trematodes, cestode an nematodes as most of them are host-specific (FAO, 2008).

Group	Species	Biology ecology and nutrition	Environmental constraints	Diseases and Factors inhibiting growth
	Milkfish *Chanos chanos*	The species belongs to the Family Chanidae and its natural distribution is restricted to low latitude tropics or the subtropical northern hemisphere. The adults are found near the coast or around islands. They have a seasonal pattern of migration and can grow up to 1.5 m and 20 kg. The species rich a sexual maturity in 5 years, having a good advantage for aquaculture as they do not spend energy for reproduction before this age. Usually milkfish spawn near coral reefs and feed from small food items such as microbial mats to detritus, epiphytes and zooplankton. Sex determination is difficult as there are no morphological differences between males and females. The eggs and larvae are pelagic and stay in the plankton for up to 2-3 weeks. The larvae migrate to coastal wetlands (mangroves and estuaries) and in some cases to freshwater lakes during the juvenile stage. After that, they go back to the sea having reached big sizes or when they rich the sexual maturity (FAO, 2007).	Generally marine or brackish water farming depends on natural fisheries environment for stocking and feed, although hatcheries have constructed to provide seed for culture (Gyllenhammar and Håkanson, 2005).	Nematode infestation by *Capillaria* sp. was reported to cause loss of appetite and colour pattern darkens. The *Lernaea cyprinacea* is a parasite copepod that cause anchor worm disease on *C. chanos*, characterised by haemorrhages and open wounds, weight loss and ulcers (FAO, 2007). Additionally, dark colorations and difficulties in breathing as well as occasional skin lesion are symptoms presented due to infection by a protozoan *Cryptobia* sp.
Mollusc	Abalone	Abalone in general is considered highly valued seafood in the world. They are herbivorous and present a nocturnal	Because abalone is filter feeder, the species is susceptible to blooms of phytoplankton organisms. Nutrient	The infection by the sabellid polychaete *Terebrasabella heterouncinata* is the main issue

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	Haliotis midae	grazing behaviour, being inactive during the day. The post-larvae feed on benthic algae and after 4 to 6 months they feed on seaweeds. Their diet is rich on carbohydrates and can easily adapt to artificial diets (Sales, 2004).	enriched environment in coastal areas can accelerate these blooms and the appearance of biotoxins that can harm the human health. Filter feeders are also susceptible to contamination by domestic sewages that may contain bacteria and pathogenic virus (Chinabut et al., 2006).	affecting abalone production, forming burrows and shell deformation, growth reduction and in extreme cases can lead to death (Simon et al., 2004). Salinity and water temperature are the main factor that is directly connected to abalone growth and abundance (Simon et al., 2004).
Seaweeds	Spinosum, agar-agar *Eucheuma denticulatum*	This species in considered one of the fastest growing species of seaweed. The species inhabits from below the low tide water mark to the upper subtidal zones. They grow in the apical meristem and present a triphasic lyfe cycle: gametophyte (n), carposporophyte (2n) and the sporophyte (2n). The eggs are fertilised by spermatium in the carpogonium of the female and a zygote is developed into the carposporophyte. The gametophyte and sporophyte fases are long in the life cycle of the seaweed. Furthermore the species is characterised by its high vegetative regenerative capacity, being in this way advantageous for farming. However, favourable ecological conditions must be adequate	The most common impact of *E. denticulatum* farming is related to the clearing of the area before the building of the supporting structures fixed off-bottom affecting the fauna and flora. However, this impact is considered low as the area recovers in a short period after planting. Intensified farming into the same area may exceed the carrying capacity of the environment. On the other hand, this may cause changes in the hydrology of the area, affecting the water movement and consequently the production of the crops has the seaweed need good water movement to enhance its	Outbreak disease may affect the thallus. The FAO (2009c) stated that herbivores are responsible for the loss of biomass and epiphytic algae bloom are also susceptible to occur. The "ice-ice" disease caused by various microorganisms slows the growth rate of this species specially in calm weather and summer months.

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		for high unit production (Munõz et al., 2004).	growth. Due to its high growth, the seaweed serve as shelter and feeding ground for diversified fauna such as fish and invertebrates, increasing the biodiversity in the farming area. However, the biodiversity is affected by the farming cycles and can be reduced during the planting and harvest periods. Floating methods may impact the coral communities below as hardwood and iron bars are used as anchors to support the lines.	
	Cottonii *Kappaphycus alvarezii*	The demand for carrageenan has increased worldwide and is giving species to commercial production of this species as it is the best source of carrageenan compared to *Eucheuma denticulatum* and other species (Gerung and Ohno, 1997; Thirumaran and Anantharaman, 2010). For successful cultivation, the species requires warm sea water, high light penetration and nutrient enriched environments (Muñoz *et al*., 2004).	*K. alvarezii* has specific habitat requirements within biophysical conditions. This species do a minor impact in foreign environments and causes minimal impacts on the environment (Muñoz *et al*., 2004).	Temperature is the main environmental condition that may affect the growth rates of *K. alvarezii*. The species grows better in warm waters (Gerung and Ohno, 1997).