THE POTENTIAL OF AQUACULTURE IN LIBERIA

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ABSTRACT

Aquaculture was first introduced in Liberia in the 1950s. Although conditions for aquaculture are good in Liberia, there has been no significant growth in the field since then. The study developed methods for assessing the aquaculture potential in different parts of Liberia. Firstly, criteria were developed for assessing different factors that are relevant for developing aquaculture. The criteria developed were water, soil, topography, market and agricultural by-products. Secondly, the criteria were used to assess the potential for aquaculture in different counties. One limitation to a study such as this is the lack of information, both statistical and factual, about factors relevant for aquaculture. Therefore, the criteria could only be tested on a limited dataset. Some of the gaps were bridged by the author's knowledge of the country. The results from this study showed that there are potential for aquaculture based on the following: water is in abundance and can be available year round; latosols, which make up 75% of the soil has a compact texture with a water retentive capacity; population density in most of the counties is favourable for the marketing of aquaculture products; the topography of the country consists of flat land mainly and plateaus that are convenient for pond construction; and the total of 2337 household livestock farmers indicates that livestock wastes are available throughout the country for pond fertilization.

Keywords: Aquaculture potential, Liberia, Evapotranspiration, Biophysical factors, Socio-economic factors

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ABBREVIATIONS

BCRADP	Bong County Rural Agriculture Development Program
BNF	Bureau of National Fisheries
CAAS	Comprehensive Assessment of the Agriculture Sector
CIA	Central Intelligence Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
INGO	International Non-Governmental Organizations
LISGIS	Liberia Institute of Statistics and GEO-Information Services
MLME	Ministry of Lands, Mines and Energy
MOA	Ministry of Agriculture
PRS	Poverty Reduction Strategy

1 INTRODUCTION

The coastal waters of Liberia are richly endowed in biodiversity with abundance of various finfish, molluscs and crustacean species. However, in recent years, the sector has witnessed reduced landings. The marine artisanal fisheries account for 80% of the total marine fish landed locally and operate without much official control measures (EAF-NANSEN 2010).

From 1980-2002 the per capita consumption of fish declined from 14 kg to 4.3 kg, which is far less than the average global per consumption of 16 kg (FAO 2010a). Despite the decline in the consumption of fish, the dependency of fish for the supply of animal protein is still high, accounting for 65% of animal protein consumed. For many rural populations, fish is the best alternative source of protein due to the fact that it is cheaper than chicken and meat (FAO 2010a). According to the Poverty Reduction Strategy (PRS), in 2006, 81% of the rural population was either moderately vulnerable (41%) or highly vulnerable (40%) to having access to food, while 11% of the rural population completely lacked access to food and only 9% had acceptable food. About 40% of children under age five suffered chronic malnutrition, and even in farming communities' access to food was insecure, and supply was not sufficient to meet the demand of the people. Despite the food insecurity, the annual growth of the Liberian population was 2.1% from 1984 to 2008, increasing the population from 2.1 million people to almost 3.5 million in 2008 (LISGIS 2008). With the present growth rate the population is expected to double every 33 years. This means that the economic activity needs to double in order to maintain the current standard of living and services to the population. Unemployment is on the increase and is currently around 85% (CIA 2011).

Options are limited for combating the nutritional and livelihood crises in Liberia. Prior to the civil crisis, the economy of Liberia was driven by the agricultural sector and the extractive industries such as production of diamond, gold and iron ore. As a consequence of the civil crisis, regulations lacked, and these sectors were destroyed and overexploited (CIA 2011). One possible approach in addressing issues such as food security and population growth for the long-term benefit of the population is a shift from an economy driven by extractive industry to one driven by renewable resources. Extractive resources are non-renewable and will in the long term get depleted. According to the World Bank in 2008, extractive industry revenues tend to be uncertain, volatile, and exhaustible - all characteristics that pose enormous challenges to policy makers. Renewable resource is a natural resource with the ability of being replaced through biological or other natural processes and replenished over the passage of time. Aquatic resources are a perfect example of such renewable resource.

With the current condition of malnutrition, high unemployment, limited supply of fish and increased population growth, aquaculture is a renewable resource sector that can bridge the gap between fish supply and demand, and reduce unemployment and malnutrition. Indeed, there is a global trend for the development of aquaculture, increasing its contribution to many countries over the past decades (FAO 2009). However, despite the inception of aquaculture in Liberia in the 1950s, it still remains underdeveloped. One major reason for this underdevelopment is the non-determination of suitable areas for aquaculture development (BNF 2008).

1.1 State of World Aquaculture

In almost all regions of the world, with the exception of Sub-Saharan Africa, aquaculture is expanding and production is as well increasing to meet the ever-increasing demand of aquatic food. Production from world capture fisheries has levelled off and most of the fishing areas have reach their maximum potential yield (FAO 2010a).

It is estimated that in order to maintain the current level of per capital consumption, global aquaculture production will need to reach 80 million tonnes by 2050. Aquaculture has the potential to address the projection of fish demand, but will face enormous challenges to achieve this goal (FAO 2010a).

1.2 State of Aquaculture in Africa

The production of aquaculture in Sub-Saharan Africa is limited despite its natural potential. The aquaculture of tilapia, which is considered promising and native to the continent, has not been developed in the area (FAO 2010a).

There is high possibility for the development of aquaculture in the continent, and can be done through intensive use of the abundant inland water and coastal areas. In order to achieve this milestone, the continent will need to address the following existing constraints, such as: inadequate knowledge on aquaculture among farmers; prevalence of foreign aid programs organized on top down basis with inconsistent, short term goals and excessive independence on donor funded aquaculture development programs; low allocations for aquaculture development in national budget; whole sale importation of traditional crops agriculture practices into aquaculture, such as seed recycling; poor or slow growth of cultured species; poor broodstock management; and poor species identification (FAO 2010a).

The region's top producer is Nigeria with a total of 44,000 tonnes of freshwater fishes, mainly catfish. Egypt, which is the world's first and second producer of mullet and tilapia respectively, is playing a dominant role in Northern Africa producing 92% of the region's total. There are other potential species such as the black tiger shrimps (*Penaeus monodon*) in Madagascar, Eucheuma seaweed in The United Republic of Tanzania, and the niche species such as abalone in South Africa that are thriving (FAO 2010b).

1.3 Rationale

The key players in the development of aquaculture in Liberia are International Non-Governmental Organizations (NGO), Local non-Governmental Organizations and some private individuals. Approximately 30 NGOs have operated in Liberia between 1995 and 2008 implementing over 35 aquaculture projects under the food security thematic frameworks. A vast majority of these projects have failed because of the unavailability of first-hand information on feasible regions for aquaculture development (BNF 2008). As a consequence, number of organizations involved in aquaculture has dropped drastically over the years and even those still engaged in aquaculture projects are sceptical about future funding. In spite of this scenario, there is a considerable interest for the development of aquaculture among various stakeholders, but the lack of a proper planning and management scheme remains a major impediment to the development (BNF 2008).

For further development of aquaculture in Liberia it is important for government and financing institutions to have reliable information on suitable regions such that they can maximize the use of their scarce resources. Aguillar-Manjarrez and Nath (1998) and Pillay and Pillay and Kutty (2005) claim that most developing and industrial countries have in recent times deemed it necessary to develop national plans clearly defining objectives, policies and strategies that are favourable for a selected goal. However, these plans can only be attained by conducting detailed feasibility studies, including site surveys and studies on technical and economic viability in the proposed area. Therefore, it is my hope that the results obtained from this study will enhance the development of aquaculture through proper planning and management and subsequently renew the interest of donors who are the drivers of the development of aquaculture.

1.4 Objectives

The main objective of this study was to develop a tool to locate regions in Liberia that are suitable for aquaculture of tilapia (*Oreochromis niloticus)* and African catfish (*Clarias gariepinus)*

1.5 Research question

1. How can the suitability of different regions in Liberia for aquaculture be assessed?
2. What are the criteria needed to evaluate the potential of aquaculture?

2 AQUACULTURE CONDITIONS IN LIBERIA

2.1 Location of Liberia

Liberia is situated on the coast of Western Africa (Figure 1). The surface area is approximately 111,400 km^2, with water covering 14% of the total area. Liberia borders with Sierra Leone to the west, Ivory Coast to the east, Guinea to the north and the Atlantic Ocean to the south.

The climate of Liberia is tropical with relatively small temperature differences between day and night. There are two seasons, the wet season from May to October and the dry season from November to April. During the dry season, which is the hottest part of the year, temperature never exceeds 37 degrees Celsius. The average annual rainfall is 4,320 mm inland. The average humidity in the costal belt is 78% during the wet season, and decreases to 30% from December to March when the Harmattan winds blow from the Sahara (MLME 2008).

Figure 1: Liberia and its neighbouring countries (CIA 2011)

2.2 Development of aquaculture in Liberia

Aquaculture activities in Liberia began in the 1950s, with fish ponds developed at the Central Agriculture Experimental Stations in Suacoco, Bong County, for breeding common carps, Nile tilapia and catfish varieties. Figure 2 delineates the total aquaculture production from late 1990s' to 2009. Peace Corps Volunteers provided extension to small-scale farmers. The Bong County Agriculture Development Program, Nimba County Rural Agriculture Development Program and Lofa County Agriculture Development Program in Bong, Nimba and Lofa Counties promoted it, with pre-war production reaching 29 tonnes. By 1989, more than 900 ponds had been developed throughout the country and stocked with fingerlings. From 1990s to 2004, a period characterized by a civil crisis, the sector received enormous support from several donor-supported projects. The technical and financial assistance provided by the NGOs was the driver of the spread of aquaculture in rural Liberia. The European Union supported, from 1999 to 2002 the rehabilitation of three hatcheries, Klay (Bomi County), Duoyee Town (Grand Gedeh County) and Salayea (Lofa County). Brood stocks of *O. niloticus* were imported for seed production and further distribution to farmers. The project rehabilitated and developed ponds in six counties, with some 380 farmers benefiting from pond construction materials, training and extension services (FAO 2010b).

At present, there are seven NGOs operating in the aquaculture sector under the thematic framework of food security in Liberia. These NGOs include Concern Worldwide, Samaritan Purse, APDRA, Africare, German Agro Action (Welt Hunger Hilfe), Care International, Faimba Fisheries Development Cooperative (FFDC), and Solidarites International (BNF 2010). Fish farming in ponds is the most common form of aquaculture in Liberia. Cages were introduced in 2009. The number of fish farmers rose from 350 in 2000 to 1050 part-time, subsistence farmers in 2004. Majority of farmers practice the integrated aquaculture-agriculture technologies. Fish production rose from 22 tons in 2000 to 38 tons in 2004 (BNF 2007).

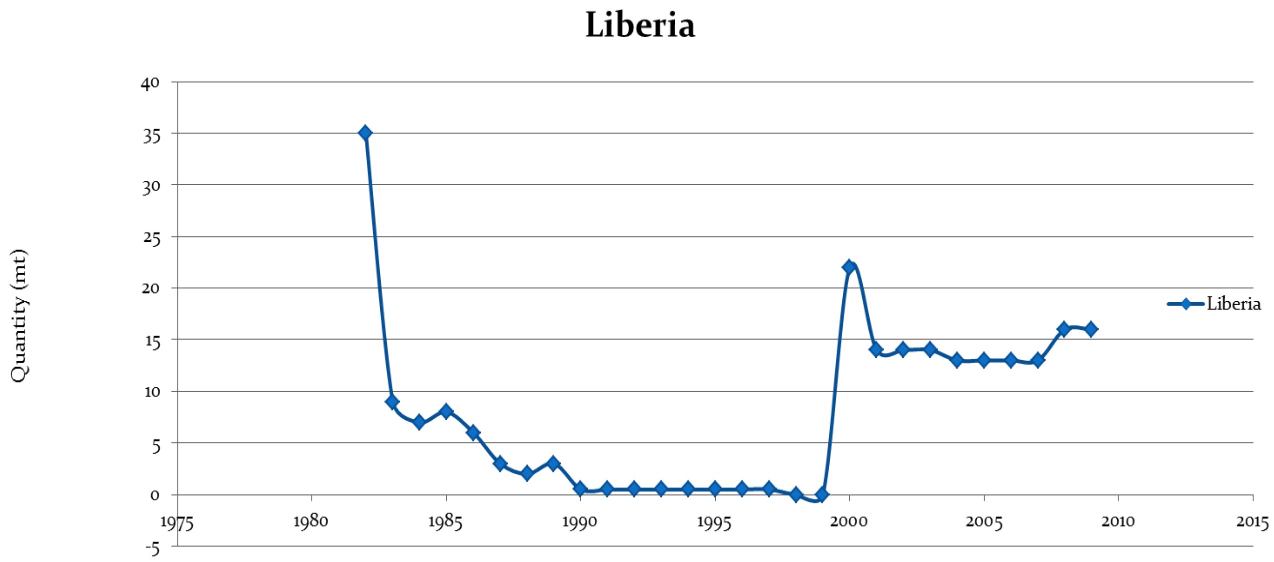

Figure 2: The graph points out the total aquaculture production in Liberia (FAO 2000)

2.3 Practices and systems of aquaculture

A typical aquaculture farm in Liberia has 1 to 2 ponds ranging from 200 m^2 to 400 m^2 or even less, depending on land availability. The production is extensive to semi-intensive with the use of very low inputs. Fingerlings left over during harvest are usually what the farmers use to stock their fishponds. The stocking density practiced by most fish farmers is 2-3 fish per m^2. Fish ponds are fertilized with poultry, goat and cattle manure. Fish is also fed with leftover food from the livestock and agricultural by-products (BNF 2007).

Integrating aquaculture with other agricultural activities is widely practised in all parts of the country. Semi-intensive culture of tilapias in ponds is being carried in the north and southeastern regions. In 2009, floating cages were introduced in the St. Paul river through the initiative of Mr. Jonan Tarley, a private farmer (BNF 2007).

2.4 Cultured Species

Five main species are commonly cultured in Liberia: Nile tilapia, African catfish, Sampa, Mango tilapia and Red belly tilapia. Nile tilapia, Tilapia zili and other tilapia varieties accounts for 95% of production while African catfish and *Heterobranchus spp.* account for the remaining 5% (Figure 3). The use of exotic species is restricted to some extends despite the lack of formal law regarding its introduction into fish farming in Liberia. The Bureau of National Fisheries executes the restriction of the importation of exotic species in order to protect Liberia's fish biodiversity. In 2009, the Bureau of National Fisheries put a halt to the introduction of the African Bony tongue (*Heterotis niloticus*) by APDRA, a French NGO implementing inland fish-farming project In Liberia. However, in 2010 the introduction of the species was allowed in Liberia after thoroughly researching its biology and impacts in other neighbouring countries where it is being cultured (BNF 2010).

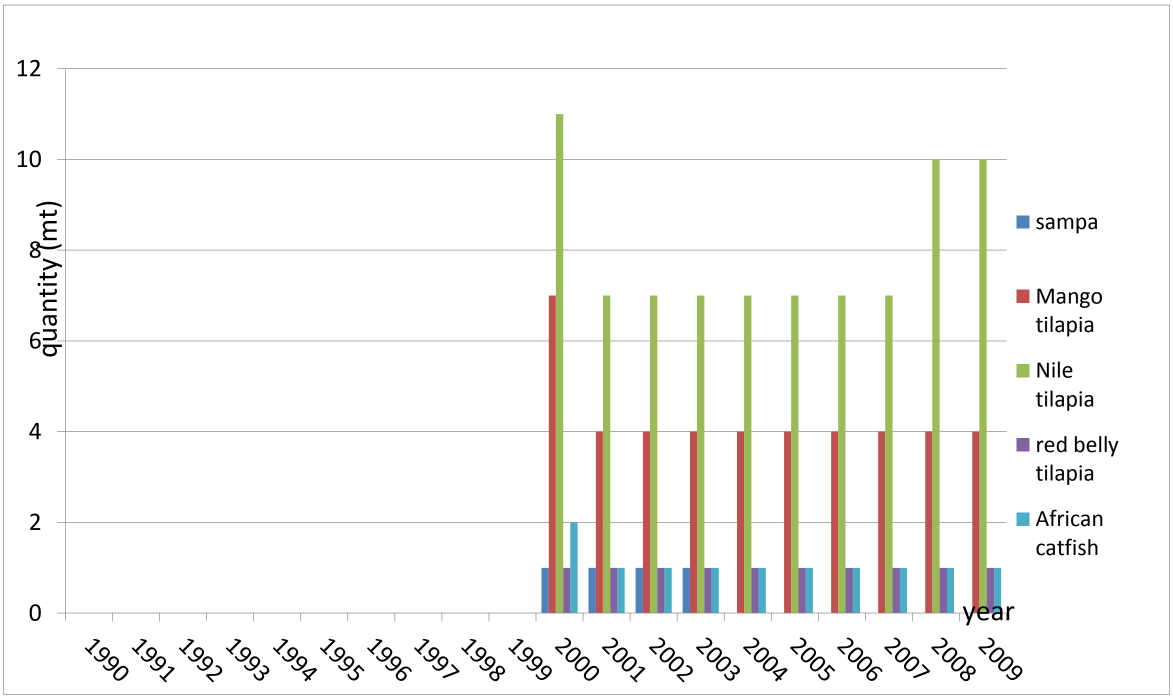

Figure 3: The graph shows the total production per species in Liberia (FAO 2009).

2.5 Contribution to the economy

Aquaculture in Liberia is practiced with the objectives to contribute to food security in terms of increased food production, improved household access to food and improved utilization of farmland for food production. Fish farming is a convenient source of fish supply to the rural part of Liberia, especially to the six non-coastal counties. Most often, frozen seafood sold in rural areas is of poor quality due to bad handling. Fisheries in general contributed 12% to agricultural GDP and 3.2% to national GDP in 2002. The contribution of aquaculture as an independent sector is unknown or perhaps negligible (FAO 2010).

2.6 Human Resource

Fish farmers are the primary stakeholders of the aquaculture sector. There are about 1050 part-time, subsistence fish farmers. Approximately 2,500 people are involved in fish farming activities including pond construction and management, extension services and fish harvesting. There is no detailed information on the gender ratio and the level of education of fish farmers; however, It can be assumed that 80% of fish farmers are illiterate (BNF 2007).

2.7 Institutional and legal framework

The Bureau of National Fisheries, in the Ministry of Agriculture founded in 1950, is responsible for the management and development of aquaculture. The Bureau has four functional sections comprising administration, research and statistics, marine and aquaculture and inland fisheries.

Before the official declaration of the new 'Draft Marine Fisheries Policies and Regulation' in 2011, the only instrument for fisheries management was the revised fisheries 'Rules and Regulation' of 1973 enshrined in the 'Natural Resources Law' of 1956. In the regulation, the Ministry of Agriculture was authorized through the Bureau of National Fisheries to impose fees and fines and take measures to enhance the sustainable management and utilization of the fisheries resources of Liberia. In both of these policies and regulations, there is no specific clause clearly explaining the management and planning of aquaculture (BNF 2007).

3 METHODOLOGY

The study was carried out at the Holar University College in Saudarkrokur, Iceland. The main focus of the study was on assessing the potential for pond aquaculture in all of the 15 counties in Liberia.

The study was a desk study involving both development of criteria to identify suitable locations for aquaculture operations and evaluation of aquaculture potential in different counties in Liberia. Existing data and information were collected from governmental ministries and agencies where possible. Library, on-line articles, databases and the author's personal knowledge and experience on aquaculture activities in Liberia formed part of the data sources.

The first task was to develop suitable criteria for assessing the potential of pond aquaculture in different regions, and the second task was to use the criteria as a tool and using Liberia as the test country. Aquaculture potential for pond culture was assessed on the basis of biophysical factors (water, soil and topography) and socio-economic factors (market, link with other activities such as farming of livestock and education). The environmental requirements of two fish species, Nile tilapia and African catfish, were gathered to develop the criteria for pond aquaculture of the species.

4 ENVIRONMENTAL REQUIREMENTS OF TWO FISH SPECIES -NILE TILAPIA AND AFRICAN CATFISH

In selecting a species of fish suitable for farming, various biological and economic factors are of particular relevance. These include market price, ability to feed, fast growth, efficient feed conversion, temperature tolerance, hardiness and adaptability to heavy stocking density, simple larval development, and the ability to reproduce in captivity. However, this section will briefly deal with the environmental requirements for the above-mentioned species.

4.1 Nile tilapia

Tilapia is a freshwater species that is native to Africa and part of the Cichlid family (Figure 4). The aquaculture of tilapia is believed to have developed about 4000 years ago and was introduced to sub-tropical, tropical and temperate regions of the world in the middle of the 20th century (Mjoun *et al.* 2010). FAO recognizes tilapia as an ideal species for aquaculture due to its characteristics, such as fast growth rate, tolerance to a wide range of environmental conditions, resistance to stress and disease, ability to reproduce in captivity and short generation time, feeding at a low trophic level and acceptance of artificial feeds immediately after yolk-sac absorption (El-Sayed 2006). Table 1 provides basic water quality requirement for Nile tilapia and Table 2 highlights the critical temperature range.

Figure 4: Nile tilapia

Table 1: Limit and optimal water quality requirements for Nile tilapia (Mjoun *et al*. 2010).

Parameters	**Range**	**Optimum for growth**
Salinity ppm	Up to 36	Up to 19
Dissolved oxygen (mg/l)	Down to 0.001	>3
pH	3.7-11	7-9
Ammonia mg/L	Up to 7.1	<0.05

Table 2: Upper and lower critical ranges of temperature for Nile tilapia (Mjoun *et al.* 2010).

Lower critical range (^{0}C)	**Optimum range (^{0}C)**	**Upper critical range (^{0}C)**
11-12	31 - 36	42

4.2 African catfish

The aquaculture of African catfish in Africa goes back 40 years although success have been mixed. The total aquaculture production of this species in 1994 was 3,978 tonnes, contributing 7.4% of total aquaculture production for the same year in Africa (Britz and Hecht 1987). The species is the most widely distributed freshwater species in the world and can survive under varying climates (temperate to tropical). Its habitats include water bodies such as shallow and deep lakes, rivers, swamps, flood plains, underground sinkholes, and impoundments. African catfish (Figure 5) are efficient opportunists and survivors, equipped to exploit whatever resources are available. The species can tolerate wide ranges of environmental extremes (Table 3).

Table 3: Catfish ranges of environmental factors (Bruton 1988).

Factors	**Ranges of tolerance**
Water temperature	8 to 35^0 C, breeding >18^0 C, and for egg hatching 17 to 32^0 C
Oxygen	0 to 100% saturation
Salinity	0 to 12 ppt and 0 to 2.5 is optimal
Desiccation	The species has the ability to live out of water for so many hours due to the presence of an accessory breathing organ
pH	The species can tolerate a wide range of pH
Density	Wide tolerance

Figure 5: African catfish

5 BIOPHYSICAL CRITERIA

Before starting an aquaculture operation, it is important to assess the suitability of the location (Ngugi *et al.* 2007). When assessing a site for the construction of earthen ponds, the topography, water supply and its quality, and the soil type are key factors to consider.

5.1 Water requirements

High quality water is essential for aquaculture, and a simple test for its quality is its potability. When water is drinkable by humans, fish should be able to grow in it. On the other hand, when the water has odour, does not taste well, is irritating or contaminated with bacteria; it is not advisable for aquaculture. Another simple test often used is to rear few individuals in a cage in a waterway to see if they survive and grow. The water quality requirements in Table 4 are a standard for salmonids with modification for warm water fish farming. The standard is for the water requirement of hatcheries in terms of quality, and can be used as a requirement for the production of fingerlings depending on the temperature and volume of water provided (Conte 1993).

Table 4: Water quality requirements for aquaculture hatcheries and production facilities (Bruton 1988)

Chemical	**Upper limits for continuous exposure and/or tolerance ranges**
Ammonia (NH_3)	0.125 ppm (un-ionized form)
Cadmium	0.004 ppm (soft water< 100 ppm alkalinity)
Cadmium	0.003 ppm (hard water> 100 ppm alkalinity)
Carbon dioxide	0.0 to 10 ppm (0.0-15.0 ppm)
Calcium	4.0 to 160 ppm (10.0-160.0 ppm)
Chlorine	0.03 ppm
Copper	0.006 in soft water
Hydrogen sulphide	0.002 ppm
Ferrous ion	0.0 ppm
Lead	0.03 ppm
Magnesium	Needed for buffer system
Manganese	0.0 to 0.01 ppm
Mercury (organic or inorganic)	0.002 ppm maximum, 0.00005ppm average
Nitrate (NO_3)	0.0 to 3.0 ppm
Ferric ion	0.05 ppm (0.0-0.5 ppm)

5.1.1 Water temperature

Water temperature is the most limiting factor in aquaculture and should be given special attention when deciding to establish an aquaculture farm (Boyd and Tucker 1998). The growth and the activity levels of fish depend on their body temperature (Coche *et al*. 1995). Fish are poikilothermic animals, that is, their body temperature is the same as, or 0.5 to 1^0 C above or below the temperature of the water in which they live. The metabolic rate of fish is closely correlated with the water temperature, the higher the temperature the greater the metabolism. This generalisation applies particularly to warm water fish (Svobodova *et al.* 1993). However, each fish species is adapted to grow and reproduce within well-defined ranges of water temperatures. The optimum temperature for growth and reproduction is within narrow ranges but differ among species (Tables 2 and 3). Therefore, It is important to know the water temperature regime at a designated site for fish farming to select the right species of fish and to plan its management accordingly (Mishra *et al*. 2008).

5.1.2 Water temperature in Liberia

Data on water temperature in Liberia is scarce. The only data that are available, and inaccessible, are the one gathered for 1950s to 1980s from the Liberia Hydrological Service Bureau of the Ministry of Lands, Mines and Energy. However, considering the rapid global climate change, these data are no longer valid because they can't show the present day temperature regime of the waters. Air temperature can be used as an alternative, since indeed it is correlated to water temperature.

It is difficult to quote figures for temperature in different regions in Liberia since they vary with locations and altitude, but 27°C to 32°C and 23°C to 28°C for day and night respectively is ambient for Tilapia niloticus and African catfish growth and reproduction (Table 5 and 6). The temperature of Liberia as indicated in the introduction does not exceed 37°C.

Table 5: Temperature requirement for Nile tilapia in pond aquaculture

Temperature (^{0}C)	**Score**	**Interpretation**	**Justification**
32-35	4	Very Suitable	Fish grow the fastest in this range of temperature (FAO 2006)
31-36	3	More Suitable	This is the optimal range of temperature over which feeding occur
19-21	2	Suitable	Within this range of temperature, spawning percentage averaged 10 and 34.9% respectively (EL-Naggar et al., 1997)
<19^{0}C	1	Unsuitable	Tilapia do not lay egg when water temperature drop below 19^{0}C (EL-Naggar et al., 1997)

Table 6: Temperature requirement for African catfish (Britz and Hecht 1987)

Temperature (^{0}C)	**Score**	**Justification**
30	Very Suitable	At 30 ^{0} C, fish growth rate is high (Britz and Hecht 1987).
25-33^{0}C	Suitable	Between 22-33 ^{0}C, is optimal for fish growth

5.1.3 Salinity

Salinity is another important water variable that should be given keen attention during the evaluation of water quality of a proposed site (Pillay and Kutty 2005). The salinity of water supply dictates to the initial salinity of the ponds (Boyd and Tucker, 1998). During the rearing process, the introduction of feed and fertilizers may increase the salinity of the water. Considerable evaporation and precipitation can alter the salinity of a pond, especially in regions with rainy and dry seasons. In tropical locations the salinity of the pond water decreases during the rainy season due to heavy inflow of freshwater and while during the dry season the salinity level of the pond water is high as a result of low inflow of freshwater.

Salinity tolerance is species specific, and every species has its range of salinity that they can tolerate with certain level being optimal. It is within this range that fish can efficiently regulate their internal body fluid composition of ions and water. Species reared outside their optimal salinity range may have to expend considerable energy on osmoregulation, leaving less energy for other processes (Boyd and Tucker 1998).

5.1.4 Salinity in the inland waters of Liberia

I was unable to find any information on the salinity of inland water bodies in Liberia. However, given the high annual precipitation the salinity of inland water bodies is likely to be low and most likely does not affect the culture of Tilapia and African catfish.

5.1.5 pH in aquaculture ponds

The pH of water is an expression of its acid and base content. The pH scale is between 0 and 14. When the pH is higher than 7.0 it is alkaline, and conversely, when the pH is below 7.0, it is acidic (Tucker and D'Abramo 2008).

The pH range suitable for aquaculture is between 6.5-9.0 (Boyd and Tucker 1998). When the pH is either lower than 4 or higher than 11, the fish will not survive. Most freshwater animals have over time adapted to living in a wide range of pH where it fluctuates considerably with respect to seasonal and daily time frames (Thomas and D'Abramo 2008). However, abrupt changes in pH can be stressful for aquatic animals or even lethal. The pH of pond water can fluctuate. Photosynthesis of algae consumes carbon dioxide, which causes a rise in pH (El-Sherif and El-Feky 2008). The pH levels that are optimum for the growth and survival of tilapia fingerlings are shown below in (Table 7). The pH of Liberia inland water is discussed in the soil section, since most pH in ponds is derived from pond soils.

Table 7: pH requirements for Nile tilapia juvenile (El-Sherif and El-Feky 2008).

pH	Score	Justification
7	Very suitable	At pH7, the food conversion ratio was the best at 2.7 with a specific growth rate (SGR) of 1.16
8	Suitable	At pH 8, food conversion ratio of 2.9 was achieved with a specific growth rate of 1.11
9	Moderate suitable	The food conversion ratio at pH 9 was found to be the highest 3.3 and with a specific growth rate of 0.95
6	Unsuitable	at pH 6 the food consumption ratio was highest at 3.3 with a standard growth rate of 0.53

5.1.6 Water availability

A reliable water supply is an important factor to consider when selecting a site for aquaculture. The quantity of water required depends among other factors on the type of aquaculture system, evaporation rate, leaching from ponds, species cultured, management practices, culture densities, and skills of the culturist (Lawson 1995). When calculating a water budget, all factors that influence water use should be taken into consideration (Homziak *et al*. 1993).

5.1.7 Water resources of Liberia

The climate and water resources of Liberia are very suitable for the aquaculture of African catfish and Nile tilapia and other freshwater species with respect to their environmental requirements. The climate of Liberia is almost the same everywhere with just minor variation between areas during certain part of the year with slight rainfall and sunshine. The annual rainfall varies from 1,700 mm in the north to 4500 mm in the south with a temperature between 22-28 ^{0}C. Relative humidity is from 65% to 85%. Approximately 75% to 85% of the rainfall is experienced between June and October. It is also established that most part of Liberia have excess water for up to 8 to 5 months with an estimated evapotranspiration rate between 3.0 and 4.5 mm daily. There are nine major river system that are characteristic of perennial that flow from the northeast to southwest and drain into the Atlantic Ocean. The country stands as one of the top African countries with abundance renewable water resources of about 232 km^3/yr.

In most levee ponds with an average depth of 1.5-2.0 m the annual water requirement would be approximately 250 mm/yr for wet climate and up to 900 mm/yr for very dry region (eg. desert area). The quantity of water can further increase up to 3000 mm/yr when ponds are drained annual for harvest and other losses, thus making aquaculture a water intensive sector as compare to rice sector that will need just 1000 mm/yr for a staple crop (Yoo and Boyd 1994).

Considering the worst-case scenario of water requirement of 3000 mm/yr and assuming the total aquaculture area of 20,000 hectares for sustainable aquaculture, the total water requirement will be 6 billion mm^3/yr or 6 km^3/yr. The amount is just 2.6% of the total renewable water resource of 232 km^3/yr of Liberia.

5.2 Soil

The four most important soil features for aquaculture production are texture, organic matter content, pH, and presence or absence of particular soluble compounds that may be beneficial or harmful to water quality. Much is known about the classification of soil for agricultural and engineering work, but little is known about the desirable characteristics of soil for aquaculture ponds (Boyd 1995).

Pond bottom soil plays a vital role in providing nutrients for phytoplankton, the primary food organism in a pond. As a result, ponds bottom soil must be suitable to enhance productivity of the ponds (Datta 2011). The pH of pond water is influence by the interaction between water and pond bottom soil. Acidic soil reduces the concentration of bicarbonate, carbonate, magnesium and calcium in water and such water does not support the process of photosynthesis in the pond (Boyd *et al*. 2002). Soil is responsible for retaining water in ponds.

Water retentiveness in pond is greatly influenced by the characteristic of the soil. Soil can be classified as gravel, clay, silt and sand based on the distribution of particle size. A good pond bottom should have a soil composition of 30% clay with a mixture of different sizes of particles (Boyd 1995).

Water and air exchange in the soil takes place in small and large openings called pores that are interconnected, and can be characterized by the sizes of particles found within them. The size of pores decreases when the particle size decreases. Coarse textured soil has many large pores because of the loose arrangements of larger particles, unlike fine textured soils that have smaller pores due to the tight arrangement of their particles (McCauley *et al*. 2005). The ability of a soil to retain water is entirely dependent on the volume of pore space (Boyd 1995). For proper planning and management, soil and its properties should be investigated (Pillay and Kutty 2005). Soil criteria for aquaculture ponds (Table 8) were developed to assess the soil suitability for aquaculture in Liberia.

Table 8: Soil quality criteria for aquaculture ponds (Aruleba and Agbebi 2010).

Parameter	**Critical level**	**Unsuitable(S4)**	**Marginally suitable**	**Moderate suitable**	**Highly Suitable (S1)**
Organic carbon (%)	1-2	<1	1-2	2-3	>3
Clay (%)	20	<5	10	11-19	>20
Permeability (cm/hr)	10	<5			
Bulk density (g/cm3)	1.4	>1.2	1.25-1.4	1.4	>1.4
P (mg.kg-1)	8	<6	6-7	7-8	>8
Total N (%)	0.15	<0.08	0.08-1.0	0.1-0.13	>1.5
Soil texture	SCL,L	LS,S	L	SL, SCL	CL
Depth (cm)	75	<50	50-75	75-100	>100

SCL=Sandy, clay, Loam, L=Loam, LS= Loamy Sand, S= Sandy, SL= Sandy Loam, SCL=Sandy Clay Loam, CL= Clay Loam

5.2.1 The soil of Liberia

According to the study conducted on the Comprehensive Assessment of the Agriculture Sector (CAAS-Liberia, 1997) there are three categories of soil in Liberia (Table 9). Latosols make up 75% of the soil in Liberia and suit the use for aquaculture with one minor limitation that is the high level of acidity. The soil texture ranges from sandy loams to clay loam with an organic matter content of 2 to 6% that is favourable for water retention in the ponds and the enhancement of the production of phytoplankton. The accumulation of pH in water is attributed to pond soil. The optimum range of pH for growth and reproduction is from 6.5-9.0 pH, although tilapia can tolerate as low levels as pH 5. Below pH 5 conditions are lethal for the fish, wherein the fish becomes stressed and may eventually die (Boyd 1995). However the condition of soil acidity does not preclude aquaculture from a certain area since the acidity can be neutralized with proper measure. Liming can neutralize pond soil acidity and at the same time enhance productivity. Table 10 shows the type of liming and their recommended quantity of applications for ponds.

Table 9: Soil of Liberia (CAAS-Liberia, 2007).

Soil type	Liberian classification	% Area	Area (ha)	Properties
Lateritic soil or Latosol	Kakata, Voinjama and Suacoco series	75%	8,352,750	Reddish brown, leached top soil, 4-6%, OM, acidic, well drained, agricultural soil
Regosols or coastal sandy soil	Clara town, sinkor and Freeport series	20%	2,227,440	Well- drained, 60% coarse sand, very low water holding capacity, little humus and few mineral nutrients, not productive agriculture soil
Alluvial or swamp soil	Gbelle, Ballam, Grayzohn, and cuttington series	5%	556,850	Waterlogged, grey hydromorphic soils, poorly draining, thick dark layer of loamy-peaty organic material, with relatively high humus content

Table 10: Types of liming agents and recommended dosages (Russell *et al.* 2008).

Crushed oyster shells	**CaCO**	**At least two tons per acre**	**Recommended**
Pelletized lime	CaCO, Mg CO_3	At least two tons per acre	Not recommended due to high cost and the potential problem with binders
Fulid Lime	$CaCO_3$, Ca(OH) In some formulation	Depends on formulation	Not recommended due to high cost and the potential to raise pH to toxic level
Lime wastes	$CaCO_3$, Ca(OH)	The smaller of either 200 lb per acre or the amount required to deliver 50 lb per acre of Ca(OH)	Not generally recommended and could also raise pH to toxic levels
Quick lime, Brunt lime	CaO	Less than 50 lb per acre	Not recommended and could raise ph to toxic leves with only short term effectiveness
Shaked Lime, Hydrated lime, Builders lime	Ca(OH)	Less than 50 lb per acre	Not recommended and could raise ph to toxic leves with only short term effectiveness

5.3 Topography

The topography of an area is an important factor to consider when designing fish farms (FAO 1998). Pond design (width, depth, orientation) and farm layout (breeding and culture areas, building sites, settlement and holding dams) is influenced by the topography of the land. The cost of constructing a pond can be minimized by building a pond on a land with a gentle slope (1-3%). The steeper the land the more work is required, and the higher the water pumping cost (Ghosh 2009). A suitable site for fishpond has a topography that can be converted into a pond economically. Topographic surveys at scales of 1:500 to 1:5000 and with contour lines of 20 to 30 cm (about 1 ft.) vertical spacing (10 cm for flat land) are appropriate for site planning and design of project facilities (Homziak *et al*. 1993). Table 11 shows the topographical criteria for site selection.

Table 11: Topography criteria (FAO 1995).

Types of topography	**Score**	**Interpretation**	**Justification**
A terrain with a slope between 2% and 4% is ideal	2	Very suitable	This feature enable the filling and draining of ponds by simple means of gravity
A flat terrain with a slope more than 4%	1	Less suitable	Filling and draining of ponds is not possible under this kind of features and will need extra funds to pump water into the ponds

5.3.1 Topography of Liberia

The topography of Liberia is broadly sub-divided into four belts that run parallel to the coast rising in steps, one behind the other. They are the coastal belt, rolling hills belt, the dissected plateau belt and the northern highland belt. The coastal belt is about 15 meters above sea level, while the rolling hills belt is 100 meters above sea level. The dissected plateau and northern highland are 300 meters and 1,800 meters above sea level respectively (Reed 1951).

Among the high elevation of mountains and hills that can be found throughout the country there are areas that are relatively flat and suitable for aquaculture ponds. The dissected plateau also has extensive areas that are flat and suitable for aquaculture.

6 SOCIO-ECONOMIC FACTORS

6.1 Market

Marketing is as important as production, financing, cash flows and other profit determining factors for an aquaculture enterprise, whether it be a commercial or small-scale. A good survey of a market potential of a site or area that is intended for aquaculture is the key to the overall success of the operation.

In Liberia, there is no complete data on fish consumption and marketing, and as an alternative, on farm sale was used to evaluate market potential. Market potential as on farm sale (Table 12) was inferred from the population density (individual/sq. mi or I/sq. mi). Many small-scale fish farmers in the United States generate more income from selling their fish and crustaceans on the farm (Dasgupta *et al.* 2009). The basis of the analysis is, the higher the population density, the larger the market demand, and also the impact of population on land tenure or ownership.

Table 12: Population density of counties (LISGIS 2008).

County	[I/sq. mi]
Montserrado	1540
Margibi	202
Maryland	153
Bomi	113
Nimba	104
Bong	99
Lofa	75
Grand Bassa	73
Grand Cape Mount	69
Grand Kru	39
Rivercess	33
Grand Gedeh	30
Sinoe	27
River Gee	24
Gbarpolu	22

6.2 Agricultural by-products

Agriculture provides livelihood for a large proportion of the economically active population in Liberia, who are engaged in smallholder agriculture, according to the poverty reduction strategy 2008.

There is good potential for aquaculture in farming areas. The presence of agriculture indicates that there is already basic infrastructure such as farm to market road and availability of labour force. Secondly, agriculture and livestock farming produces agricultural by-products that can be used both as sources of feed for fish and fertilizer for fish ponds (Kapetsky 1994). In

Liberia, 25% of the nutritional requirements of the aquaculture fish are met by feeding them rice bran, kitchen leftover and other vegetable by-products. The remaining 75% of the food is produced in the pond. The fertilization of ponds with livestock waste enhances the productivity of the ponds.

Information regarding livestock and crop production for each of the counties is lacking, which would have been the most preferable data to use in this study. As a proxy, the number of household livestock and crop farmers were used for each of the counties and was inferred from the 2008 National population and housing census (LISGIS 2008).

The results in Table 13 is in descending order, and the top five counties (Nimba, Bong, Lofa, Montserrado and Grand Bassa) are considered to have the highest potential of livestock waste availability, while (Gbarpolu, Rivercess, Grand Gedeh, Margibi, Grand Cape Mount) which are intermediate on the table, are the ones with moderate potential for livestock wastes availability, and the five counties at the bottom of the table (Grand Kru, Maryland, Sinoe, River Gee, and Bomi) are considered to be the counties with the least potential for livestock waste availability.

Table 13: Household livestock and crop farmers (LISGIS 2008).

County	# of household farmers
Nimba	62917
Bong	49807
Lofa	40815
Grand Bassa	30558
Montserrado	24500
Margibi	17725
Grand Cape Mount	16017
Grand Gedeh	12640
Rivercess	11646
Gbarpolu	11400
Sinoe	10833
Maryland	10717
Bomi	10460
River Gee	8464
Grand Kru	7765

6.3 Education

Education plays a pivotal role in the development of aquaculture, enabling farmers to adopt readily modern technology to enhance production. A survey conducted in Malawi on fish farming households, shows that the most productive and higher income earning fish farmers were people with higher education (Russell *et al*. 2008). The assessment further shows that the success of these farmers was attributed to their ability to adopt different levels of technology (Russell *et al*. 2008).

In Liberia, a detailed assessment has not yet been conducted to establish the educational levels among fish farmers, but it can be assumed that approximately 80% of fish farmers are illiterate. This has been a major barrier in the development of aquaculture in Liberia.

It is not feasible to develop a criterion for education due to the lack of information on the educational levels in each of the counties. Based on what I perceived, education could be an impediment to aquaculture development in Liberia.

7 DISCUSSION

The results from this study suggest that there is good potential for aquaculture in Liberia. When conditions are evaluated based on biological and physical criteria (soil, water and topography) they all suggest that most parts of the country are suitable for pond aquaculture. Liberia has numerous water bodies, high level of precipitation and abundant resources that could allow other forms of aquaculture such as cage culture. Latosols, which make up 75% of the soil covered in Liberia is ideal for aquaculture due to its compact texture and impermeability. Even though, hills and mountains characterize the topography, there are areas of relatively flat lands, such as plateau, that are suitable for small-scale aquaculture. These areas can be found at various locations in the country. There are some variations in population density in among counties and as a result, the available market is variable in size. However, there is, at present, a decrease in per capital fish consumption due to reduced landings of fish by artisanal fishers, which suggests a good market potential for aquaculture products. The strong tradition of fish consumption in Liberia will also keep demand high for aquaculture fish. The total of 326,264 household livestock farmers in the country signify that livestock wastes are accessible to fertilize aquaculture ponds. Due to the lack of information on education, the author assumed that education is a threat to the development of aquaculture based on his experiences. The study indicates that there are some differences between counties in the number of students. Thus the availability of well-educated people may vary accordingly.

The study could only address certain factors that affect aquaculture development. However, other factors will also affect the future development of aquaculture. Some of these threats are:

Pollution: Pollution has been identified as a potential risk rather than a major source of losses to aquaculture. Despite of the abundance of water supplies in Liberia, the valuable resource is under increased pressure from population growth, uncontrolled disposal of waste, agricultural activities, mining, logging, aquaculture and other activities. Pollution of streams with reduced water quality is common in urbanized areas (MLME 2008). Furthermore, the entire sewerage system that was destroyed during the civil crisis has resulted into domestic waste being dumped into coastal lagoons, estuaries, deltas, mangroves that are rich resource of fish protein (Brandolin and Tigani 2006).

Access to Loans: Most fish farmers or wanting to be fish farmers lack access to initial capital to ignite an aquaculture farm. This is a major constraint that can hamper the development of aquaculture in rural settings.

Other issues: There are issue that could directly or indirectly affects aquaculture by introducing socio-economic conflicts with other users for the same water body, particularly tourism and fishing. Usually, there should be a 1 km demarcation between aquaculture, tourism and fishing grounds to avoid conflicts of rights. Aquaculture like any other farming activities involved the use of land. Land cost and ownership can arise in populated area. The population of Liberia is increasing by 2.1% per annum, meaning that in the next few years increase in land cost is inevitable. This situation will be a constraint to the development of aquaculture in Liberia, because the poor farmers who constitute about 75% of fish farmers in Liberia will find difficulty in acquiring land.

8 CONCLUSION AND RECOMMENDATIONS

The results of this study suggest that there is a good potential for aquaculture in Liberia. However, evaluation of aquaculture potential in different counties is required for further studies to access the potential in different parts of the country. Some of this information is not accessible but should be obtained. The study relied in part on surrogate indicators, e.g. on market size and education level, and these must be confirmed in further studies.

Regarding the future prospects and development of aquaculture in Liberia, a more detailed assessment taking into consideration all of the 15 counties should be conducted to map out potential zones for aquaculture development. This will create an environment for proper planning and management of the sector, that which has been lacking since the inception of aquaculture in the 1950s. This present study shows how important this information is.

This study evaluated the potential for aquaculture in Liberia. The following recommendations arise from the study, and are as follows:

- It is recommended that the government of Liberia support the development of aquaculture to help balance the shortfall in supplies that are resulting from; increased population and reduced landings of catches by artisanal fisher folks
- It is recommended that a strategy framework for aquaculture in Liberia is formulated to enhance planning and management of the sub sector
- The government of Liberia should recognized the need to undertake a strategic assessment of the potential of aquaculture to contribute to share food security and livelihood of rural inhabitants. Economic activities are scarce in rural communities
- A holistic approach involving NGOs, government, fish farmers and other stakeholders should be envisaged to enhance the development of aquaculture
- A detail assessment on the potential of aquaculture in Liberia should take into consideration all of the 15 counties so as to stimulate improved planning and management of aquaculture.

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