Sustainable nondestructive mangrove-friendly aquaculture in Nigeria I: ecological and environmental perspectives

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Abstract. Nigeria's mangroves possess qualities for profitable semi-intensive and intensive aquaculture, ponds such as brackish water, physicochemical, physiographic, biological and tidal parameters. They also provide abundant harvestable fry of several indigenous fin and shell fish species, cheap land and low-lying area, making it convenient to easily set-up aquafarms. This paper highlights the invaluable ecological services provided by mangrove habitats of Nigeria and suggests aquaculture and conservation approaches to deltaic, coastal and island mangrove habitats. Presently aquaculture has recorded attractive and growing followership, with wide spread networks of urban and peri-urban fish farms, fish processors and feed producers as well as increasing capitalization and production. This trend has been identified to pose a low but increasing threat to mangroves in Africa, Nigeria inclusive. Intensification and diversification of land-based agriculture to meet sustainable food supply have tended towards exploitation of marginal lands such as mangroves, as exemplified in Asia with negative impacts largely owing to lack of firm policy frame work. In the face of this possibility this paper advocates institutional and community preparedness.
Key Words: agricultural transformation, coastal ecosystem, productivity, ecosystem interrelationships.

Introduction. Aquaculture to a large extent contributes to the growth of national economies and supports the sustainable livelihoods of many communities by improving incomes, providing employment opportunities and increasing the returns on resource use (FAO 2006). Increased production from aquaculture will help combat hunger and malnutrition, which remains one of the most devastating problems facing the majority of the poor in the world. According to WHO (2000) nearly 30% of humanity, including infants, children, adolescent, adults and elderly within the developing countries are currently suffering from one or more of the multiple forms of malnutrition, food insecurity and abject poverty. Apart from providing food for home consumption, aquaculture reduces fish imports, thereby reducing drain in foreign exchange. The current Nigeria Agricultural Transformation Agenda (ATA) seeks to unlock the potential of her agriculture and to move the country from its ignoble status as one of the largest food importers in the world to a food self-sufficient country with expanded exports. This policy is currently being pursued through the rapid value chain approach by treating agriculture as a moneymaking business and not a charitable development project. The agricultural value chain is knowledge-based facilitating improved linkages between highly-motivated producers and service providers to higher-value and export-oriented markets working all the way through the different stages of production/manufacturing. ATA seeks to increase the annual production of fingerlings by 1.25 billion, 400,000 meteric tonnes (MT) of fish feed, additional 250,000 MT of Table Fish and 100,000 MT of value added fish and fisheries products (Federal Ministry of Agriculture and Rural Development 2011).

Subasinghe et al (2009) noted that the key to the development of aquaculture is its intensification in production, diversification in the use of new species and modification of its systems and practices in an integrated eco-friendly manner. Soto et al (2008) further recommend an ecosystem approach for aquaculture to integrate it into the wider ecosystem, such that it is equitable and promotes the sustainability of interlinked social–ecological systems. Therefore, ecological, social and economic issues must be addressed at the farm, the watershed (e.g. containing clusters of aquaculture farms in interaction with other sectors) and the global market levels; which often require articulated policies and agreements. One environment that has hardly been utilized for aquaculture in Nigeria and in need of clear policies is the mangrove, despite its huge potential. World Bank (1998) report on land-use changes in Nigeria indicated that undisturbed forest including rainforests and savanna woodlands which made up 2.9% of the total area of the country in 1976-78 had reduced to 1.3% in 1993-95, with exception of the coastal mangroves and swamp forests, which showed little loss in extent over the course of the study. USAID (2008) identified that harvest as fuelwood and for construction material is the main threat to mangroves presently. It further observed that although mangrove soil is not conducive to agriculture, but “if and when shrimp farming takes off in Nigeria, no doubt these forests also will be under threat of conversion”. This paper therefore highlights key perspectives and issues that favour aquaculture development in the mangroves and the challenges they pose to eco-friendly aquaculture. The perspectives include: resource profile, valuation, culture, presence of tides, coastal habitats, physiographic properties, historical insight and others.

Background. Mangroves serve as a link between marine and terrestrial ecosystems and provide unique for habitat for their respective species. They form a vibrant community of fauna and flora that control the supply and fluxes of nutrients along the marine and terrestrial ecosystems. Mangrove swamps in Nigeria usually feature high rainfall and humid conditions, and stretch along the entire coastline. The largest extent is found in the Niger Delta (Figure 1) between the region of the Benin River in the west and the Calabar, Rio del Rey estuary in the east. A maximum width of 30 to 40 km of mangroves is attained on the flanks of the Niger Delta, which is itself a highly dynamic system. Two large lagoons, Lagos and Lekki, dominate the coastal systems in the west of the country. Both are fringed by mangroves, backed, in turn, by swamp forests. In the far east of the country there is a second major delta/estuary system associated with the Cross River which has a considerable area of mangroves extending in a belt of 7-8 km on both sides of the estuary and up to 26 km in the deltaic zone at the head of the estuary (USAID 2008).

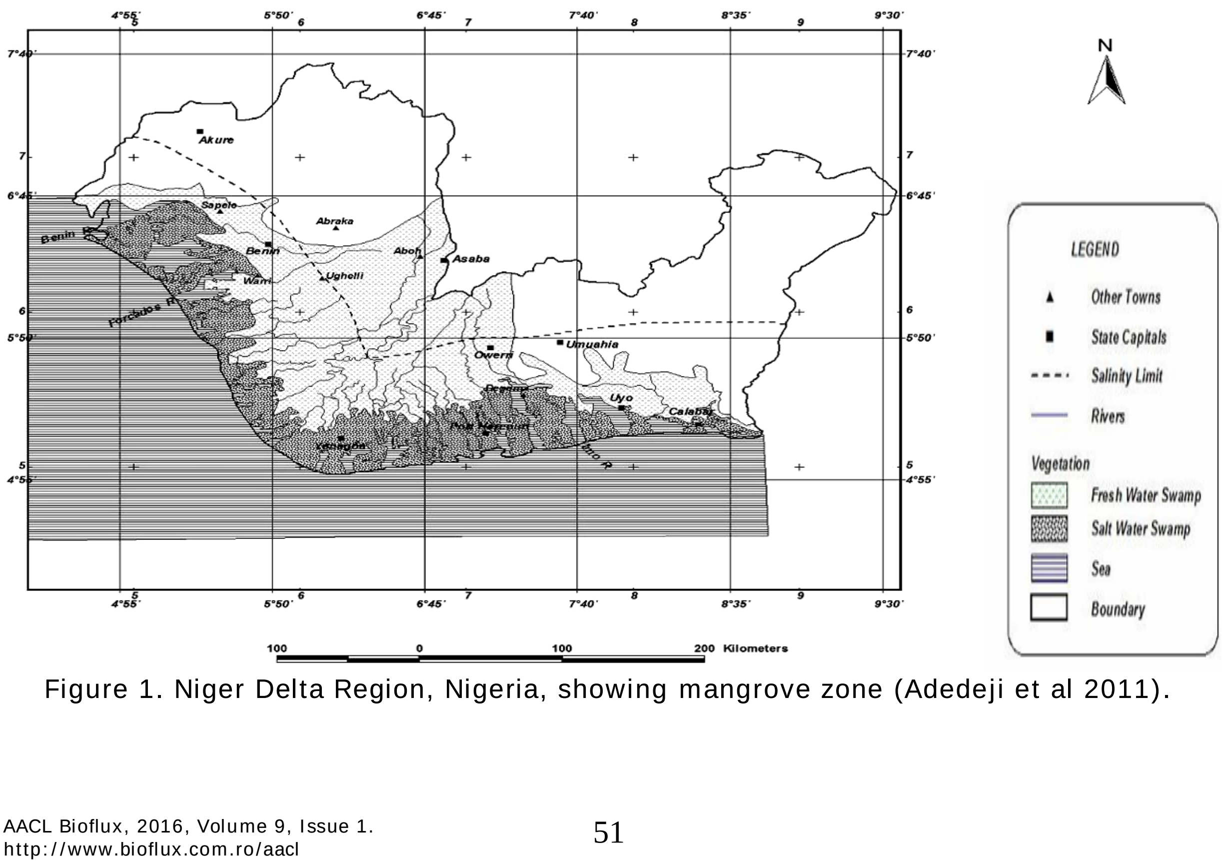


Figure 1. Niger Delta Region, Nigeria, showing mangrove zone (Adedeji et al 2011).

Nigeria's mangrove resource inventory. The mangrove forests (Figure 2) provide many services beyond their intrinsic beauty. Many diverse species inhabit mangrove forests, including fishes, birds, reptiles, amphibians, molluscs, crustaceans and invertebrates. Over 70% of coastal fish catches in Nigeria are directly or indirectly dependent on the mangroves.

The aquatic flora and fauna of the Nigerian mangrove and coastal zone are well represented by numerous plants and animal communities (Adekanmi & Ogundipe 2009). The Biodiversity Country Study (FEPA 1992) estimates that there are 3,423 fungi species in Nigeria, 134 "plankton" species, more than 500 virus species, 55 bacteria, etc. Aside from the fungi, these numbers most likely do not come close to the true situation of biodiversity of these taxa. The flora consists of phytoplanktons and macrophytes.

Figure 2. Mangrove formation along the coast.

The FEPA/World Bank (1998) and USAID (2008) itemize the mangrove fauna in the Coastal Zone of Nigeria to include the following:

- major freshwater phytoplankton are about 91 species predominantly of Bacillarophyceae, Chlorophyceae and Cyanophyceae:
- the phytoplankton assemblage in the brackish waters vary with season; with higher densities and diversities in the dry season,
- dominant groups include diatoms (mostly *Coscinodiscus* spp., *Pleurosigma* spp.), green and blue algae;
- the major zooplankton groups include copepods, calanoids, amphipods, bivalve larvae, brachyuran larvae, rotifers, coelenterates, gastropod larvae and natantia larvae and ostracods;
- dense macrophytic communities occur especially in non-flowing waters:
- in flowing rivers, submerged and free floating macrophytes (particularly, water lettuce (*Pistia sp.*), the hornwort *Ceratophyllum* spp., bladder wort - *Utricularia* spp., and water hyacinth - *Eichornia crassipes, Azolla africana*) are restricted to back waters and support a large variety of insects and worm species,
- typical rooted aquatics include *Nymphaea lotus* and *Vossia cuspidate*;
- the benthic macrofauna consists of important groups such as oysters, brachiostoma, bloody cockle (*Senilia* spp.), molluscs, crustaceans and polychaetes.

The systematic distinction between some mangrove species are unclear and still pose a number of problems in mangrove taxonomy. It is hoped that molecular genetics and DNA sequencing would be useful tools in resolving these problems (Dodd et al 1995; Conti et al 1996; Kathiresan & Bingham 2001). Tomlinson (1986) observed 34 major mangroves species (belonging to 9 genera and 5 families), 20 additional minor species in 11 genera and 11 families making a total of 54 mangrove species in 20 genera and 16 families. Duke (1992), on the other hand, identified 69 mangrove species belonging to 26 genera in 20 families. By reconciling the common inter- and intraspecific genetic and phenotypic variability among mangroves from Tomlinson (1986) and Duke (1992), Kathiresan & Bingham (2001) arrived at 65 mangrove species in 22 genera and 16 families. However, Saenger (2002) suppose that mangroves throughout the world comprise 84 species of plants belonging to 39 genera in 26 families. UNEP (2007) identified only eight true mangrove species within the Atlantic Coast of West Africa and in Nigeria.

The spatial boundary of the mangrove ecosystem in Nigeria is unique because it is shielded from sea water by the sand barrier, unlike in several other African countries where they are directly exposed to sea water. Over sixty percent of the mangrove stands in Nigeria are found in the Niger Delta coastal region (FEPA/World Bank 1998). Another unique feature of mangrove swamps in West Africa is formation of fossils, generated by aridic climatic conditions, heavy soil and water salt content (Marius & Lucas 1991).

The Nigerian mangrove comprise principally three endemic families represented by six plant species dominated by the red mangrove Rhizophoraceae (*Rhizophora racemos*a, *R. harrisonii* and *R. mangle*) in association with white mangroves (Avicenneaceae; *Avicennia africana*) followed by woody species of Combretacea (*Lagancularia racemosa* and *Conocarpus erectus*). The typical zonation sequence basically reflects the adaptation of the various species to saline conditions. It has *R. racemosa* in front as the pioneer species at the outer edge of the alluvial salt swamp. It is the most abundant covering over 90% of the mangrove forests, forming a dense growth throughout the region and can grow to a height of 45 m and dbh > 90 cm at maturity under favourable conditions on soft mud. It is commonly followed in the middle zone by *R. harrisonii* which attains heights of 5-10 m, with *R. mangle* on the inner edge - grows to less than 5 m. *R. mangle* are resistant to high salinity and occupy the harder parts of the fibrous peaty clays of the mangal soil, as the land gets drier and salinity deceases. *Avicennia Africana,* a smaller tree than *Rhizophora* spp., grows singly on firm land. *L. racemosa, C. erectus* and other woody species that grow at the edge of the swamps may be associated with the main species, mainly near the sea (Abere & Ekeke 2011). *Avicennia germinans* is sparsely represented. In the estuaries the mangrove species composition may be different and Nypa palm (*Nypa fruticans*), an introduced species, becomes more abundant (USAID 2008).

Besides mangroves, the other common vegetation in areas where salt water content is not too high include ferns, *Acrostichum aureum*, *N. fruticans*, and herbs, *Paspalum vaginatum.* A major feature in the mangrove swamp in the eastern flank of the Niger Delta is the conspicuous presence of *N. fruticans*, an exotic species which has out-competed native mangroves over very large areas.

Ecological group classification shows that *A. africana* and *N. fruticans* occur almost exclusively in mangrove soils with very high calcium values of 20.8 and 17.6 meq per 100 g, respectively, with overlapping range of occurrences for most mangrove species with varying ecological optima along the salinity gradient (Ukpong 2001).

Tidal waters bringing nutrients along with other essential minerals to the on-shore region where they become available to mangroves (Mandal & Naskar 2008), high annual rainfall of 200-300 cm, atmospheric humidity of 60-90%, and moderate temperatures of 19-35°C (Naskar & Mandal 1999), as well as continuous upstream freshwater supply which usually carry silt, sediments and organic matter (Mandal 1996), all play major roles in the regeneration, growth and productivity of mangroves. Adequate fresh water supply enables mangroves to continue their physiological process until they develop salt secretary organs, such as salt glands, corkwart, gall, and other related mechanisms (Naskar et al 1997; Naskar & Mandal 1999).

Mangroves are valuable and important. The mangrove forests in West Africa belong to the Atlantic type and exhibit features of an immature ecosystem such as low species diversity and high productivity (Marius & Lucas 1991). The ecosystem is considered pioneer because aluminum and organic matter caught by mangrove roots in addition to biomass created by the trees, develop their own medium and literally extend land into the lagoons, creeks, and rivers (Ashton-Jones 1998). The excess organic production of the ecosystem is exploited by many marine species especially fishes and crustaceans that enter the mangrove environment as juveniles and return to the sea as adults for reproductive purposes, thereby exposing them to the risks of pollution and destruction of the mangrove ecosystem by man (John & Lawson 1990).

Values and importance of mangroves are numerous and may be described as ecosystem services, i.e., benefits that people derive from nature; which are tangible such as crops, fish, and freshwater (provisioning services); or less tangible such as pollination, erosion regulation, climate regulation (regulating services) and aesthetic and spiritual fulfillment - cultural services (Barbier 1994). Debenay et al (2002) observed that both canopy and litter of the mangrove forest protect the sediment from heating, drying and increases in salinity due to sun and wind. Macintosh & Ashton (2002) lists the peculiar attributes of mangrove forests to include biological diversity, socio-economic value, cultural value, historic value, aesthetic value, wilderness value and educational value. Mangrove forests also provide several goods and services in the coastal ecosystem including:

Goods:

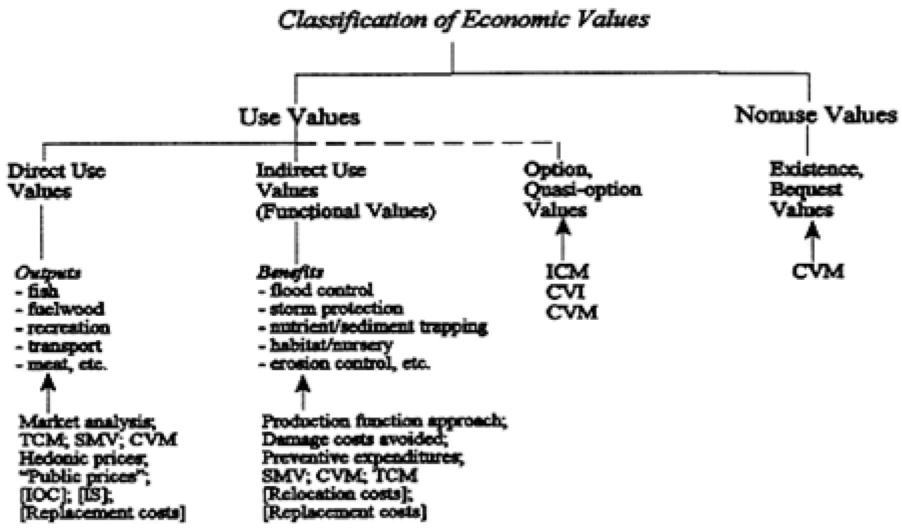
- forest products - timber, firewood, tannin, and honey. The red mangrove *R. racemosa* is the most exploited species and is used for poles and timber;
- fuelwood - due to its high thermal capacity, the mangrove, particularly, the red mangrove *R. racemosa* is widely used as fuel/charcoal for firing small scale industrial boilers;
- stakes – the riverine communities utilize mangrove trees as stakes for smoking, drying and holding fish for sale;
- fodder;
- food;
- non-timber products (e.g. medicines);
- fish and shellfish;
- fishmeal (animal feed);
- seaweeds (for food and industrial use);
- salt - the numerous roots as well as stumps are used locally for the preparation of salt;
- drinking and irrigation water;
- genetic resources (Macintosh & Ashton 2002; Debenay et al 2002).

Services:

- provide human and wildlife habitat - the tilt roots provide diversified wildlife habitat (including marine and terrestrial habitats such as core forests, litter forest floors, mudflats, adjacent coral reefs and seagrass ecosystems as well as the contiguous water bodies - rivers, bays, inter tidal creeks, channels and backwaters);
- productivity - mangroves are among the richest and most productive ecosystems with capacity for high rate of primary productivity (~ 24 tons ha^{-1} $year^{-1}$). The leaf fall from mangrove trees also contribute substantially to formation of detritus which supports coastal fisheries. Standing crop in the mangrove forest is greater than any other aquatic systems in the world;
- shore line protection and moderating storm impacts from wave energy, acting as a “live sea wall” more effective than concrete wall structures to keep away the seawater;
- nursery ground - mangroves provide breeding and nursery grounds for many commercially important species of fish and shell fish. This is recognized worldwide as significant to the fishing industry;
- maintain biodiversity;
- sediment trap - thereby assisting in the accretion of coastal sediments and further, adding to the protection of the low-lying inland areas;
- they dilute and treat wastes - receives municipal sewage mixed with brackishwater from the river loaded with heavy metals/pollutants;

- provide harbours and transportation routes;
- provide employment;
- contribute aesthetic beauty and provide recreation;
- remove air pollutants, emit oxygen;
- sequester atmospheric Carbon - mangroves have a capability of fixing an estimated 17 metric tonnes of carbon ha^{-1} year^{-1} and accumulating atmospheric CO_2 (0.055 g C cm^{-2} soil);
- cycle nutrients - as accumulation site of sediment, carbon, nutrients and pollutants, they also play a central role in biogeochemical cycles in the coastal environment;
- generate soil;
- maintain array of watershed functions (infiltration, purification, flow control, soil stabilization);
- eco-tourism, education and recreation sites – endowed with arching roots, breathing roots, salt-vomiting leaves, mud-dancing fishes, and breath-taking beauty intact stands of mangroves offer many opportunities for bird watching trips to observe rufous crab, hawk, and other uncommon birds of the coast, as well as educational purposes.

Figure 3 and Table 1 illustrate approaches to the valuation of ecosystem services of mangroves. Padilla & Janssen (1996) applied benefit-cost analysis in the valuation of a mangrove reserve area and favoured semi-intensive mangrove aquaculture, while considering mangrove conservation alone as an unviable option.



Notes:
ICM = individual choice models
CVI = conditional value of information models
CVM = contingent valuation method (including contingent behaviour/ranking methods)
TCM = travel cost method
SMV = surrogate market valuation (household production function models)
IOC = indirect opportunity cost approach
IS = indirect substitute approach
[ ] = valuation methodology to be used with care

Figure 3. Values and ecosystem services of mangroves (Barbier 1994).

Table 1

Valuation of mangroves ecosystem services

Economic valuation of mangroves	*Ecosystem diversity: structure, processes and functions*	*Environmental functions*
Economic value	*Ecosystem diversity*	*Regulation functions*
The value of a good or service placed by an individual or society through his willingness to pay using market price or other indicators	The variety of habitats, biotic communities and ecological processes in terrestrial, marine and other aquatic environments in a particular area, together with the processes and interactions that take place within and between these systems	Protection against harmful cosmic influences; local and global energy balance; chemical composition of the atmosphere; chemical composition of the oceans; local and global climate; run-off and flood prevention; water catchment and groundwater recharge; prevention of soil erosion, sediment control; topsoil formation, maintenance of fertility; solar energy fixation, biomass production; storage /recycling of nutrients; storage/recycling of wastes; biological control mechanisms; migration and nursery habitats; biological (and genetic) diversity
Economic valuation	*Ecosystem functions*	*Production functions*
Measuring the preferences of people or society for a good or service or against economic activity	The biophysical processes of production and dynamics of resources (organic matter, nutrients, biomass, elements) and energy that take place through ecosystems. The level of function depends on the capacity of the ecosystem (onsite features) and certain aspects of its landscape context (e.g., connectedness to other natural/ human features, accessibility to birds, fish)	Oxygen; water (drinking, irrigation); food; genetic resources; medicinal resources; raw materials for construction; fuel and energy; biochemical; fodder and fertilizer; ornamental resources
Valuation		*Carrier functions*
The process of placing monetary value on goods and services that do not have accepted prices. Many environmental gods and services (such as biodiversity) do not enter the market and therefore have no commonly accepted market price		Providing space and a suitable substrate: human habitation (indigenous settlements); cultivation (fish, crops, cattle); energy conversion; recreation and tourism; nature protection
Direct use value		*Information functions*
The productive or consumptive values derived from direct use or interaction with a biological resource which may be marketed or non-marketed		Aesthetic information; spiritual and religious information; historic information (heritage value); cultural and artistic inspiration; scientific and educational information
Indirect use value		
The value of an environment's ecological functions which support or protect the life forms dependent on that environment, or an economic activity		
Option value		
The potential value of a resource for future (direct and indirect) use by protecting or preserving it today		
Existence value		
The benefit an individual or society receives from merely knowing that a good or service exists. Society's willingness to pay towards the conservation of biological resources for their own sake regardless of their current or optional uses		
Total economic value (TEV)		
Comprises direct use value, indirect use value, option value and existence value		
Modified after Macintosh & Ashton (2002)		Source: Costanza et al (1997)

Twumasi & Merem (2006) using geographical information system (GIS) outlined priority areas for conservation in the Niger Delta region including birdlife, primates and some mammals (such as elephants) sanctuaries and protected areas; other designated priority areas include the shoreline beaches and barrier islands and mangrove/tidal flats. Figure 4 identifies five major causal factors (Drivers, Pressures, State, Impacts and Response - DPSIR) affecting utilization of mangrove resources. In the case of Nigeria, the Drivers are oil and gas exploration and exploitation including gas flaring in the mangrove ecosystem – the oil industry resides largely in the mangrove ecosystem; and rapid urbanization through reclamation of mangrove forests for residential building and for urban development. The Pressures on mangrove forests are mounted by indiscriminate dredging activities and laying of oil pipelines and fragmentation of mangroves as well as continual dumping of dredged materials destroying mangrove vegetation; equally devastating is mangrove logs/wood extraction (fuel economy), extraction of crabs, shrimps, periwinkles, roofing materials, salt and medicines, etc. by rural communities and the luxuriant growth of the exotic *N. fruticans* at the expense of local mangrove species. Currently little is known of the state and valuation of Nigeria's mangroves and its impacts on the people. Worse of all is the lack of institutional and community response to mangrove exploitation, which in most localities is taken for granted with absence of clear property rights and management strategies. There is no clear statement on mangroves in the Nigeria's Forest or Fisheries policies, despite its contribution to the gross domestic product, GDP, through fish and timber production.

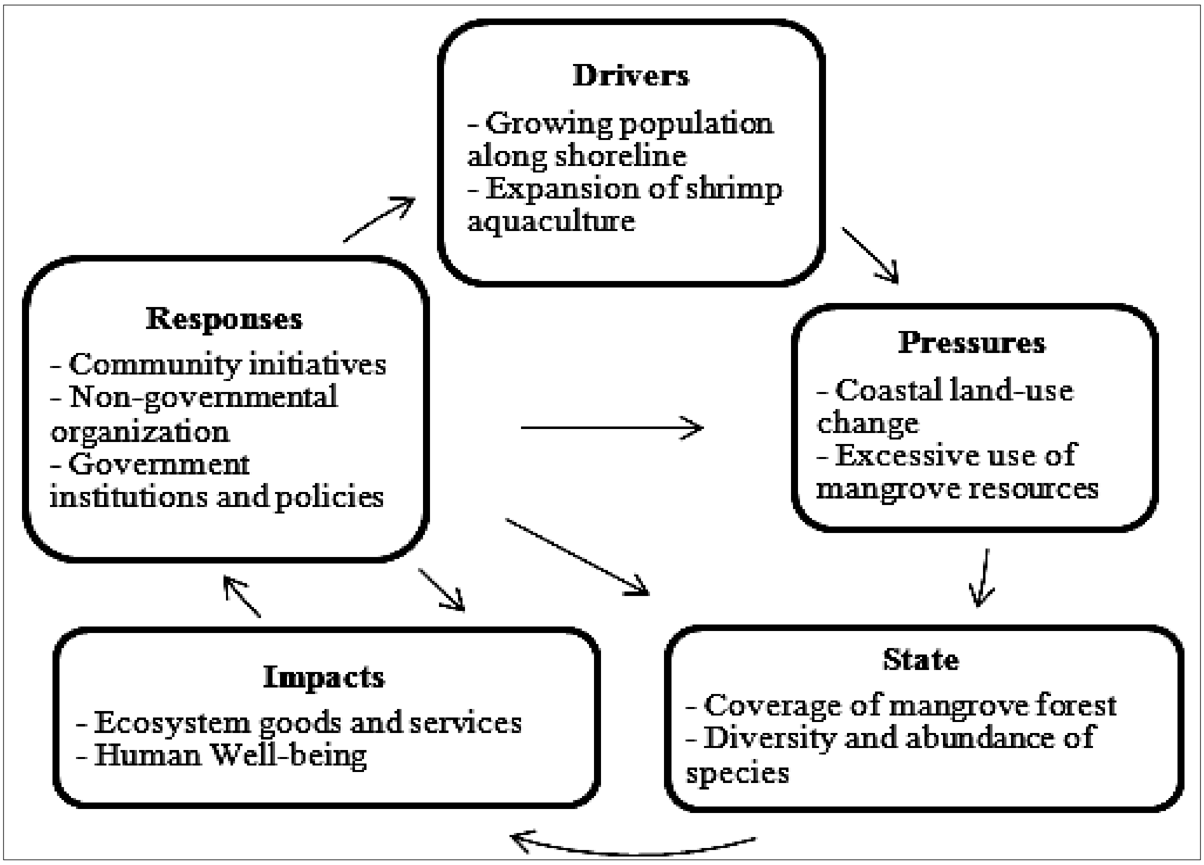


Figure 4. Cause-effect analysis using DPSIR framework in the context of mangrove resources.

Mangrove as suitable environment for aquaculture development. Scott (1966) noted that Nigeria's mangrove swamps possess qualities, such as saline conditions, brackish water, abundant fry, cheap land and low-lying area, which make them suitable for brackish water aquaculture systems, in which water exchange is accomplished by tidal currents. These potentials put mangroves at risk of destruction or conversion to fish/shrimp farms. This paper however, recommends integrated silvofishery models which are environmentally sustainable as opposed to direct conversion of pristine mangrove to aquaculture.

Globally, a major fraction of natural mangrove forests in the coastal zones of most tropical or subtropical countries, are utilized for aquaculture (Hamilton & Snedaker 1984). Countries like Indonesia, Thailand, Philippines, Ecuador, Panama, Brazil, Bangladesh, India and Malaysia are noted to have converted mangrove to ponds, though with attendant environmental challenges

Increased rate of mangrove exploitation has greatly led to serious degradation and loss of the mangroves with about 90% of the global mangroves sited in developing countries nearing extinction in 26 countries. Most of these countries incidentally have high mean population densities and low values of per capita gross national product, GNP (Hamilton & Snedaker 1984). Nigeria has the fourth largest area of mangrove in the world (the largest in Africa) covering an estimated area of 997,700 ha or 9,723 km^2 (Tables 2 and 3) and forming a vegetative band of 15-45 km wide above the barrier islands and running parallel to the coastline. About 305 km^2 (3.13%) of Nigeria's mangrove forest are in reserves (Tables 2 and 3). Unlike the Asian countries mentioned earlier, except for oil exploration, Nigeria's mangrove remain largely unexploited mainly because of a lack of legal framework, and its difficult terrain: comprising a maze of creeks and shallow estuaries interspersed with swamps and sandy ridges reminiscent of vast netting spread out on a flat ground (Alagoa 1985).

Table 2

Distribution of mangrove forest in the Nigerian coastal area (FEPA 1992)

State	*Area of mangrove (Km^2)*	*Mangrove in Forest Reserve (Km^2)*	*%Reserved*
Lagos	42.20	3.13	7.42
Ogun	12.18	-	0.00
Ondo	40.62	-	0.00
Edo/Delta	3,470.32	143.75	4.14
Rivers/Bayelsa	5,435.96	90.62	1.67
Cross River/Akwa Ibom	721.86	67.19	9.31
Total	9,723.14	304.69	3.13

Padilla & Janssen (1996) recommend semi-intensive mangrove aquaculture, while Bagarinao & Primavera (2005) supposes that mangroves are not the best sites for modern aquaculture for three main reasons:

- new technologies require deeper ponds and more excavation;
- once excavated and exposed, soil with high iron sulfide content becomes acidic;
- at high stocking density and high feeding rate, higher water exchange rate is required, and cannot be provided by tidal action.

However, Siahainenia et al (2012) reported differently that disturbance of mangrove through aquaculture:

- promotes strong and sturdy root development and structural complexity (as a self defense system);
- does not disturb the nursery function of mangroves for juvenile fish and shrimp communities;
- does not indicate distinct possible variations between changes in discharge and in area;
- does not impact catch rates (e.g., of shrimp and fish); since catch rates are dependent on characteristics of receiving habitat (such as area and perimeter) than on mangrove change.

Table 3

Estimated areas of major lagoons, estuaries and lower river sectors that are fringed by mangrove (Ssentongo et al 1986)

Brackish water system	*State*	*Brackish water area (km^2)*		*Brackish water system*	*State*	*Brackish water area (km^2)*	
		Based on federal survey maps	*Based on radar mosaics*			*Based on Federal survey maps*	*Based on radar mosaics*
Epe Lagoon	Lagos	460	-	Sangana River	Rivers	37	-
Lagos Lagoon	Lagos	460	-	Nun River	Rivers	67	52
Lekki Lagoon	Lagos	-	-	Brass River	Rivers	94	91
Ogun Lagoon	Ogun	26	-	St. Nicholas River	Rivers	44	21
Benin River	Edo	150	109	San Barbara River	Rivers	49	48
Escravos River	Delta	150	160	San Bartholomeo River	Rivers	84	81
Forcados River	Delta	120	201	Sombreiro River	Rivers	117	132
Ramos River	Rivers	50	46	New Calabar River	Rivers	92	163
Dodo River	Rivers	-	-	Andoni River	Rivers	160	117
Pennington River	Rivers	21	17	Imo River	Rivers	-	51
Kulama River	Rivers	10	12	Kwa Ibo River	Akwa Ibom	-	7
Fishtown River	Rivers	5	5	Cross River	Cross River	50	510

World Bank et al (2005) also noted that aquaculture poses a low but increasing threat to mangroves in Africa (Table 4). For this threat level to remain low proper policy formulation and adaptable and nondestructive technologies/approaches that meet global best practices must be promoted and utilized.

Table 4

Scale of the threats to mangroves in tropical Asia and Africa

Threat	*South and Southeast Asia*	*Africa Central and South*
Natural disasters	Low-High / Increasing	Medium / Increasing
Population pressure	High / Increasing	High / Increasing
Overexploitation by traditional users	High / Increasing	Medium / Increasing
Forestry	High / Stable	Medium / Increasing
Agriculture	High / Decreasing	High / Increasing
Aquaculture	High / Increasing	Low / Increasing
Salt production	High / Decreasing	High / Stable
Urban and industrial development	High / Increasing	Low / Increasing
Tourism	Low-Medium / Increasing	Low / Increasing
Hydrological diversions, e.g. dams	Medium-High / Increasing	Localized medium-high Increasing
Coastal pollution	Medium-High / Increasing	Medium-High / Increasing
Mining	Low-Medium / Decreasing	Medium / Increasing
Management shortcomings	Medium-High / Decreasing	Medium-High / Stable

Source: Bagarinao & Primavera (2005), World Bank et al (2005).

Mangrove areas experience tides – a pre-condition for siting aquaculture facilities in mangroves. A common feature of the mangrove ecosystems is the presence of tides and associated extensive lagoons. Tides are one of the major factors that determine the occurrence of mangroves. Mangrove vegetation usually occur between MSL (Mean Sea Level) and HATL (Highest Astronomical Tide Level) with the major mangrove zone lying between the MSL and MHWSTL (Mean High Water Spring Tide Level), and minor mangroves zone - between MHWSTL and HALT (Lear & Turner 1977).

The tides offshore Nigeria generally approach from the south west and are of the semi-diurnal type with two inequalities. Tidal amplitude along the coast increases from west to east; varying from 1.1 meter within Lagos area to 1.5 meters at the Forcados area through to 2 m at the Opobo River and 3 m at the Cross River estuary (Ibe 1988). The tides generate strong currents of between 0.4 and 1.8 m s^{-1} in the tidal inlets while maximum velocity of between 0.3 and 1.5 m s^{-1} is attained at mouth bar during the ebb tides. The flood tides which are of shorter duration have lower velocities of between 0.3 and 1.5 m s^{-1} (Ibe 1988). Tidal parameters at important river entrances and coastal areas are presented in Table 5. The presence of these tides is pre-conditions for siting aquaculture facilities in mangroves.

Table 5

Tidal information at important coastal locations in Nigeria

Stations	*Mean HWS*[a]	*Mean HWN*[b]	*Mean LWS*[c]	*Mean LWN*[d]	*Mean MSL*[e]
Lagos Bar	0.945	0.701	0.091	0.213	0.457
Escravos River	1.616	1.281	0.303	0.640	0.975
Forcados River	1.402	1.128	0.152	0.427	0.823
Warri River	1.402	1.373	0.366	0.462	1.036
Port Harcourt	2.530	2.134	0.183	0.732	1.463
Bonny Bar	2.347	1.890	0.488	1.006	1.433
Calabar	3.048	2.652	0.488	1.036	1.951
Riol Dey Rey entrance	2.439	1.920	0.152	0.762	1.402

HWS[a] - High water spring; HWN[b] - High water neap; LWS[c] - Low water spring; LWN[d] - Low water neap; MSL[e] - Mean sea level (Sources: Ibe 1988; FEPA 1997).

Mangroves provide suitable habitats for aquaculture. The mangrove habitats/coastal zone of Nigeria have been classified by different researchers (Figure 5). Scott (1966) divided it into four major sections as: (i) the fresh water zone (rivers, shallow lakes, and swamps), (ii) the brackish water zone (coastal rivers, creeks, and mangrove swamps), (iii) the coastal zone (beach ridges and estuaries) and (iv) the offshore zone (coastal waters of the sea). Ezenwa et al (1990) also classified it into four major sections (i) marine flood plain (above 30 ‰); (ii) high brackish water flood plain (10-29.9 ‰); (iii) low brackish water zone (1.0-9 ‰) and (iv) fresh water areas (less than 1 ‰).

Ibe (1988) also classified the coastal habitat of Nigeria into four broad regions based on differences in general morphology, vegetation and beach type. The regions from West to East are:

- (i) Barrier-lagoon complex (200 km along the Nigeria/Benin Republic border);

- (ii) Mahin transresssive mud coast (75 km from the of Badagry, Lagos and Lekki beach mud up to the mouth of Benin River on the northwestern flank of the Niger Delta);

- (iii) Niger Delta coast (stretching from the Benin River estuary for about 500 km eastward and terminates at the mouth of the Imo River estuary; a total of 21 estuaries open and discharge into the sea through the Delta). Allen (1965) further subdivided the Niger Delta into four major ecological zones as the barrier island complexes comprising a series of 20 beach islands; the vegetated tidal flats comprising mangrove swamps; the lower flood plain, relatively flat covered by thick vegetation and the upper flood plain, braided with deposits of coarse sand;

- (iv) the Strand coast (extends about 85 km east of the Niger Delta from Imo River estuary to the Cross-River estuary).

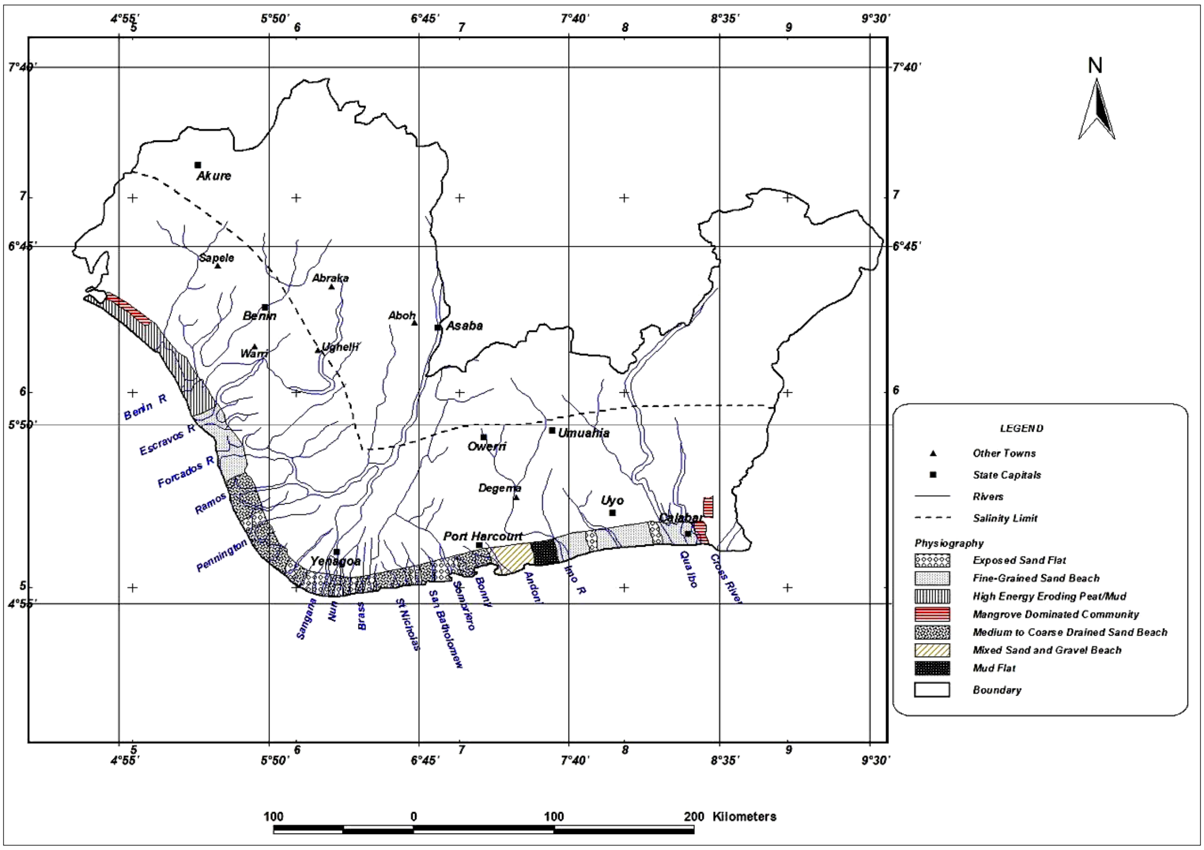


Figure 5. Coastal habitats in Nigeria (Ogba & Utang 2010).

An integrative classification (Mandal & Naskar 2008) results in three habitats:

(a) Deltaic mangrove habitat: funnel shaped and fed by numerous tidal creeks; characterized by high tidal range with associated strong bi-directional tidal currents which are responsible for the dispersion of sediments brought to the coasts by rivers and the main river channels. It includes the major estuaries of Niger Delta coast. A maximum width of 30 to 40 km of mangroves is attained on the flanks of the Niger Delta. A major delta/estuary system is associated with the Cross River which has a considerable area of mangroves extending in a belt of 7-8 km on both sides of the estuary and up to 26 km in the deltaic zone at the head of the estuary (FAO, UNEP 1981). The mangrove here is highly impacted and disturbed by oil production/exploration activities, illegal dumping, deforestation, urbanization and over harvesting of mangrove resources. It is ideal for community-based mangrove restoration, eco-tourism, environmental social impact assessment (E.S.I.A) and semi-intensive silvofisheries;

(b) Coastal mangrove habitat: characterized by low tidal range with river discharge of fresh water and sediments leading to rapid deposition of terrigenous sands, silts and clays to form deltas. These deltas build seawards over flat offshore slopes composed of fine-grained pro-delta sediments. It includes the inter-tidal coastlines, minor river mouths, sheltered bays and backwater areas of the Mahin Transressive mud coast on the northwestern flank of the Niger Delta and the two large lagoons, Lagos and Lekki, fringed by mangroves, backed, in turn, by swamp forests, which dominate the coastal systems in the west of Nigeria. These are ideal for recreational, cultural, research, and educational purposes and establishment of national parks;

(c) Island mangrove habitat: commonly found at the mouths where rivers are seen to border the open sea. These are ideal for conservation purposes.

Mangroves provide physiographic properties (soil and water quality) suitable for aquaculture. The average soil physiography (Table 6), water parameters (Table 7), and land topography of the mangrove are suitable for brackish water culture (Ezenwa et al 1990) and are closely influenced by the tidal cycle. Spatial distribution of acid sulphate soils however, still remain a challenge (Udoh et al 2007).

Table 6

Ranges of water parameters within the mangrove and coastal flood plains of Nigeria

Zones	*Oxygen (ppm)*	*Salinity (‰)*	*pH*	*Temperature (^oC)*	*Turbidity (cm)*	*Remarks*
Barrier-lagoon complex	3.5-5.0	0-31.5	6.8-7.5	28-31.5	43.5-65.0	Influx of fresh water from rivers and streams upland mix with oceanic waters creates varying salinity levels.
Transgressive mud coast	3.0-5.5	2.5-30.5	6.5-7.0	26.0-30.5	15.0-85.2	Flat shores and more of brackish and marine waters. Less of influx of fresh water from upland.
Niger Delta	2.5-6.0	0.0-25.5	6.0-7.2	26.5-29.0	9.0-85.1	Consists of 8 major coastal rivers. Influx of fresh water and ocean waters create varying salinity levels. Three major zones – fresh, brackish and marine.
Strand Coast	4.0-5.5	0.5-30.5	7.0-7.5	27.0-29.5	25.4-61.5	Four major coastal rivers. High level of mixture of marine and fresh water in the estuaries, creeks and mangrove swamps.

Source: Ezenwa et al (1990).

Table 7

Ranges of soil data of the mangrove and coastal flood plains of Nigeria

Zones	*Soil pH*	*% Sand*	*% Silt*	*% Clay*	*% OM*	*Remarks*
Barrier-lagoon complex	6.5-7.0	50-80	10-19.5	1.9-10.5	1.0-4.5	The presence of high quality of coarse and medium sand act as filtration bed for nursery grounds.
Transgressive mud coast	6.0-6.8	40-75	12-25	0-6.5	5.5-15.0	Very muddy and consist of fine sand, coarse silt. Existence of marine canyons confirmed and act as shelter for juvenile stages.
Niger Delta	5.8-7.0	28-95	4.5-12.0	1.1-5.5	3.5–15.5	High quality of fine sand, medium silt, coarse silt, mangrove swamps and vegetation; organic peaty top soil (1m) followed by organic rich clay (1-2m) and below is pure clay.
Strand Coast	6.5-7.5	70-86.2	13.5-32.0	1.10-5.5	0.4–2.5	Very high percentage of fine sand; silt and clay are also available as in Niger Delta areas.
Brackish water pond (Udoh et al 2007)	4.5–4.7	69.90-79.71	6.70-7.8	19.9–22.9	4.5–11.5	The soils are essentially loose, acidic and medium textured sandy clay loam and low in fertility.

Modified after Ezenwa et al (1990), OM = organic matter.

Aquaculture development in mangrove swamps in Nigeria. Aquaculture in the Nigerian mangrove is a recent development. It is carried out mainly in small tidal ponds constructed on mangrove swamps; and at rudimentary level in cage or pen culture, "acadja" or "brush-park" (Anyanwu et al 2007; Blow & Leonard 2007). It is generally hindered by the acidic nature and soil characteristics of the mangrove swamps rendering the area unproductive for aquaculture, resulting in low fish yields and mass mortality (Dublin-Green 1987).

Culturable species in mangrove swamps in Nigeria. At least 51.7 million seeds of fin and shell fish species are harvestable from the brackish water mangrove and coastal zones of Nigeria, each with its own indigenous, characteristic culturable fish species, which are well known and exploited by the local fishers (Ezenwa et al 1990). Euryhaline species such as *Liza (Mugil) falcipinnis,* (mullets), *Tarpon atlanticus* (tarpon) and cichlids are aided in their movement from marine to brackish water and fresh water zone by the influence of tidal waves. Floating fertilized eggs, larvae, fry and fingerlings of *T. atlanticus* are washed ashore during high tide into flat, muddy coastal flood plain of Ondo State, southwest Nigeria. Local fishers collect the seeds in man-made burrow pits when the tide precedes. The same tidal waves sweep juveniles of shrimp, mullets and tilapia, into the flat mangrove swamps of estuaries, creeks, lagoons and major coastal rivers and their tributaries. Culture system is extensive to semi-intensive with polyculture of *Tilapia* sp. in combination with *Mugil* sp., *Liza* sp., *Clarias gariepinus, Heterobranchus* sp., *Tarpon* sp., and *Lutjanus* sp. Fish production ranges from 0.8-2 t ha^{-1} $year^{-1}$ in extensive system to 2.5-4.5 t ha^{-1} $year^{-1}$ in well managed semi-intensive culture system (Ezenwa et al 1990). Other important marine and brackish water fishes cultivable within Nigeria's mangrove include Sea catfish (Ariidae) *Arius gambiensis, A. latiscutatus, A. gigas, A. heudeloti*; Toad fish (Batrachoididae), *Batrachoides liberiensis;* Jack fish and moonfish (Carangidae) - *Alectis alexandrina, Caranx crysos, C. hippos, C. senegallus, Trachurus trachurus, Chloroscombrus chrysurus* and *Decapterus punctatus;* West African Lady fish *Elops lacerta* (Elopidae); African red/brown snapper *Lutjanus agennes, L. dentatus, L. goreensis* (Lutjanidae); Croaker fish (Sciaenidae) - *Pentheroscion mbizi, Pseudotolithus brachygnatus, P. elongatus, P. epipercus, P. senegalensis, P. typhus* and *Pteroscion peli;* Tuna and tuna-like fishes (Scombridae) - *Auxis thazard, Euthynnus alleteratus, Katsuwonus pelamis, Sarda sarda, Thunnus alalunga, T. albacares* and *T. obesus* (FEPA 1992).

Historical insights from mangrove aquaculture in Asia. Much of aquaculture in Asia arose from conversion of mangrove swamps into shrimp farms, with attractive short-term dividends and negative impacts. This failure could be traced to the lack of a firm policy frame work by Asian governments before the brisk and unrestricted exploitation of the mangrove resources by aquaculture entrepreneurs. The factors that contributed to the development and collapse of brackish water (shrimp) farming in Asia and problems militating against sustainable aquaculture and fish production in the mangroves include intensification and overcapitalization of mangrove farming, involvement of multinational companies, lack of property rights, over-exploitation by traditional users and management failure, particularly, the existence of conflicting, ambiguous and inconsistent mangrove utilization and conservation policies (Quarto 1992; Primavera 1998; Huitric et al 2002). They are listed as:

- loss of about 768000 km^2 of traditional fishing grounds in Thailand following the establishment of Exclusive Economic Zones in the 1970s negatively impacted its fishing industry (Ruyabhorn & Phantumvanit 1988);
- the rise of OPEC oil prices further aggravated conditions of the fishers due to increased fuel prices (Primavera 1998; Huitric et al 2002);
- a steady price and a large demand for shrimp from Japan, US and Western Europe created alternative employment and prompted the Thai Department of Fisheries to promote semi-intensive marine shrimp farming as early as 1973 through the establishment of hatcheries and rearing shrimp larvae for stocking as opposed to stocking larvae from tidal waters (Flaherty & Karnjanakesorn 1995);
- development of improved technology in the mid-1980s in Taiwan encouraged the intensification of shrimp farming, with very high stocking densities of hatchery-raised shrimp, the use of processed feed, frequent water flushing, and the mechanisation of the farm (aerators, water pumps, lighting, etc.) (Huitric et al 2002);

- expansion and widespread adoption of intensive shrimp farming from 1987-1991 (as opposed to extensive system), and by 1994, 80% of the shrimp farms in Thailand were intensive (Primavera 1998);

- production was monoculture, monospecific and dominated by *Penaeus monodon* (90%), with *P. merguiensis* and *P. indicus*, around 5% each (Rosenberry 1998);

- the Taiwan shrimp farming industry collapsed in 1987 as a result of disease, reduced resistance from over-use of antibiotics, over-stocking, incorrectly processed food and the over-exploitation of groundwater (Kautsky et al 2000). The vacuum created was quickly filled by Thailand shrimp which peaked in 1991, accounting for 30% of the global cultured shrimp production and for 45% of tiger prawn production globally (FAO 2000). Thus the cycle of expansion, increased farm size and input continued till the fishery collapsed also;

- rice farmers took advantage of the boom to practice polyculture of rice-shrimp. Their earnings increased up to 60-fold by converting their rice fields to ponds (Lavallee 1995; Flaherty & Karnjanakesorn 1995);

- farm owners tended to be relatively wealthy and usually hiring farmers as well as a few farm hands to manage the ponds (Quarto 1992);

- the intensification of shrimp farming increased production and investment costs, transforming the industry from labour-intensive to capital-intensive. Analysis of nutrient budgets of intensive shrimp ponds by Briggs & Fvnge-Smith (1994) revealed that 92% of nitrogen is supplied by feeds while harvested shrimp account for 21% nitrogen, 31% in sediments, 22% in effluent water and 13% drained during harvest. Phosphorus (51% from feeds, 21% from fertilizer and 26% from old pond sediment) is transformed less efficiently-84% in sediments, 10% lost during regular exchange and harvest, and only 6% becomes shrimp biomass. The pollution potential of shrimp pond effluents is aggravated by the large volumes of water discharged from intensive farms compounded by the high concentration of farm units in areas with limited water supplies and inadequate flushing;

- local communities that often do not have legal titles to land were easily displaced when shrimp farms move into an area (Bailey 1988; Quarto 1992). Indirect displacement also occurred as a result of environmental degradation of mangrove ecosystems beyond shrimp farms due to farm effluents, and the effects of segmentation and drying out of mangroves. Thus reducing the local flow of ecosystem goods and services available to local appropriators;

- large multinational companies with several scattered branches were involved in the market as shrimp feed producers, shrimp processors and exporters as well as producers/marketers of pharmaceuticals (Quarto 1992);

- two different departments in the Ministry of Agriculture and Co-operatives regulated shrimp farming. The Department of Fisheries promoted and regulated shrimp farming while the Royal Forestry Department regulated mangrove forests;

- the mangroves provided good conditions for shrimp farming, such as brackish water, abundant fry, cheap land and low-lying area, making it convenient to easily set-up shrimp farms while exploiting the mangrove (Kongkeo 1995). This encouraged its full exploitation;

- inconsistency in what is defined as 'mangrove'. Some policies devalued mangroves and classified them as "waste and unproductive land" (Huitric et al 2002).

Several authors have identified the major causes of mangrove degradation and loss to include:

- over-exploitation by traditional users: generally traditional use of mangroves had been at a low levels usually with little impact. However, over the years as populations grow, demand for products increase, leading to over-harvesting and a decline in the natural resource. In the absence of sustainable management practices this could lead to the decline in livelihoods of the mangrove-dependent communities. In many instances though, the reason for over-exploitation may be due to some other external pressure, for example drought, storms, and war such as in Vietnam (Bagarinao & Primavera 2005; Hai et al 2007);

- commercial utilization: mangrove wood (especially *Rhizophora* spp.) is good for charcoal production because it is heavy, dense, hard and with a high calorific value. Mangrove wood is also resistant to decay in saltwater, so it has been a favoured material for pilings and fishing structures in coastal areas. In several countries commercial forestry projects have used rotational felling and replanting of mangroves;

- conversion to other natural resources use: increasing populations put pressure on the production for food. Large tracts of coastal mangrove in Asia have been converted to rice farming (agriculture), salt pans for salt production, and to the construction of aquaculture ponds (Huitric et al 2002);

- conversion for other uses: increasing populations also put pressure for urban and industrial development of mangroves, including coastal infrastructure such as ports, harbours, airports, roads, sea walls, dikes, and tourist facilities; dredging and flood;

- protection, coastal mining and oil pollution activities: many of the cities in Asia are built almost entirely on former mangrove land, for example Bangkok, Kuala Lumpur and Manila (Bagarinao & Primavera 2005);

- indirect/off-site activities: off-site activities, unrelated to the mangrove ecosystem but detrimental to it, for example offshore dredging, oil exploration, exploitation and pollution (such as in the Niger Delta). Indirect effects of agriculture on mangroves can be seen through interception and diversion of upstream freshwater resources for irrigation by agricultural schemes (such as in the Indus delta of Pakistan) and run-off of agricultural residues. In Sao Paulo, Brazil the mangroves have been heavily impacted by landfills, solid waste disposal, industrial and domestic effluents, chemical, organic contamination and oil spills from nearby ports and oil terminals. Other destructive effects include sediment diversion due to dams and floods, change in waterways due to construction of canals and roads, increased soil salinity by changes in freshwater runoff (Macintosh & Ashton 2002; Twumasi & Merem 2006);

- natural disasters: storm damage, coastal erosion, naturally shifting hydrology, climate change, sea level rise, drought and typhoons;

- management failure: the existing policies for mangrove utilization and conservation are ambiguous and inconsistent:
    - uncertain land ownership and rules governing access to mangrove areas,
    - illegal encroachment can be because the regulations are too complicated and ambiguous to follow, even government officials may not understand forest laws or recognize boundaries and consequently fail to implement or enforce rules,
    - governance and institutional failure to effectively manage coastal mangrove resources,
    - poor planning of coastal land use and implementation of development plans,
    - issues related to enforcement, realistic design of implementation of laws e.g., zonation,
    - lack of involvement of communities in decision making (management, development of legislation, enforcement),
    - lack of understanding and awareness of the value of mangrove ecosystems among various groups of people including policy makers, officials, developers and local people,
    - compatibility issues - conflicts are common between the various departments involved; weak coordination between different levels and different sectors of government,
    - availability of infrastructure, manpower and equipment are inadequate for effective control over the utilization of mangrove resources (Abere & Ekeke 2011; Bagarinao & Primavera 2005).

In a study, Ekpenyong (2008) critically examined the mangrove cover in Akwa Ibom State in southeast Nigeria and observed a 61.67% decline (mangrove loss) with 16.81% fresh growth within a 21 year period (1982-2003). The decline corresponds with areas with high incidence of poverty; as the poor indigenes harvest the mangrove trees for sale as firewood. A similar observation was made by Holzlohner et al (2002). The co-occurrence of poverty, unregulated aquaculture expansion and mangrove loss is a disturbing trend recorded in Southeast Asia that could repeat itself in Nigeria. Nigeria's mangroves possess qualities for profitable semi-intensive and intensive aquaculture, including suitable physicochemical, physiographic, biological properties and millions of seeds of several indigenous fin and shell fish species harvestable from the mangrove. While aquaculture growth is slow in many African countries, Nigeria is noted as having a sprawling, dynamic, private sector – and market – driven aquaculture subsector with growing and wide spread networks of urban and peri-urban fish farms, fish processors and feed producers. An army of civil/public servants, retirees, youths and fisheries graduates are turning to fish farming, attracted by a booming catfish industry. Pretty et al (2011) noted the rapid growth of aquaculture in Nigeria with the participation of private sector investors and establishment of over 3,000 "successful" fish farms in less than 10 years most of which are located in peri-urban environments. The private sector driven aquaculture development in Nigeria has so far employed improved feed and management techniques, attaining catfish productivity of 50–100 t ha^{-1} $year^{-1}$ with waste recycling capabilities. The high market demand for fish is partly the driving force behind the emergence of these *novo* aquapreneurs. Such private sector- and market-driven rapid, and relatively uncontrolled, development, lacking effective institutional framework for matching production methods with ecosystem dynamics, largely contributed to mangrove degradation in Asia (Huitric et al 2002).

Conclusions. With dwindling oil fortunes Nigerian government presently hopes to grow the GDP through agricultural development to employ excess workforce, reduce unemployment, reduce import of fish and drain in foreign exchange, and produce locally to shore up the value of the Naira, local currency. With the government policy to upscale production and transform agriculture into a money-making venture through ATA, the expansion of aquaculture into new environments, including vulnerable areas like mangrove in the near future is a strong possibility. Conversion of mangrove to aquaculture ponds is a growing dilemma and could pose a threat. Key players like multinational companies should not be ignored. Rather, institutional and community training and capacity building programmes, research into and application of best indigenous knowledge and enforcement of community by-laws should be initiated, encouraged and promoted by Forestry, Fisheries and conservation-minded institutions. Poverty reduction through aquaculture is a feasible option and should be promoted within limits of sustainable development.

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