Perspectives in the Limnology of Shallow Tropical African Reservoirs in Relation to Their Fish and Fisheries

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Abstract: *Reservoirs serve important functions for the socio-economic needs of the people in tropical Africa, which include fish production. However, the limnology of these reservoirs is usually not taken into consideration during the planning, construction, operation and management of the reservoirs. The impoundment of water usually brings changes to the physico-chemical and biological properties of the water with attendant serious impacts on the fish biodiversity and fisheries of reservoirs. Eutrophication, multiple uses of reservoirs, soil erosion and siltation, thermal stratification, aquatic macrophytes explosion, reservoir construction, operation and management are some of the limnological challenges facing the fisheries of shallow tropical African reservoirs. Various mitigation measures to overcome the challenges such as the use of Best Management Practices (BMP) on the reservoir watershed, carrying out Initial Environmental Examination (IEE), Environmental Risk Assessment (ERA) and Environmental Impact Assessment (EIA) on the reservoir before construction and other limnological driven management programmes were proposed. A better way to ensure that fish biodiversity does not decline or totally collapse is to incorporate fish production into the reservoir management programmes and the use of limnological data for reservoir design and operational management. In the light of this, limnologists, aquatic ecologists and fisheries biologists should be consulted and carried along in the initial planning, construction, execution and subsequent management of the reservoir to ensure wise use and sustainable fish production from the reservoir irrespective of the purpose of creation of the reservoir.*

Keywords: *Limnology, reservoir, eutrophication, management, impact, fish, fisheries*

1. Introduction

Reservoirs are an important method of impounding water so that society can ensure that water is available all the year round and they help in maximizing abstraction from rivers. Nearly all the major African rivers have been dammed for one purpose or the other and majority of these reservoirs have now multipurpose roles. Many of these reservoirs were built as a result of societal demand for drinking and industrial water supplies, irrigation, hydroelectric power generation, fish production and recreation. With time, however, most of these reservoirs have secondary functions such as navigation, sediment control, insect and water borne disease control, industrial processing and cooling, flood protection, urban run-off control and tourism superimposed on them. Other benefits these reservoirs could offer include, water and biodiversity conservation, enhancement of local environments and landscapes, provision of jobs and food security. Mustapha (2005) highlighted the various ways by which reservoirs could alleviate poverty, enhance food security and help in the attainment of Millennium Development Goals (MDGS) by 2015 in sub Saharan Africa. Reservoirs provide a significant contribution to global fisheries (Miranda 1999) but at the same time can impact negatively on fish and fisheries.

In Africa, there are many shallow reservoirs, but their number is still few considering their functions, population demand for their resources and their roles in meeting the MDGs by 2015. In order for these reservoirs to perform the purpose(s) of their creation as well as other functions that might be superimposed on them, limnological characters of these reservoirs should be well known. This will provide a valuable insight to its effective management, ensure better water quality and quantity, protect and preserve its biodiversity for sustainable exploitation of its resources as well as ensure its operation effectively.

The goal of this paper is to review the limnology of shallow tropical African reservoirs and the impact it has on the fish and fisheries. This is with a view to providing effective management of the reservoir and its fisheries and provides solutions to some of the challenges posed by the reservoir in terms of construction, operation, management, nutrient loadings etc to its fisheries.

2. Limnological Features of Shallow Tropical Reservoir

The impoundment of water through dam construction strongly interferes with river functioning and hydrological cycles producing many changes in the cycles and biodiversity of the affected rivers. The impact of reservoir construction on the main river includes alterations in the natural flow regimes with subsequent changes in current speed, flow volume, water temperature, oxygen concentration and obstruction of fish breeding and migrations (Dudgeon 2003). Shallow tropical reservoirs critically exhibit longitudinal (up lake to down lake) gradients in turbidity, nutrient concentration, mixing depth, euphotic depth, with sufficient light for photosynthesis, flushing rates, chlorophyll concentration, plankton productivity, fish standing stocks, macrophytes abundance, benthic community structure and other limnological and biological variables. These reservoirs are classified as river-lake hybrids (Kimmel et al. 1990) because they have the characteristics of riverine and lacustrine environments. They are often made up of three zones namely the lotic (riverine zone), the lentic (reservoir region) and the transitional zone which is found between the riverine and reservoir zones. Each of the zones is characterized by different transparency, different causes of light attenuation, different nutrient regimes and different biota. The transparency is low in the riverine section as a result of washing of debris into it by flood, while light attenuation is high in the lacustrine and transition zones due to shallow nature and high productivity of the zones. The transition zone is also the area with high nutrient and diverse fish and plankton assemblages (Mustapha 2009a).

Building and utilization of nutrients known as bottom-up and top-down mechanisms as well as seasonality occur between phytoplankton, zooplankton and fish components of these reservoirs. This interaction is termed trophic cascade (Carpenter et al. 1985). Tropical reservoirs have unidirectional changes of limnological variables (Tundisi and Tundisi 2003) with several outlets that produce extensive changes in reservoir functioning (Straskraba 1997). They have many tributaries, narrow and elongated. Shallow reservoirs are sensitive to eutrophication (Ekholm et al. 1997), this is because of the intense exchange of nutrients between water columns and sediments. Phytoplankton and zooplankton which are food for the fishes are found in high biomass in many shallow tropical reservoirs. Their assemblage is influenced by several abiotic and biotic factors operating in the reservoir. The fish diversity in these reservoirs is also high due to the abundance of food, shallow depth and high productivity of the reservoir (Mustapha 2010). Aquatic macrophytes are conspicuous features in these reservoirs. Their presence provides refuge for zooplankton against predation by fish, change the nutrient dynamics and prevent resuspension of sediments.

Many shallow tropical African reservoirs are eutrophic with high potential fish yield. Mustapha (2009b) estimated the potential fish yield of Oyun reservoir, Offa, Nigeria at 125.72kg/ha, which is higher than large deep reservoirs. This is due to the high conductivity and shallowness of the reservoir. Shallow tropical reservoirs do not thermally stratified, polymitic with short but varying water residence time, which is particularly pertinent in the dry season. They poses high watershed/water body area, high shoreline development index with high level of water fluctuations due to seasonal influences.

Literature on the limnology of shallow tropical African reservoirs is limited, the few works of this importance, but often neglected water bodies include Akin-Oriola (2003), Kemdrim (2005), Kadir (2000) and Mustapha and Omotosho (2006).

3. Limnological Challenges of Shallow Tropical African Reservoirs to Their Fisheries

Human activities pose a lot of challenges to the reservoir functions as well as its biodiversity. The problems that could arise include eutrophication due to run-off of organic and inorganic materials into the reservoir, siltation from catchment land erosion and excessive loadings of material from domestic and industrial effluents. These challenges are felt more on the reservoir fisheries and other biodiversity. Reservoirs could impact fish directly by blocking or creating hazards to migration and by mortality or damage when fish pass through dam discharge structures (Barnacsek 2001). It could also be indirect through the modification of the habitat i.e. from river to reservoir, alteration of flow regime, aquatic macrophytes infestation and explosiveness and so on. Two of the greatest challenges to the fisheries of shallow tropical African reservoirs are cultural eutrophication and the multipurpose use of the reservoir for domestic and industrial water supply, irrigation, recreation among others. Cultural eutrophication occurs as a result of increase loading of nutrients most especially nitrate and phosphate and probably sulphate into the reservoir. These nutrients are often washed into the reservoir from the run-off of nitrate, phosphate and sulphate based fertilizers which are applied on farms located near the reservoir to which the reservoir serves to irrigate. Examples of such scenarios have been documented on Oyun reservoir, Offa Nigeria (Mustapha 2008) and Kangimi reservoir, Kaduna, Nigeria (Kemdrim 2005). The effects of cultural eutrophication include shift in species composition of fish community and loss of floral and fauna (Scheffer 2004).

Many small shallow tropical African reservoirs are constructed for a single purpose of either domestic and industrial water production, irrigation or hydropower electric generation, therefore fisheries opportunities offered by the reservoir are often given less consideration, in spite of the fact that fisheries of these reservoirs contribute significantly to the livelihoods of the people where the reservoir is located (Mustapha 2009c). Most times, these reservoirs are constructed in ignorance of the existence of fishes and the opportunities the fisheries could offer. Even after the construction, the management of the reservoir is only limited to water quality, while the management of the biodiversity most especially the fish and fisheries are ignored. It is only when there is aquatic weed invasion or explosiveness in the reservoir that the aquatic biota is given attention. With the construction of a reservoir for any purpose, fisheries activities in the locality usually increase tremendously. This is due to the fact that reservoir results in productive fisheries (Jackson and Marmulla 2001) and at the same time attract people and industry to the area. This, consequently, also puts pressure on the reservoir through pollution, eutrophication, increased exploitation and other watershed abuses. The impact of the reservoir on their fisheries depends on the stakeholders' level of interest. This interaction could be spatial or temporal and could be looked at on large, small, long or short terms bases.

Another interesting challenge is the reservoir construction itself. In the construction of tropical reservoirs, the mitigation of negative impacts on fish biodiversity, stocks and the fisheries in general is often neglected. This is due to the fact that environmental impact assessments (EIA) are hardly carried out. As reported by Colt and White (1991), important advances in management approaches and engineering of mitigation measures have resulted in new dam projects becoming more environmentally friendly than in the past. But in spite of this, significant technical shortcomings still exist and there are more negative impacts for which consistently effective mitigation measures have not been devised (Roberts 1995). Soil erosion and silt run-off into the river during reservoir construction are the main potential environmental impacts on fisheries. This creates limnological problems of low transparency, poor water quality and impairs the nursery or breeding habitats of fishes (Bernascek 2001). Even after construction, the impacts of the reservoir on fisheries still continue. Petts (1984) and Welcomme (1985) produced a comprehensive reviews of dams impacts on fisheries and aquatic ecology at global level, while Bernacsek (1984) carried out a detailed analysis of the impacts of dams on aquatic environment and fisheries in Africa. These impacts could affect the fish directly or its habitat or both at the same time. These impacts could result in loss of fish biodiversity, production stocks and assemblages. Reservoirs can provide a barrier to upstream migration of fish, thereby preventing brood stock from reaching their spawning grounds during the breeding season. The dam may also prevent downstream migration for the fish which could also affect spawning and recruitment. Reservoirs constructed for hydro electric power generation bring severe mortality or damage to fishes passing through the discharge structures through abrasion against dam walls, turbine blade mangling, rapid pressure changes, water shearing effects and nitrogen super saturation in the stilling basin (Bernasckek 2001).

Limnological problems that often arise during reservoir operation phase include thermal stratification during the dry season. This results in deoxygenation of hypolimnion (the lake bottom) which can reduce the water quality thereby decreasing fish stocks. Turbidity resulting from sediments trap or release from the reservoir can create severe problems of fertility, productivity and pollution for the fish and water body. Invasion and explosiveness of aquatic macrophytes which sometimes occurs from cultural eutrophication also produces severe negative impacts on fish production. Mustapha (2008) highlighted some of these impacts on the fish and fisheries of Moro reservoir, Ilorin, Nigeria.

Though reservoirs results in productive fisheries and fish yield from them are usually higher in shallow, managed tropical reservoir (Marshall and Maes 1994), the construction of the reservoir in most cases results in changes in fish diversity and stock abundance (Bernascek 2001). Usually, some of the fish species decline, some disappear, others migrate, while some increase. This is due to changes from riverine to lacustrine conditions of the water body after the reservoir construction. Fluctuations in water level as a result of seasonal differences in the tropics and unregulated water withdrawal for irrigation, domestic and industrial water supply etc also produce disastrous effects on fish. Walker et al. (1979) have reported this scenario in Murray reservoir, Australia. Modification of thermal and chemical characteristics of the water occurring as a result of reservoir construction with the reservoir acting as a nutrient and heat traps and exporters is another known factor which impact negatively on fish (Petts, 1984).

4. Overcoming the Challenges for Sustainable Fisheries and Increase Fish Production

Sustainable fish production in reservoirs depends on its limnological character and the manner in which it is operated. Effective management of the reservoir for increased fish production can only be achieved if there is sound pre and post impoundment limnological data, good design and efficient operational management of the reservoir (Tundisi and Straskraba 1999). The first of the challenges to be solved is to have a pre-impoundment study of the limnology and fish assemblages on the river where the proposed reservoir is to be constructed. Environmental impact assessment (EIA) of reservoirs on the fish and aquatic biodiversity which is usually not carried out before and after the construction of reservoirs in many sub-Saharan Africa countries should be a must before a reservoir is approved for construction. This assessment will incorporate all data obtained and provide prognostication on reservoir aging, eutrophication, ecological interactions and the impacts of watershed uses. This could then be used in the reservoir management, operations and conservation of the reservoir resources. Environmental changes anticipated through studies developed by Tundisi et al. (2002) in Itaipu reservoir, Brazil became an important tool in the management and operation of the reservoir. In the light of these, limnologists and fisheries biologists should be consulted in the initial planning, construction, execution and subsequent management of the reservoir. According to Bernascek (2001), initial environmental examination (IEE) which provides a baseline assessment of the nature and value of fish biodiversity and fisheries in the project impact area, the type of severity of the impacts that could be expected, and the possible mitigation measures that might be implemented should be first carried out before the full EIA. Environmental risk assessment (ERA) from the perspectives of fish stocks should also be carried out in association with IEE. To overcome the challenges posed by the multipurpose uses of reservoirs to its fisheries, fish production should be integrated into the management programmes of the reservoir. This can be achieved by establishing and connecting the linkages between reservoir typology, water quality, biodiversity and reservoir operations (Tundisi and Straskraba 1999). In order to solve the problems of negative impacts of reservoir construction on fish, effective fish passage facilities for fish migration up and down stream across the dam should be provided. To do this effectively, a comprehensive study of the fish assemblage in the river is highly essential; also important is the type of fisheries that will develop in the new reservoir. This will not only be beneficial to the fish, but will also increase fish production, biodiversity and conservation in the reservoir. According to Tundisi and Tundisi (2003), the bulk of knowledge of the limnology of reservoirs produced

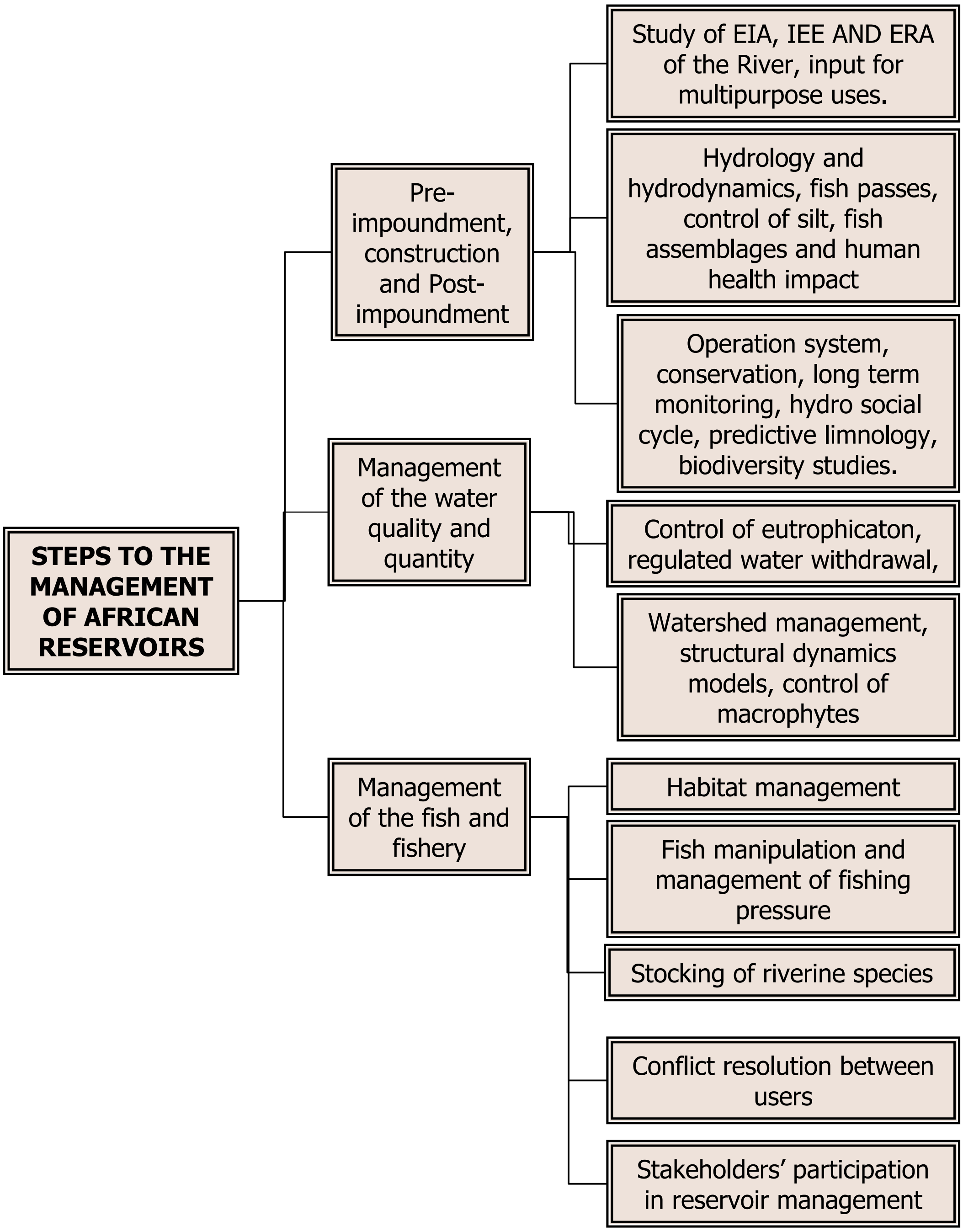

Figure 1: *Steps to the limnological management og multipurpose African Reservoirs from pre-impoundment to operation.*

in the last 30 years turned into a tool for managing artificial ecosystems, including watershed input and in elaborating the new technology for reservoir construction and operation.

The problem of soil erosion and silt run-off into the river during construction could be solved by ensuring proper construction practices. Control of erosion near the banks will minimize the problems of turbidity and thereby reduce the situation of the breeding habitats of fish. Special care and attention should be paid to the clearing of trees and bushes near the reservoir during construction. Drummed trees provide a large surface area for periphyton and zoobenthos growth and thus substantially increase the food supply for fish (Ploskey 1985), however, the trees also readily entangle fishing gear, thus decreasing the fish catch and bringing about a low catch per unit effort. Besides entangling fishing nets, trees also readily anchor mats of floating aquatic macrophytes such as *Eichhornia crassipess*, the water hyacinth which can form a massive growth covering of the whole reservoir. Partial clearing of the vegetation should be done to complete bush clearing. This allows cleared areas to be used for fish harvesting and uncleared areas as foraging and shelter for fish. Thermal stratification in reservoir could be prevented by ensuring that the reservoir depth does not exceed 10m. According to Straskraba et al. (1993), reservoirs that have maximum depth of 10m or less are usually unstratified. These shallow reservoirs are highly productive (Jackson & Marmulla 2001) and their fish yield are usually high (Mustapha 2009b).

Watershed activities which often contribute to eutrophication of reservoirs could be stopped or reduced by adopting BMP's (Mustapha 2009a). The use of BMP to control eutrophication will also help in controlling the explosiveness of aquatic macrophytes. Other limnological mechanisms which can boost fish production, mitigate the impact of reservoir on fisheries have been highlighted by Mustapha (2010). This includes guided and regulated water withdrawal and the establishment of Minimum Flow Levels (MFLs) in shallow tropical reservoirs especially in the dry season when water levels in these reservoirs are usually at critically low level.

5. Conclusion

In order to have a sustainable fisheries and effective management and operations of shallow tropical African reservoirs, a serious perspective of the limnology of the reservoirs based on information driven by management needs should be given adequate attention. A better predictive and adaptive management strategy is based on good predictive limnology (Straskraba et al. 1993). As reported by Tundisi and Tundisi (2003), management of reservoirs and new technology for construction and operations in the last 30 years were achieved based on the knowledge of the limnology of several reservoirs. There is a tightly coupled interaction between physico-chemical and biological properties of water, hydrology, construction, operations and functioning reservoirs. Therefore, there should be continuous monitoring of reservoir impacts on fish biodiversity and fish production as reservoir ecosystem changes with time. This is especially more applicable to Africa since there is dearth of limnological data on several shallow reservoirs as well as lack of information on ways to mitigate the reservoirs' impacts on their fish and fisheries. But it is possible to do it on African reservoirs. This can be done through developing a work plan to evaluate the situations and setting directions to achieve the goals. A local management organization involving a facilitator and the whole lake community should be established. Adequate funding for the programme should be sourced and finally periodic meetings involving technical advisory committee to analyze and take stock of the situation should be held regularly to know whether the goals have been achieved and further take actions on those goals not yet met.

One thing that should be borne in mind is that fisheries of reservoirs are tightly bonded to the limnology of the reservoir and one cannot exist without the other. We should therefore bear it in mind that fish biodiversity should not be lost during reservoir construction, operation, functioning and management.

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