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Emerging research priorities for the aquaculture sector in sub-Saharan Africa - a case study of Nigeria

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Abstract. This paper reviews the role of aquaculture research in Nigeria. The achievements and limitations of research in aquaculture development are discussed. It identifies strategic prioritization of research objectives in three phases namely; the short term, medium term and long term to properly foster real growth in the aquaculture sector with the dawn of privatization in the country. Ex post assessments are also fundamental in evaluating the viability and effectiveness of past research activities. Participatory approach in research prioritization and process, increased private funding of research and extension, programmes of intervention by the government are required to maximize the untapped potentials in aquaculture for its rapid transformation to a full-fledged economically viable sector. Thus, profitable, sustainable ecological aquaculture and 'water smart' culture systems consistent with different geographical zones of the country must be designed with potentials for sequestration of anthropogenic carbon and nutrients. Adoption of Guidelines on Best Management and Practices in Aquaculture Schemes is a necessity. Above all is the question of an enabling institutional framework, autonomy and pragmatic sector - specific policies without which nothing can be realistically achieved.

Key Words: prioritization, ecological, aquaculture, research, guidelines, participatory.

Résumé. Ce papier reconsidère le rôle de recherche d'aquaculture au Nigeria. Les accomplissements et les restrictions de recherche dans le développement d'aquaculture sont discutés. Il identifie l'attribution stratégique d'objectifs de recherche dans trois phases à savoir; le court terme, le moyen terme et le long terme pour correctement encourager la croissance réelle dans le secteur d'aquaculture avec l'aube de privatisation dans le pays. Les évaluations de poste d'Ex sont fondamentales aussi dans le fait d'évaluer la viabilité et l'efficacité d'activités de recherche passées. L'approche de Participatory dans l'attribution de recherche et le processus, le financement privé augmenté de recherche et d'extension, les programmes d'intervention par le gouvernement sont tenus de maximiser les potentiels inexploités dans l'aquaculture pour sa transformation rapide à un secteur économiquement réalisable véritable. Ainsi, l'aquaculture écologique profitable, durable et 'les ' systèmes de culture intelligents d'eau en harmonie avec de différentes zones géographiques du pays doivent être conçus avec les potentiels à la séquestration de carbone anthropogenic et d'aliments. L'adoption de Directives sur la Meilleure Direction et les Pratiques dans les Plans d'Aquaculture est une nécessité. Est surtout la question d'un cadre institutionnel permettant, une autonomie et un secteur pragmatique - les politiques spécifiques sans lesquelles rien ne peut être de façon réaliste accompli.

Mots Clé: l'attribution, écologique, l'aquaculture, la recherche, les directives, participatory.

Rezumat. Lucrarea, de tip referat, sumarizează rolul cercetării în acvacultură în Nigeria. Se discută realizările și nerealizările cercetării în dezvoltarea acestui sector. Sunt identificate obiectivele prioritar-strategice ale cercetării, în trei etape, mai precis: pe termen scurt, mediu și lung, pentru a se facilita corect dezvoltarea sectorului acvacol în prag de privatizare a Nigeriei. De asemenea o retrospectivă a eficienței și viabilității unor demersuri este fundamentală. Abordarea participativă în prioritizarea procesului de cercetare, creșterea finanțării din surse private a cercetării și extensiei, dezvoltarea programelor de intervenție de către guvern sunt necesare pentru maximizarea potențialului unor activități neîncepute în acvacultură pentru o transformare rapidă într-un sector economic deplin viabil. Adoptarea 'Ghidului Celui mai Bun Management și a Celor mai Bune Practici în Acvacultură' este o necesitate. Însă, înainte de toate, se ridică problema existenței unui cadru instituțional, a unei autonomii și a unui sector pragmatic – politici specifice fără de care nimic nu este realizabil.

Cuvinte cheie: prioritizare, ecologic, acvacultură, cercetare, model, politici.

Introduction. Fish is a basic food in sub-Saharan Africa. It plays a key role as a supplier of a concentrated form of food energy and protein of high biological value that is often complementary to the limiting amino acids in the plant foods eaten so heavily in the diet of people in the developing countries. For the majority of the human population, fish has a lower income elasticity of demand than meat with vegetables and beans as substitutes for fish (Delgado & McKenna 1997). Though it provides an estimated 22% of the protein intake in the region, per caput supply/availability is the lowest in the world (Dugan 2003).

Based on an estimated national demand of 2.66 million tones for fish, Nigeria's fish deficit stands at 1.30 million tones. These figures are projected on a domestic production of 0.62 million tones and approximately 0.74 million tones of fish imports (FDF 2008). Demand for fish is also anticipated to rise with a growing affluent and more health conscious population particularly residing in urban areas. Stagnation and declining productivity, high costs of industrial fishing principally due to high prices of fossil fuel and neglect of small water bodies are major causes of low domestic fish production. Globalization of markets and free trade (Ahmed et al 1999), high domestic inflation rates coupled with the weak national economies further resulted in higher rates of increase in fish prices with consequent reduction in the purchasing power of the low and middle classes. As a result, caput fish intake of the average Nigerian ranges between 1-9 kg/year and ranks as one of the lowest in the region (Akinyemi 1998). Currently, the country ranks second to Egypt in terms of aquaculture production on the African continent but is the largest producer in sub-Saharan Africa (SSA). Even an increase in yield from 30664 metric tons to 85087 metric tons between 2002 and 2007, as shown in Fig. 1 (FDF 2008), still suggests sub-optimal production levels in contrast to the existing vast and untapped physical potentials.

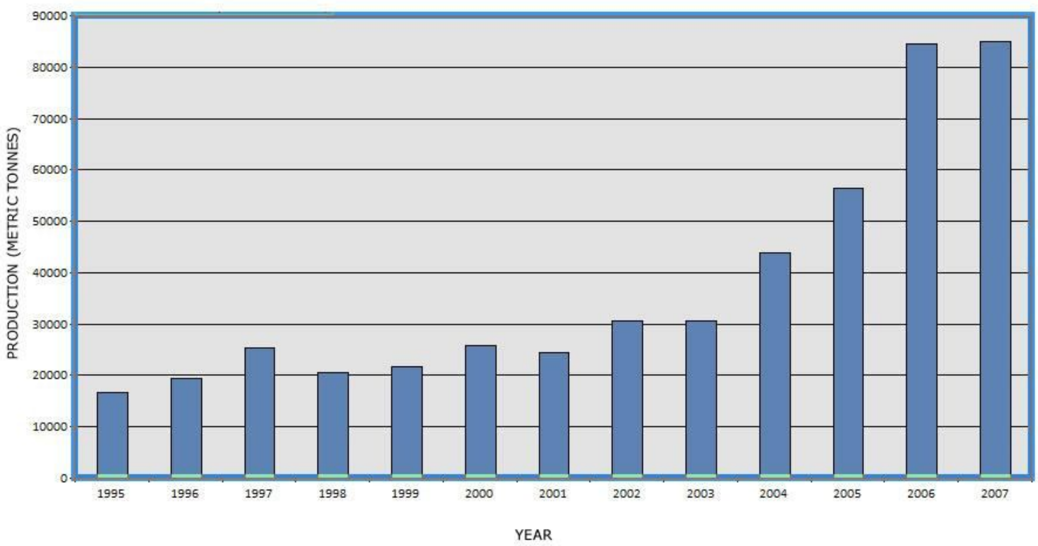

FIGURE 1 AQUACULTURE PRODUCTION IN NIGERIA

Unfortunately, the story is much the same for the SSA region. Many false starts in aquaculture in the region are tied to mere modification of technologies developed in temperate and/or industrialized countries with little regard to their suitability to the region in many of the adaptive research programs (Hecht & de Moor, unpublished data). Many aquaculture practices have not proven to be as efficient a means of production as was originally expected. Energy input/output ratios and consequent production costs are higher for some cultured fish than for fish from capture fisheries. In particular, intensive production systems such as Water Recirculation Aquaculture Systems are energetically costly, and more energy is often required to produce protein than in marine capture fisheries; Also, energy ratios for aquaculture systems are higher than those for most livestock systems. Consequently, one might be tempted to ask if aquaculture has proven to be the solution to wild fishery production (Pimenthel et al 1996; Jennings et al 2001). Aquaculture practices also constitute a largely undefined source of carbon and other greenhouse gas emissions (Bunting & Pretty 2007) whilst many aquaculture activities have also led to serious environmental and ecological consequences in some parts of the world (Wu 1995; Lin & Yi 2003; Primavera 2006).

In spite of its shortcomings, it is widely believed that aquaculture could be the only viable option to guarantee food security and generate a chain of multipliers effects on the national economies in the region. On one hand, there is actually limited potential of increasing landings from the capture fisheries even if appropriate fishery regulations and environmental standards are enforced. Correspondingly, a rapidly expanding domestic market for cultured fish and prospective export potentials; changing macroeconomic environments, opportunities of job creation and poverty alleviation in sub-Saharan Africa are key factors which ought to facilitate increased private-sector investment in food fish culture (Jamu & Ayinla 2003; Fakoya et al 2004). Harnessing merely 5% of Nigeria's estimated potentials for fish culture based on the availability of vast areas of underutilized water and land (Anetekhai et al 2004) can increase significantly per caput consumption level and bridge the huge fish deficit. Nigeria's estimated aquaculture potentials are estimated at 2.5 million tones (FDF 2008). However, an assessment of these potentials for aquaculture development rarely takes cognizance of the dependence of existing stakeholders/users, mainly poor and marginalized members of the rural communities on the natural resources and the disruptions resulting from utilization such as commercial aquaculture that is more intensive (Townsley 2001).

New (2003) opined that responsible aquaculture rather than sustainable aquaculture is meant to be profitable aquaculture with a conscience. This form of aquaculture can be assumed to be without any negative impact on the environment. It is also consistent with the shift in paradigm for the adoption of sustainable, ecological - integrated aquaculture systems, capable of nullifying the detrimental of aquaculture, particularly the intensive practices. The objective is to sustain equilibrium in the natural ecosystems for their perpetuity. Therefore, a fundamental goal of research should be to promote responsible practices in the production of food fish, to develop other areas of aquaculture hitherto neglected and alleviate development constraints in production.

Background Information. In the early 50's, the establishment of the 160-hectares Panyam Fish Farm located some 65 km south of Jos in Plateau State, heralded modern fish culture practices in Nigeria (Tobor 1994). Despite the successful culture of *Tilapia* species and the exotic common carp (*Cyprinus carpio*), the project was assessed to have failed due to the inability to breed indigenous species. In 1962, a brackish water aquaculture station was established at Buguma, Rivers State to increase fish production (Oribhabor et al 2005). Research and extension activities helped popularized fish farming during the 4th National Development Era [1975-1980] (Ezenwa 1994). The Nigerian Institute for Oceanography and Marine Research (NIOMR) and National Institute for Freshwater Fisheries Research (NIFFR) were established in 1975 for technology development and training in aquaculture. The African Regional Aquaculture Center (ARAC), a subsidiary of NIOMR and some tertiary institutions offering courses in fisheries, aquaculture or zoology in the country also provide additional research and training in aquaculture development.

Some breakthroughs in aquaculture research are mentioned below:

- Technology for breeding out of season of *Clarias gariepinus*, *Heterobranchus bidorsalis*, fertile hybrids of *Heteroclarias*. Initially, catfish propagation required hatchery technology but now farmer-friendly technologies are possible. Thus, problem of sufficient quantities of strong, disease-free and disease-resistant seed is gradually been solved by the private sector. Furthermore, production of triploids in Clariids is also boosting yields. As a result, Clariids have overtaken Tilap ia as major culture species. In 2004, cultured catfishes accounted for about 63% of total aquaculture production in the country (Hempel 2006). Hence, this has positioned Nigeria as the largest catfish producer in SSA.

- Artificial production of *Chrysichthys nigrodigitatus*. There is minimal culture of this species in the country. Fish seed production is still a constraint.
- Production of seeds of *Tilapia guineensis, Sarotherodon melanotheron*, mangrove oyster (*Crassostrea gasar*) and mullets (Oribhabor et al 2005).
- Production of *Tilapia* hybrids.
- Introduction of the flow–through system and the Dutch model of water recirculation system. These have been successfully adapted or modified to suit local conditions (Oguntade et al 2006). Plastic chippings, pumice stones, crushed oyster stones etc packed in coca-cola crates or plastic containers are being used to replace polypropylene filter in the Dutch model. Fuel can be conserved via intermittent shutdown of pumps subsequent to scaling down in operational time from 24 hours to 8-15 hours in the Nigerian model. Finally, there is substantial reduction in poaching unlike on most fish farms in the country (Anyanwu et al 2005).
- Introduction of cage culture, pens and enclosures.
- Improved yield from pond culture systems.
- Integrated culture of fish with piggery, livestock or poultry. According to NSPF report (as cited in Akinrotimi et al 2005) as much as 50% of fish farmers in the country are practicing these forms of culture while there is also an increase in fish cum crop culture.
- Induced breeding of *Gymnarchus niloticus* and *Heterotis niloticus*. However, seed production of these fishes is still a constraint.
- Production and hatchery rearing of shellfish, principally, *Macrobrachium vollenhovenii* at the trial stages.
- Production of live food and zooplankton organisms.

Constraints to Effective Research in Aquaculture Development in Nigeria. Limitations to effective aquaculture research cannot be absolutely divested from the major problems that hinder the growth of the sector in the country.

State of Macroeconomic Environment in SSA. With a recent history spanning over five decades, development of aquaculture as a viable economic activity may likely take a much longer time to materialize (Pedini & Shehadeh 1997). Moreover, they contended that the elements crucial to its sustainability which is an enabling environment encompassing so many variables must also be present. However, this environment has been conspicuously lacking in Nigeria as in other sub-Saharan Africa countries. Generally, the early 60's and the early 90's can rightly be described as eras of slump or meltdown in aquaculture development in the region. While the former period is related to the winding up of many colonial regimes and scarcity of resources leading to series of abandoned ponds due to low yields, poor location and /or lack of government support; the latter period climaxed with deteriorating global economies that accentuated the challenges to long-term viability of aquaculture. Thus, poor macroeconomic environments of most sub-Saharan Africa countries also severely incapacitated the public sector to deliver (Machena & Moehl 2001). For instance in 1994, devaluation of the Communaute Financiere Africaine (CFA) eroded the purchasing power of the consumers and led to the near collapse of the Ivorien catfish industry. The industry became increasingly unprofitable and farmers lost the incentive to produce fish (Hishamunda 2007).

Lack of Autonomy, Absence of Sector-specific Policies and Underfunding. Aquaculture sector has remained as an offshoot of the capture fisheries sector because of its continued integration under the inland fisheries subdivision in addition, there have been no aquaculture-specific polices in the country (Ogunlaru 2001). Lack of legislative framework, instability in institutional arrangement and bureaucracy between 1975 and 1990 were also responsible for the poor state of the sector (Ezenwa 1994). More importantly, implementations of strategies or plans for the promotion of aquaculture in the past under the aegis of the National Agricultural Policy have been curtailed more often by the lack of political will to follow through in a determined manner. Similarly, infancy of the sector and its small weight in the national economy seriously contributed to gross under funding of aquaculture research (World Bank et al 1991; Drawbridge 2002).

Poor Managerial and Advisory Services. Pilot/demonstration fish farms established in different parts of the country to encourage private participation in the sector between the 3rd and 4th National Development periods (1970-1974) and (1975-1980) respectively, were also economically unviable. Poor managerial skills and gross under funding following economic austerity of the 80's also led to many of such projects eventually becoming moribund. High initial investments costs of these model fish farms relative to their lower yield probably also discouraged private sector participation in fish farming (Oyatoye 1982). Lack of quality hatchery- reared fish seeds, poor nutritionally - balanced feeds chiefly obtained from kitchen wastes and agro-industrial by-products, poor extension and advisory services rendered to the private fish farmers were also responsible for the near demise of fish farming. Adoption of government instead of the private investor as key elements in aquaculture development efforts by bilateral and international agencies may also be responsible for the poor take-off of aquaculture during this period (van den Berg 1996). According to Hishamunda (2007), public-funded research was formally directed towards the rural sector and diversification rather than to support business-oriented aquaculture.

High Production Costs and Insufficient Domestic Fish Feed Supplies. Production costs from energy and feed are often quite prohibitive and may render intensive production systems economically unsustainable, eventually becoming a disincentive to local production and placing export-oriented farmers at a competitive disadvantage on the long term. Firstly, Nigeria still lacks sufficient and steady electricity supply. This tends to cause incessant disruptions in the operation of such systems and there is a huge shift or dependency on power generating sets. Fuel especially diesel in recent times has been prone to interrupted supply and subsequent fluctuating prices (Bunting & Pretty 2007). Secondly, such intensive production systems require intensive feeding. In such systems, feed generally accounts for more than half of operating costs and even assumes a larger portion of the production cost when the feed is imported. Unfortunately, fish feed is less than 1% (an estimated 25,000 tons) of total animal feed produced in the country while an estimated 4000 metric tones of formulated fish feed used in the country is imported from Denmark and the Netherlands. Ratio of fish feed producers to fish farms in the country, estimated at 1:11, is also very low. In the early 80's, the earliest fishmeal plant at the Nigerian Institute for Oceanography and Marine Research was to provide the take-off for pelleted fish feed in the country (Akinrotimi et al 2007). However, only few large-scale feed millers such as Topfeeds, Livestock feeds, Pfizer, Chi Ltd., produce floating/pelleted feeds. Increasing cost of fish meal and the cost of extruders are also limitations to the expansion of production capacity in the fish feed industry. Therefore, evolution of a full-fledged fish feed industry is yet to materialize and cater to the needs of fish farmers, both in quality and quantity.

Lack of Regulatory Framework for the Industry. Recently, there is a growing concern on the possibility of a glut in farmed catfishes in Nigeria's domestic market despite increasing demand for fish and fishery products. This can be attributed to lack of regulation in the developing industry. Many small –scale farmers are actively engaged in virtually all facets of catfish farming ranging from seed or fingerling production, table-size or growers production to feedmilling (Oyeleye 2007). But more importantly, the glut could also arise if there is a decline in taste or appeal for farmed catfishes especially in the absence of alternative farmed fish, processed or novel catfish products, inadequate supplies and persistent high selling prices for popular fish species such as *Chrysichthys nigrodigitatus*, *Gymnarchus niloticus, Heterotis niloticus* etc., with high potentials for culture.

Lack of Technology for Culture and Breeding of Marine/Brackish Water Fishery Resources. Moreover, there is a lack of adequate technical know-how on the hatchery management and farming of indigenous marine species in the country despite the larger marine and brackishwater environments (Madu 1996). This has further limited the expansion of the industry in terms of a rather narrow cultivable species base.

Adoption of Non-suitable Technology and Preponderance of Supply–driven Research Objectives. World Bank et al (1992) reported a preponderance of applied and adaptive aquaculture research in developing countries making use of basic and strategic research results imported from industrial countries. While results from adaptive and policy analysis may have impact within a few years, results from strategic and applied research can take several years (Fitzhugh 1998a). Research policies limited to immediate development concerns do not create exigencies for the emergence of new knowledge acquired through basic and strategic or innovative research. According to FAO (as cited in Chimatiro 2007), insufficient funds, lack of core research staff and weak research infrastructure are the three factors that constrain fisheries and aquaculture research and development in Africa. NIFFR and NIOMR, the two major fisheries research institutes in the country were ranked as "poor" on the assessment of available infrastructure, equipment and support facilities required for viable and result-orientated research. Similarly, FARA (as cited in Chimatiro 2007) reported prevalent weakness of about 42 % of African research institutions in fisheries and aquaculture, leading to a lack of a common and strategic understanding of the challenges being faced by the sector and the importance of fisheries and aquaculture research for development. Research objectives are still to some extent, supply- driven dictated or defined by the existing expertise and interests which emphasized the biotechnological aspects with less concentration on issues of policy, planning, socio-economics and management. As a result, the effectiveness of research strategies and performance of development activities have been seriously undermined (World Bank et al 1991). Research programs were further characterized with short duration of 2-4 years, lacked proper evaluation of the effects of the political and cultural environment within which the technology was being promoted and the impacts of aquaculture development projects and their realistic viability. The trend of research has also failed to recognize the needs of farmers, that is, adjustment of aquaculture practice within their specific context as well as integrate effectively aquaculture into existing farm economy. In addition, there is limited involvement of the private sector despite the increasing importance of this sector in a liberalized economy. More recently, research has focused more on close systems and intensification and has neglected the potential importance of open systems relevant in small water bodies, brackish and marine environments respectively.

Insufficient Network Linkages Among Fisheries Research Institutes, Tertiary Institutions, Extension and End-users. Diffusion or dissemination and the adoption of research results are poor and often beset with problems. There is an apparent lack of coordination or cooperation on aquaculture among research institutes and tertiary institutions in the country. This might not be unconnected with the absence of a central thrust on research that emphasizes on linkages among research institutes and institutions. Research outputs from tertiary institutions are rarely communicated to the private sector; often research projects suffer from lack of continuity and rarely see the light of the day.

In addition, there is an apparent missing linkage between research and extension. Dugan (2003) opined that in Africa, research was followed by extension. Extension research to boost fishery development in Nigeria was neglected until 1987 when it was included in the Unified Agricultural Extension System under the auspices of a World Bank funded project (Ajetomobi et al 2001). Since then, aquaculture extension has been fully integrated into decentralized Agriculture Development Projects, which operate at the District level (CTA 2001). Because of the traditional topdown approach, research findings and technology were often inappropriate and therefore unworkable for the complex and diverse socio-economic environments associated with the farmers. The R-E-F continuum, which stands for Researcher - Extension - Farmer link, has been enshrined in the Training and Visit (T&V) Approach to extension. Research designs technology is passed to extension (through training) and thence to farmers. Unfortunately, there are few success stories in the Training and Visit approach. Communication problems between researchers, extension officers and farmers have been identified as key problems to this extension approach (Hecht & de Moor, unpublished data). Generally, declining Government funding and limited logistics support has also severely curtailed the impact of extension. Lack or absence of sole fisheries/aquaculture extension specialists is also bound to affect the quality of extension services delivered.

Aquaculture Research Priorities. Setting research priorities arises from the need to optimize the resources available, which is usually less than would be required to fund all the projects put up for consideration. According to Ahmed (1999), research in addition to extension and information services are non-price factors that will be the major determinants of food fish supply in the short and medium term. Hence, research proposals should be prioritized based on the exigencies of their objectives and goals most relevant to the society. A consequence is the creation of competition between disciplines and subjects and between applied and strategic themes.

Informal and informal approaches are used to produce a ranked list of possible projects or programmes in agricultural research. These methods are also applicable in prioritizing fisheries and aquaculture research. Informal approaches are qualitative in methodology and tend to be based on discussion and subsequent ranking or scoring by stakeholders or small groups of knowledgeable people. Formal methods are quantitative, include mathematical programming, simulation and most commonly involve a comparison of benefits and costs of the research to estimate its economic impact (McLeod et al 1998). The benefits from research should accrue to producers in the form of increased yields, improved efficiency and reduced wastage from fish kills and also accrue to the consumers in terms of more and high quality products and lower retail prices. Also implied should be related social and environmental costs and benefits in the analysis (Fitzhugh 1998).

However, as it is with livestock research, effective research prioritization in aquaculture will also depend on ex post assessments to (i) improve future research design and document the benefits and costs from previous research; (ii) to support public awareness and resource mobilization; (iii) for accurate prediction of future demands; (iv) for identification of constraints to future development and (v) for estimating potential impacts from research.

Research priorities for aquaculture sector in Nigeria are discussed in the short - term, medium - term and long -term research objectives. Selection of the most appropriate research design for implementation of each objective should be based on the complete evaluation of all possible alternatives based on criteria such as levels of adaptability, application on field and degree of integration/ cohesion with other subjects or disciplines. Ultimately, this would assist in optimal use of scarce resources as well as maximizing output.

Short Term Research Objectives. The first priority would be to increase or stabilize food fish supplies and make available sufficient fish at low enough prices to compete with low priced imports to the poorer sections of the society, thus fulfilling the prime objective of aquaculture.

Though still in its infancy in terms of its developmental stage, aquaculture is rapidly becoming recognized as a potential fast emerging economic sector in Nigeria. Utomakili & Fabiyi (1992) and Ogunlaru (2001) among others identified a predominance of small-scale semi-intensive fishpond operators (Fig. 2). Oguntade et al (2006) also reported a dominant trend of rearing catfish in grow - out concrete tanks in urban areas of Lagos State, the economic hub of the nation (Fig. 3).

Figure 2. An earthen fish pond located in the Fish Farm Estate stocked with juveniles.

Fig. 3. A flow-through concrete tank for growing the African catfish, *Clarias gariepinus*.

The establishment of a fish farm estate in a suburb has intensified emphasis on fish culture in the state. Small-scale fish farming in Africa has the potential to produce a substantial amount of the fish requirements, to increase income, diversify livelihood options, reduce vulnerability and improve water and land management in rural areas and urban centers (Dugan 2003). The actual contribution of small-scale initiatives is probably underestimated in terms of volume and economic value because most abound as homestead/family operated ventures. Nevertheless, profit is a strong motivating force for those engaged in aquaculture; more products are produced for sale in the growing markets and fewer are retained for household consumption (Oguntade et al 2006). Thus, commercial aquaculture as practiced on this basis can best be described as being of a partial- or quasi-commercial nature because family members chiefly provide labor. Hence, emphasis must be placed on this practice because rapid transformation in the economies of developing or under-developed countries is highly dependent on the success of small-scale businesses or cottage industries.

Management practices under-utilize the production capacities of most existing fish farms, which exist in peri-urban areas. Hence, emphasis should also be laid on increasing labor productivity and fish yield by reducing costs through lower mortality rates; develop nutrition strategies that maximize the contribution of natural and supplemental feed. In particular, Jamu & Ayinla (2003) suggested that research should deviate from the substitution of animal proteins by plant proteins and concentrate on the utilization of plant protein by fish. However, the realization that fish thrive better with the inclusion of animal protein especially fish meal implies a superior amino acid profile as well as some natural growth factors lacking in sources of plant proteins. Therefore, rather than complete substitution of animal proteins, partial substitution by a mix of fish meal, other animal proteins such as worm meal, and plant proteins in varying proportions should be continuously investigated for increasing Food Conversion Ratio (FCR). This is to reduce the overall cost of fish feed produced that anchors substantially on fishmeal. Buying preference for floating feeds or pellets should also initiate studies into inclusion levels of feedstuffs that could increase floatability of fish feeds. Application of such research findings by commercial -scale and medium -scale feed millers would lead to better quality and readily affordable fish feeds for commercial fish farmers. Other options would be to improve compatibility and promote integrated farming systems with semi-intensive culture ;thus mitigating the environmental impacts of effluents/ discharges from culturing facilities by encouraging the use of aquatic organisms for nutrient extraction in cities and urban areas. Consequences of limited availability of land in urban areas mandates the adoption of more intensive utilization of fish rearing facilities such as water recirculation aquaculture systems (Fig. 4, Fig. 5a & Fig. 5b). Further domestication of the WRS through use of local materials (Anyanwu et al 2005) and use of renewable energy source in the absence of sufficient electricity and prohibitive costs of diesel and petrol/ gasoline will reduce production cost.

Fig. 4. External view of a Water Recirculation Aquaculture System (WRS) facility.

Fig. 5a & 5b. Interior of WRS facility for growing the African catfish, *C. gariepinus* in concrete tanks.

Nationwide there are about 59 Government-owned fish farms most of which are moribund. Some of these could be readily converted to brood stock repositories in the country to provide certified farmed fish stocks of known origin. Besides serving as centers for the production of certified broodstock, these rehabilitated farms should also have well - equipped fish health laboratories for strict quarantine measures and to assist farmers in the diagnosis and treatment of fish diseases and parasites. This step would facilitate human capacity building in fish health management, an area not well understood and with a handful of specialists in the country.

Research on policies and legislation is particularly desirable because they have to be formulated in accordance with the country's own legal heritage and problems (Hishamunda 2007). Research should focus on policies based on financial viability and credit availability facilitating promotion of aquaculture enterprises. The availability and supply of inputs are likely to limit the expansion of aquaculture. In fact, greater attention should be given to socio-economic and production statistics to reduce the negative effects of inaccurate data on which most aquaculture projects are still formulated. Lack of scientific data on aquaculture sector has also been emphasized as handicap to decision-making by senior decision -makers and planners (Chimatiro 2007). Because of demographic shifts, it is inevitable that studies on urban markets should be intensified.

Medium-long Term Research Objectives. There should be a forum to define different stakeholder groups and their interests in the major geographical zones in the country so that research can be adapted to suit their capacities and needs. In line with this, it becomes imperative for appropriate community- based sustainable, ecological integrated aquaculture systems to evolve in each geographical zone. These systems must incorporate carbon sensitive technology and significantly consume less energy (both direct and indirect) to reduce emission of carbon and other greenhouse gases as well as display high level of efficiency in extracting anthropogenic nutrients, notably nitrogen and phosphorous.

Ecologically-based approaches, notably horizontally integrated production systems, can represent viable and resilient strategies for managing wastewater, aiding reuse, conservation, restoration of aquatic ecosystems (Bunting & Shpigel 2009). Diversity of species and systems makes possible the engineering of numerous ecological and aquaculture systems. Potentials of different systems must allow important variables such as treatment performance, productivity, financial returns and economic indicators besides technical aspects to be critically assessed simultaneously. In addition, the adoption of any culture system should also involve an assessment of land capability and carrying capacity assessment of the aquatic environment in a broad range of habitat types as well as ethical, social and legislative perspectives which may affect it, directly or indirectly.

In sub-Saharan Africa, mariculture is under developed except for oysters, abalone, marine shrimps, sea moss, mussels, seaweeds and sea bass in Egypt, South Africa, Madagascar, Mozambique, Namibia, Senegal and Tanzania. However in Nigeria, oil and other forms of industrial pollution, high wave action, shallowness of the continental shelf are serious problems to the development of a thriving mariculture sector. Besides pollution, faecal contamination, Nypa palm (*Nypa fructicans*) encroachment, sandfilling, nematode infection among all other environmental pressures have substantially reduced area available for culture. Similarly brackishwater culture is also undermined by a number of factors such as susceptibility of the environment to flooding, expensive maintenance of the ponds because they require pumping to be cropped and cannot be totally dried out nor harvested and the swampy terrain, which impedes easy movement of construction materials (Anetekhai et al 2004). However, against the backdrop of the adverse effects of anthropogenic activities in the marine and brackish water environments, Oribhabor et al (2005) opined that development of brackishwater aquaculture and by extension mariculture, would increase demand for cleaner environment in the coastal zones of the nation.

Silvofishery is a culture technology suitable for adoption along the coastal zone of the country, where there is rapid decimation of the mangrove ecosystems. It is a form of horizontal integration which can optimize resource use efficiency, physical infrastructure; technical and managerial skills while enhancing marketing opportunities, financial viability and minimizing environmental perturbations integral for the maintenance of a healthy aquatic ecosystem. It can serve as an alternative to brackishwater pond culture, a vital key to mangrove forest rehabilitation and conservation while capitalizing on the economic benefits of brackishwater culture. Hence, it is very important to the attainment of dual aims of ensuring overall sustainable development and management strategies of the coastal zone as well as for poverty alleviation of the inhabitants. However, because the choice of appropriate silvofishery model is site - dependent and influenced by the status of the mangrove ecosystem as well as the various inputs required (FitzGerald 2002), different silvofishery models should be conceptualized and evaluated for adoption along the entire length of the coastal zone in the country. In view of this, much emphasis should also be placed on the Niger Delta ecological region with the largest mangrove ecosystem in sub-Saharan Africa. In the last 10 years, growing profile of the exotic giant tiger prawn (*Penaeus monodon)* to pink shrimp (*P. notialis)* in the country's coastal waters in terms of comparative high market value, proliferation and high growth rate has ignited interest in its culture. Nigeria is a net exporter of shrimps to the United States and European Union. Consequently, substantial progress is being made to introduce commercial farming of *P. monodon* in 9 coastal states of the federation. Farming of the giant tiger prawn (*P. monodon*) has been particularly successful in Madagascar because of her relatively unpolluted marine environment; use of environment-friendly practices in production. Consequently, these factors ensured its high quality and have also guaranteed high net returns to the country (Hishamunda 2007). Thus, collaborative research and training on farming of *P. monodon* with Madagascar could accelerate progress in development of a responsible shrimp farming industry. It is also worth mentioning that in Nigeria, the adoption of a silvofishery model in the coastal zone is of paramount importance with consideration on the habitat type to reduce pollution loading on the aquatic environment. While an integrated shrimp-mangrove model could be appropriate for mangrove ecosystems, integration of shrimp- seaweed-oyster model or shrimp- oyster- mullet model could be adopted in other habitats naturally lacking mangroves.

Aquaculture is also a viable alternative to provide seed stock for replenishing aquatic resources and for the culture of other aquatic organisms such as seaweeds, ornamental fishes, crocodiles, alligators, and turtles which have high potentials for exports, and to provide inputs in the form of raw materials to certain industries. This compels investigation into the biology, ecology, production and management technology for the farming of new indigenous species. However of paramount importance, should be efforts to characterize genetically all cultivable species in order to identify different stocks or strains.

From an ecological point of view, it has also been suggested that stock/ recruitment enhancement could increase the production of several species. This implies a broader cultured fish spectrum from about eight of which only 3 are reproducible in the hatchery (Akpaniteaku, unpublished data) and the development of brackishwater culture and mariculture. In addition, stock enhancement programs have the dual advantage of protecting the habitat often leading to its modification. This might as well be the prerequisite for the creation of No-Take Zones (NTZ) or protected areas (PA), under which nursery areas and artificial habitats could be categorized. Drawbridge (2002) summarized the role of aquaculture as the pragmatic solution to help restore fast depleting coastal fisheries resources. Several adult marine fish stocks have being overexploited. Amiengheme (1997, 2001) reported a noticeable decline in the occurrence of big-sized commercial fishes such as snappers, groupers, grunters, croakers in inshore trawl catches. Declining abundance of fish seeds of some popular fish species with high culture potentials such as *Lutjanus goreensis, Tarpon atlanticus, Elops lacerta, Pomadasys jubelini, Gymnarchus niloticus, and C. nigrodigitatus* in Nigerian coastal waters, lagoons, creeks and estuaries (Ezenwa et al 1990), results in lower recruitment to the fishery. This is attributed to destruction of nursery and breeding grounds for fishes due to rapid subsidence of the coastline from the twin forces of erosion and sea- level rise; oil installations; sand mining; industrial pollutants and reclamation of coastal marshes. Unfortunately, these destructive actions have since reached alarming proportions in the coastal cities of Lagos, Port - Harcourt, Warri and Calabar. However, replenishing diminishing stocks is feasible through artificial propagation of marine fishes. The production technology for indigenous species principally snappers and groupers can be adopted from countries such as the Philippines where the technical know-how has been perfected and tested (Madu 1996). In 2008, diversification into marine and brackish water aquaculture commenced with the launching of Marine Cage Culture Project in Lagos State. It is suggested that this project should be replicated in the other 8 coastal states. Dependence on imported compounded fish feed is detrimental to the economic sustainability of the project. While 'trash fish' or low- value fish species from trawl catch could be used to reduce production costs, there are bound to be deleterious effects on the aquatic environment leading to local pollution especially in vicinity of the cages. Also, feed wastage could be effectively checked by integration or simultaneous development of seaweed culture. There appears to be a lingering perception that seaweed farming is an environmentally non-destructive alternative livelihood and is considered relatively benign on the environment when compared to other mariculture activities (YMK, De Silva cited in Crawford 2002). In areas adjacent to fish culture facilities such as cages, pens etc., seaweeds have proven capable of eliminating heavy metals; act as efficient biofilters or nutrient scrubbers removing dissolved inorganic nitrogen and dissolved inorganic phosphorous from aquaculture effluents in the vicinity of fish culture facilities as well as when incorporated in integrated polyculture systems (McVey et al 2002). Utilization of macroalgae as bioremediation in aquaculture systems does not only provide a second crop or product but also provides another source of food for other culture organisms (Tseng 2003). Alternatively, biculture cage ecosystems comprising of mullets (deposit-feeder) in bottom cages underneath cages of high- value finfish such as snappers are as effective in maintaining the health integrity of the environment as they also help to reduce organic matter accumulation and oxidize benthic sediments (Angel et al cited in Costa-Pierce 2002).

In areas endowed with abundant aquatic resources such as lagoons, river floodplains or fadamas, lakes, reservoirs, rice floodplains, more traditional form of culture–based fisheries such as brush parks are amenable. Culture-based fisheries are considered to have a very high potential for contributing significantly to aquaculture production, especially in developing countries. In the light of increasing competition in most places for water and land, culture–based fisheries in contrast to the more conventional and intensive aquaculture practices are generally nonconsumptive practices of primary purposes, in particular water, with the use of existing water resources and therefore compete minimally, if at all, with other uses. They are also environmentally less perturbing, often requiring minimal external inputs such as formulated feeds than conventional aquacultural practices. Furthermore, when fully functional, such fisheries could provide stable fish supplies at lower market prices over a long period through staggered harvesting (De Silva 2003). Research should focus on improving simple management techniques of intervention such as stocking and the interactions amongst factors affecting population dynamics of culture-based fisheries; supplemental feeding; competing uses of the environmental resources; testing different co-management arrangements or partnerships that maximize the social and economic benefits to the communities using these resources; providing information on costs and profitability (Jamu & Ayinla 2003). In addition, management of culture-based fisheries could also become potentially more focused on carbon assimilation and sequestration (Bunting & Pretty 2007). Rakocy (2002) suggested green water tank culture as an appropriate technology integrating fish and field crops thereby conserving water resources in arid areas. This could be adapted in Northern Nigeria challenged with desert encroachment and shortages in water supplies. Albeit not as technologically advanced as WRS, this system also has the dual advantage of not being as demanding or as expensive. This technology may also be suitable in high-population density areas in cities such as the Lagos metropolis, where adequate portable water supplies are a big issue. Similarly, Kolkovski et al (2003) discussed a variety of 'water-smart' culture systems ranging from integrated irrigation – aquaculture, greenhouse technology to aquaponics developed in Israel to maximize water use. Lin & Yi (2003) demonstrated the efficiency of rice crops in extracting nutrients, principally nitrogen and phosphorous from pond effluents. These systems may be also amenable for adoption not only in arid parts of the country but also in water-limited areas from terrestrial sources and in heavily populated areas with limited land areas available for aquaculture.

Conclusions. For aquaculture to fulfill its crucial role, then the government must take decisive steps to promote the development of commercial aquaculture by granting autonomy to a Ministry of Fisheries as opined by Anetekhai et al (2004), enabling institutional framework, prompt implementation of appropriate sector-specific policies. Research objectives must be demand-driven, based on a blend of theoretical knowledge and realistic situations. A databank for the collation of researches/ projects in aquaculture from research institutes and institutions of higher learning would help identify grey areas which need further studies and provide the platform for more multidisciplinary collaboration. Collaborative research and training on indigenous estuarine/marine fish species with potentials for fingerling production with countries where technology already exists could provide the platform for increasing the spectrum of cultured species for the purpose of recruitment enhancement; diversify fingerling base and fish farming potentials of the country. Commercialization of aquaculture can help stimulate appropriate research and technological development; some of which could be funded by the industry itself in the light of declining public funding. Subsequent industry consolidation can accelerate private research funding on the long - run. Ultimately this requires a gradual shift from the erstwhile popular pathway of researcher – extensionist - producer to the adoption of methods to encourage participation of stakeholders (producers, processors, retailers and extensionist, researchers) in the research prioritization and research process: diagnosis, planning; experimentation; assessment and diffusion. Certainly, this is a more open and interactive paradigm with numerous benefits such as better and more precise diagnosis of problems from production to consumption systems; less effort and resource wastage through 'inappropriate' research and enhances interdisciplinary collaboration. This novel approach to aquaculture research should provide the optimal technology transfer and adoption pathway for successful implementation. The feasibility of participatory approach also implies a departure from projects to programs of intervention and this would necessitate the use of a simple, local and meaningful medium of communication; training end-users in some aspects of scientific research methods and the limitation of the relative sophistication of methods used. The role of the extension workers needs to be reviewed in the light of a participatory approach and this is foreseen in the provision of more interdisciplinary advice to end-users especially in the project cycle of adaptive research. More so, with limited logistic support and government funding, panacea to this problem is envisaged in the privatization of extension services with the onset of more involvement of the private sector in the development of the industry. Concerns on the impact of a rapidly expanding aquaculture sector on the environment mandates conceptualization of ecologically- based production systems which have high potentials for removal and sequestration of anthropogenic carbon and nutrients for protection of the aquatic ecosystem and for ameliorating negative climatic changes in the global environment. These systems should provide commercial benefits both in the short and the long term. Thus, the adoption of Guidelines on Best Practices and Management Schemes for Aquaculture, as is the practice in many developed countries becomes a necessity. Emphasis should be placed on maintenance of water quality standards in different culture/production systems, solid waste and effluent standard quality, restriction on the utilization of chemicals which includes a broad range of medicinal, additives, pesticides, disinfectants and preservatives other chemicals which may be associated some metal compounds or with structural materials, feed and feeding management, pond preparation, provision of good quality seed, land capability and carrying capacity assessment classification schemes in a broad range of habitat types or geographical zones, handling or harvest management etc. This coupled with the emphasis on the implementation of Hazard Analysis Critical Control Point (HACCP) standard helps to guarantee high quality and safe aquaculture products and can be viewed as a precautionary measure towards maintaining healthy fish stocks while minimizing the incidence of disease outbreak. Awareness on the importance of the Guidelines should also be effectively communicated and disseminated through producers/ fish farmers' groups or associations in communities. However, actual implementation may be difficult and might depend on so many factors such as individual farmer's level of education, perception of farmer on environmental issues and ecological functions of ecosystems, monitoring capacity and the costs involved, large number of small – scale fish farms, difficult terrains or remoteness of some farms and lack of effective farm registrations. Ultimately, the evolution of an efficient, profit- driven and ecological -safe aquaculture industry thrives on availability of functional infrastructure and availability of social amenities such as access roads, hospitals, schools, electricity, water supply etc. This is of paramount importance the remote and rural areas of the country where opportunities for economic empowerment keeps shrinking everyday as a result of ecological disasters such as desertification, land subsidence, ocean surge, flooding, erosion, deforestation, all of which have been exacerbated by the phenomenon of global climate changes.

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