SECTION 3: CHAMBO RESTORATION STRATEGIES

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Abstract

The Chambo fisheries in the South East Arm of Lake Malawi have been severely exploited and depleted due to overfishing, habitat degradation and use of illegal gears. The government of Malawi is determined to reverse the decline in order to restore the Chambo fishery so that it fulfils its potential in meeting the food security needs of the country. This paper summarizes briefly the existing experiences aimed at increasing the production of the Chambo in the lakes of Malawi by producing and releasing juvenile fish, enhancing habitats, creating fish sanctuaries, and promoting aquaculture. The paper also describes research needed to assess the potential for these interventions to contribute to increased production of the Chambo. In the case of restocking, the paper identifies the protocols required to implement responsible programs if this intervention is demonstrated to have good potential to 'fast-track' the recovery of the fishery.

Introduction

The Chambo fisheries in the South East Arm of Lake Malawi and Lake Malombe, which are based on *Oreochromis karongae*, *O. lidole* and *O. squamipinnis*, have been over-exploited severely. The fishery in Lake Malombe is known to have collapsed (FAO 1993; Palsson et al. 1999; Bulirani et al. 1999) with catches declining from over 4 000 t per annum in the 1970s to about 100 t in 1994 (Bland and Donda 1995). The situation is not much better in the South East Arm of Lake Malawi, where landings had decreased from previous levels of 4 000 t to about 600 t in 1999 (Manase et al. 2002). The government of Malawi is determined to reverse these declines and restore the production of Chambo so that this important resource can fulfil its potential in meeting the food security needs of the country. However, restoring the production of the Chambo will not be easy because the species are characterized by late maturity, low fecundity and extended parental care (Palsson et al. 1999). These aspects of the biology of the Chambo species indicate that a relatively long period is required for the stocks to recover (Weyl 1999). Recent observations reveal that despite decreases in fishing effort, the Chambo stocks in Lake Malombe and the South East Arm of Lake Malawi still remain low, indicating that reduction of effort alone is unlikely to rebuild the fishery within acceptable time frames.

Some management scenarios for rebuilding the Chambo stocks in Lake Malombe were put forward by the FAO Chambo Project (FAO 1993). These included: (i) halting all fishing in the lake; and (ii) achieving partial recovery of stocks through total closure of the Chambo fishery while still allowing *nkacha* and *kambuzi* seine operators to fish for other species. The second scenario was predicted to result in the recovery of Chambo stocks to levels that would provide an annual yield of 1 000 t within five years. In addition, a recommendation was made to restore the weed beds that help support the Chambo stocks, which formerly dominated the lake. Unfortunately, the management scenarios identified by the Project were never implemented due mainly to their expected negative socio-economic impacts on fishing communities (Weyl et al. 2001).

It is now apparent that the sustained economic losses from the severely over-exploited Chambo fisheries far outweigh the interim hardship required to restore the production of the Chambo to reach its potential. There is a great incentive, therefore, to find acceptable social and biological methods to intervene in the management of the fishery to restore it to levels at which optimum harvests can be taken each year. Since the FAO Chambo Project was completed, at least three other biologically-based options for rebuilding the Chambo stocks have been considered: (i) release of hatchery-reared juveniles in restocking programs; (ii) enhancement of habitats that support the Chambo, e.g., construction of brushparks; and (iii) use of fish sanctuaries to protect important nursery areas and a proportion of the breeding population. Production could also be increased through cage culture.

This paper summarizes briefly the existing experiences aimed at increasing the production of the Chambo in the lakes of Malawi based on producing and releasing juvenile fish, enhancing habitats, creating fish sanctuaries, and promoting aquaculture. The paper also describes research to be done to assess the potential for these interventions to contribute to the increased production of the Chambo. In the case of restocking, the paper also identifies the protocols needed to implement responsible programs if this intervention is demonstrated to have a good potential to accelerate the recovery of the Chambo fisheries in Lake Malombe and/or the South East Arm of Lake Malawi.

Evaluation of past experiences

Release of cultured juveniles

In the past, releases of juvenile Chambo have been limited. They occurred in the South East Arm of Lake Malawi, Lake Malombe and the Upper Shire River, but were restricted to symbolic liberations of fish, e.g., during the launch of the "Save the Chambo" campaign. Nevertheless, there is capacity to produce and release larger numbers of fish for restocking programs. This was demonstrated in 2002, when the National Aquaculture Center, supported by the Japan International Co-operation Agency (JICA), released 10 000 *ningwi* (*Labeo cylindricus*) into the Upper Shire River.

Habitat enhancement

Interest in habitat enhancement of the lakes of Malawi, through artificial reefs and brushparks, is just emerging. Jamu et al. (2003) reported the feasibility of improving fish production in Lake Chilwa using brushparks consisting of substrates from *Typha*, bamboo and *Sesbania* sp. Increases in production from such interventions are estimated to range from 0.4 to 0.7 $kg \cdot m^{-2} \cdot yr^{-1}$. Artificial reefs and fish aggregation devices have also been established at several sites in Lake Malombe (Collins Jambo, pers. comm.), although little is known about the abundance and species composition of fish associated with them. These artificial reefs were established to provide sanctuary for juvenile fish and broodstock. However, due to lack of enforcement measures, these additional habitats are currently exploited by fishers. This negates their intended use as the lack of enforcement has made the fish aggregated around the artificial reefs more vulnerable to capture.

Sanctuaries

Local communities have established fish sanctuaries in Lake Malombe but lack of monitoring, and effective tests for the effects of this potential management measure, means that it has not been possible to evaluate its contribution to productivity. Anecdotal reports indicate that fishers in the Makanjila area of Lake Malawi are catching more Chambo from sites where they have placed large logs to prevent trawlers from catching fish (Moses Banda, pers. comm.).

A related example of the potential value of sanctuaries comes from Lake Chilwa. This sanctuary in the lower reaches of Lake Chilwa influent rivers is now used as a source of fish to replenish the lake when it refills after drying. This measure is now used in preference to restocking with hatchery-reared juveniles.

Aquaculture

Although there are successful cage culture operations for related species elsewhere in the Southern African Development Community (SADC) region, e.g., the *Oreochromis niloticus* in Massinjiri Reservoir, Mozambique and Lake Kariba in Zimbabwe (Windmar et al. 2000), there is little experience in rearing the Chambo species in this way. However, preliminary experiments have been done by commercial operators in the South East Arm of Lake Malawi to produce *Oreochromis karongae* in cages, and an enterprise expected to produce 3 000 t per year is being planned for the area.

Research needed to assess potential benefits of interventions

Restocking

Several pieces of information are required to determine whether releasing cultured juveniles into Lake Molambe and Lake Malawi to augment the remnant wild stock will add value to the other measures normally used to rebuild the spawning biomass to more productive levels. The various types of research needed to assemble this information for each species of Chambo in Malawi are outlined below.

Stock delineation

A thorough understanding of the size and distribution of the stock(s) supporting a fishery is essential to all forms of fisheries management, including restocking. In particular, managers need to know whether the fishery is based on a single homogeneous stock or comprised of multiple, largely self-recruiting, populations. A good indication of stock structure can be provided by a thorough analysis of the genetic population structure of the species, although it should be noted that some stocks can still be divided into relatively isolated units even when gene frequencies are generally homogeneous. Thus, other tools to help determine stock delineation, e.g., multivariate comparison of morphometrics or species composition of parasites, may also be important.

The reason stock delineation is so important is that the objective of a restoration program is to rebuild the spawning biomass and, to be fully effective, the spawning biomass of all population units within the stock needs to be increased. Thus, when a fishery is based on more than one population unit, cultured juveniles will need to be added to all the units. It is also important to note, however, that adding more fish from just one source over the general area of the fishery will not necessarily be effective because each population unit can be expected to have local adaptations. Unless juveniles released into each population are derived from parents collected there, they may not have behaviors that are adapted for effective spawning.

Stock assessment

Once the stock structure of the fishery has been identified, the status (stock size and age structure) of the population(s) must be determined. Only then can managers assess whether the spawning biomass of the population(s) is too low to make it unlikely to recover quickly simply by implementing conventional management measures, e.g., a total moratorium on fishing, or whether a restocking program will also be required to restore the number of spawning fish to levels that will once again allow for regular substantial harvests. It is important to note that restocking is normally an expensive option; so restoration of the spawning biomass should be based on other forms of management whenever possible, provided they are effective within acceptable time frames.

An integral part of this process involves modeling to find out how long it will take the spawning biomass of each population to recover with and without restocking. To do this, the desired level of spawning biomass should be identified (e.g., 50% of the virgin level) and data need to be collected that will enable the potential contribution of restocking to be assessed. These data include the remnant stock size, generation times, fecundity, larval dispersal patterns, natural mortality rates at different life history stages, and behavior of the species that may affect spawning success or survival at low population density. Different restocking scenarios, e.g. variations in the frequency, number and survival rate of released animals and the subsequent survival of their F1, F2, F3 progeny, should also be examined. Generally, restocking is likely to be most beneficial when the initial stock size is very low and the generation times are long. In such cases, however, release of a large number of juveniles annually over a number of years may be needed.

Determine capacity of hatcheries to produce sufficient juveniles

If the modeling described above indicates that restocking will be beneficial, provision then needs to be made to ensure that the hatchery has the capacity to produce the required number of juveniles. If this cannot be done, the restocking program will not deliver the expected benefits. However, in cases where the capacity of the hatchery is limited, multiple and successive smaller batches could be produced, although this may mean that the restocking model needs to be adjusted.

Identify requirements of the young fish

To ensure that the cultured juvenile fish have the greatest possible chance of surviving and contributing to the spawning biomass, they must be released in ways and at times where they can avoid predators and find food. This involves a sound understanding of the distribution and abundance of their predators and identification of nursery habitats that provide the necessary protection. Field experiments should then be conducted to identify optimal release strategies (Blankenship and Leber 1995). This aspect of the research should be linked to experiments on how to increase the productivity of the Chambo through habitat enhancement (see below).

Components of a responsible restocking program

If the modeling described above indicates that the stock, or particular population units within the stock, of a species would benefit from restocking, careful attention should be paid to: (i) how the juvenile fish are produced and released; (ii) managing the restocked population(s); and (iii) determining the relative contributions of restocking to the restoration of the spawning biomass (Blankenship and Leber 1995; Munro and Bell 1997). The relevant components of a responsible restocking program are set out below.

Hatchery protocols to maintain the genetic diversity

The measures required to ensure that the natural gene frequencies are represented among the cultured fish are described by Munro and Bell (1997) and references therein. They include using large numbers of broodstock, replacing spawning animals regularly, ensuring that most broodstock spawn and preventing selective breeding among broodstock. If there are problems achieving any of these requirements they can usually be solved by releasing multiple cohorts derived from different parents. This results in a cumulative released population that has gene frequencies representative of the original wild stock.

Where the analysis of stock structure indicates that there is more than one population unit in the fishery, juveniles should only be released in the area where the broodstock were collected. This will involve applying the protocols outlined above to separate groups of broodstock from each population unit.

Quarantine procedures

The increased risk of diseases infecting fish reared under intense monoculture in hatcheries is well known. Therefore, all batches of cultured fish to be released should be tested to ensure that they meet acceptable levels of pathogens and parasites existing prior to stocking them in the lake. This will not only help to safeguard the remnant wild Chambo, it will also reduce the risks to other species. Infectious agents are often more pathogenic in atypical hosts (Munro and Bell 1997; and references therein). To safeguard the great biodiversity of fish in the lakes of Malawi, responsible quarantine procedures must be a consistent part of any restocking program used to increase the productivity of the Chambo.

Management measures to maximize benefits

Unless appropriate measures to manage the fish released in a restocking program are implemented, there is a grave risk that the often expensive investment in hatchery production may be wasted. Such measures are usually quite simple in principle. There should be a total moratorium on the catching of the species until there has been replenishment of the spawning biomass to the desired level (Bell 2004). The practicalities are never quite as easy, however, particularly when the species under restoration is part of a multi-species fishery and vulnerable as by-catch. In such cases, gear modifications, and spatial and seasonal closures for fisheries of other species may also be needed to protect the species being restocked.

As outlined in the introduction, an effective moratorium on the capture of the Chambo until replenishment occurs is likely to cause short-term hardship for fishers. It is, therefore, important to explain the long-term benefits to them and the need for restraint, otherwise many people may assume that the release of fish means that there will now be more to catch. This would be a mistake. It is vital that fishers understand that the fish and their progeny need to be totally protected until the spawning biomass has reached the point where the stock can once again yield sustainable harvests. It is also essential to inform fishers that the level of future sustainable harvest will have to be set at lower levels than in the past; otherwise, overfishing and stock reduction will just occur again.

Allocation of property or access rights to fishers prior to the moratorium will provide them with the incentive to comply because they will be the ultimate beneficiaries. However, the hardship that a restocking program imposes on fishers in the short to medium term needs to be recognized. If necessary, other incentives may need to be provided to target other species or transfer to alternative, related livelihoods, e.g., aquaculture of *O. karongae*. Where such resources or occupations are unavailable, well-enforced temporary exit arrangements with appropriate financial compensation may be necessary.

Determine the contribution of restocking to the recovery

An important part of the responsible application of a restocking program is to measure the success of the intervention. It is important to be certain how recovery occurred and to determine the contribution of restocking to the recovery of the stocks. A genetic tag is needed for this purpose, because the F1, F2, F3, etc. generations derived from the released animals must be tracked so that their contribution to the restored biomass can be assessed in comparison with those individuals derived from the original remnant wild stock.

Adopt an ecosystem approach

As mentioned above, managers need to identify the desired spawning biomass of one or more of the Chambo species as the target for the restocking campaign. Given the strong demand for these species, however, there may be pressure to favor increasing the production of the Chambo species at the expense of other fish. If so, managers should think about the environmental costs and identify the most desirable species mix and levels of abundance of each species. If, on the other hand, the niche of the Chambo has been filled by other species and efforts to restore the spawning biomass prove to be difficult, managers may need to consider measures to reduce the abundance of competitors or key predators to facilitate the establishment of the desired stock sizes of the Chambo species.

Habitat enhancement

Nursery grounds for the Chambo species are located inshore and include inlets in the lakeshore, mouths of streams and reedy shores of the two lakes and the Shire River as well as clean sandy and rocky shores (Trewavas 1983). Chambo fry live in shallows at the water's edge among reeds in pools and lagoons, whereas juveniles (60-200 mm) live not far from the shore where they feed as adults (Bertram et al. 1942). In the South East Arm of Lake Malawi and Lake Malombe, nursery grounds have been degraded by the clearing of aquatic vegetation to construct beaches in front of resorts and cottages. Dragging seine nets along the substrate has also destroyed the nests built by the Chambo and disrupted their spawning.

Habitat restoration and enhancement, which includes rehabilitation of shoreline vegetation, and the establishment of artificial reefs and brushparks is necessary. The artificial reefs and brushparks, targeting fry and juveniles, are expected to have the twin benefits of reducing fishing mortality by preventing seining and lowering natural mortality by providing more shelter and food for the fry and juveniles.

To determine whether habitat restoration and enhancement will assist the recovery of the Chambo stocks, well-designed field experiments are now needed to assess the differences in abundance of juvenile Chambo associated with restored weedbeds, artificial shelters and bare substrata.

Sanctuaries

Two potential benefits can be envisaged from declaring sanctuaries for the Chambo. First, they should help protect aquatic habitats that provide nursery areas for juveniles, including places where habitats have been enhanced if the research described above is successful. Second, they should also protect a greater proportion of the spawning fish, leading to an increase in the supply of juveniles to areas outside sanctuaries that remain open to fishing. The design of experiments to test the importance of shelter habitats for the Chambo described above can also be applied to nursery areas protected in sanctuaries.

The second hypothesis, involving the protection of spawning fish, predicts that the number and average size of spawning fish in sanctuaries should increase relative to fished areas, and that the abundances of juveniles in areas remaining open to fishing, but adjacent to sanctuaries, will be greater than in and around those areas that are not protected. Research to test these two predictions should be based on replicate samples from multiple sanctuaries and multiple areas that remain open to fishing before and after the sanctuaries are declared. The general models for such "before versus after, and impact versus control" sampling designs are described by Underwood (1992, 1995).

Sanctuaries will presumably play their greatest role once the Chambo stocks have been restored and when they can be tested as a means of sustaining catches. This will require calculation of the number and area of sanctuaries needed to replenish each population unit within the fishery. However, it may also be necessary to use sanctuaries as part of the restoration process to prevent the fisheries for other species from damaging the nursery habitats.

Aquaculture

The key research questions to determine the potential for aquaculture to increase the productivity of the Chambo are: (i) identifying appropriate production methods and feeds; ii) selective breeding programs to achieve faster growth, better food conversion and disease resistance; (iii) development of criteria to select suitable sites; and (iv) determination of carrying capacity of the ecosystem.

Production methods and feeds

The low fecundity of the *Oreochromis karongae* and the other species of the Chambo, typically <1000 eggs per female annually (Trewavas 1983), poses a potential problem for producing a sufficient number of juveniles for large-scale cage culture. For example, it is estimated that it will be necessary to hold 20 000 broodstock to produce the 15-20 million juveniles needed to rear 3 000 t of Chambo per year at the preferred market size. However, recent research at the National Aquaculture Center is pointing the way to a possible solution. High-quality juveniles can be obtained from spontaneous spawning of *O. karongae* in earthern ponds. This could pave the way for small-holders with ponds near the shore of the lake to supply juveniles to cage-culture enterprises. Such a system would distribute the benefits of aquaculture to the rural poor and provide alternative livelihoods for people removed from the Chambo fishery during any moratorium to reduce effort and support a restocking program.

The viability of cage culture is also likely to depend heavily on the production of a suitable, low-cost feed. This may not be too much of a problem, however, because the Chambo have a planktivorous, omnivorous diet (Trewavas 1983) and so there should be scope for producing a formulated diet based partly on plant protein. This would reduce the cost of feed considerably and alleviate some of the environmental consequences of cage culture by lowering the level of nutrients stemming from aquaculture operations. Research is now needed to identify the minimum nutritional requirements of the Chambo for good growth, and the most cost-effective way of producing diets that are based on agricultural products to the greatest extent possible.

Selective breeding

The technology that has been developed to improve *Oreochromis niloticus* through family selective breeding programs needs to be applied to the Chambo species selected for aquaculture. In the case of *O. niloticus*, the growth (body weight) rate was increased by 60% after six generations of selection (Dey 2000). It is essential, however, that the cage culture of the Chambo proceeds with safeguards to prevent the escape of the cultured fish. Otherwise, the fish selected for higher performance in aquculture may interbreed with the wild stock and lower their fitness. This would undermine the other components of the strategy to restore the production of the Chambo. The production of sterile YY males may help to address this problem.

Site selection

Careful thought needs to go into the location of cages for the culture of the Chambo. The criteria for site selection should not only be based on the requirements of the fish for good growth and survival. They should also ensure that the aquaculture operations have a minimal effect on the ecosystem and other fisheries. Measures will also have to be taken to secure access to suitable sites for cage culture enterprises.

Carrying capacity

As aquaculture is just one of the measures that should be used to increase the supply of Chambo, consideration must be given to the interaction between the culture operations and the wild fishery. Some of the relevant issues have been mentioned above. However, the overall carrying capacity of the lakes for the Chambo needs to be estimated so that decisions can be made about the proportion of optimum future production to come from aquaculture and the wild fishery. There is a lesson to be learned here from scallops in Japan, where a successful restocking and aquaculture campaign got out of hand at one stage. The combined biomass from aquaculture and the enhanced fishery caused "unexplained diseases", which reduced production and growth rates by 50% until the combined stocking densities were adjusted to match the carrying capacity of the ecosystem (Ventilla 1982).

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Culture-based production systems: Options for the Chambo in Lake Malawi and Lake Malombe

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Abstract

The drastic decline of the Chambo in Lake Malawi and Lake Malombe has sparked interest in its restoration to reach its maximum sustainable yield (MSY). The paper reviews several options that are applied worldwide and provides a synthesis of what could be done for the Chambo. Experiences from several countries, especially in Asia, have shown that culture-based production systems have resulted in high production of fish such as Tilapia and hence, if adopted in Malawi, can provide an alternative approach to increased fish production in Lakes Malombe and Malawi. The paper analyzes and compares management and production methods that can be used to enhance the Chambo stock in Malawi.

Introduction

To achieve its national goal and international obligations to restore the Chambo (*Oreochromis* spp.) fisheries of Malawi to their 1980 status by the year 2015 (DOF 2003), the national government is encouraging fisheries practices that will both protect existing stocks and replenish depleted stocks. Protecting existing stocks requires a comprehensive enforcement program while the replenishment of depleted stocks is a function of enhancement. The most common approaches to fisheries enhancement for inland water bodies are to increase the stock size (stock enhancement), introduce new species to broaden the catch structure (species enhancement) and improve the water quality through artificial eutrophication (environmental enhancement). The purpose of this paper is to analyze and compare management and production methods of enhancing the Chambo stock in Malawi. In doing so, this paper will specifically review the following culture systems: pond, pen and cage, tank, and raceway. In addition, the paper will also review the use of fish aggregation devices and their potential in the Chambo production.

Culture systems

Pond culture

Pond culture refers to the stocking of fish in an artificial pond or stream impoundment. Water is supplied from a watercourse diversion, reservoir or groundwater into the pond, which is constructed as a dugout (no dykes) or with dykes made of earth and/or concrete (Figure 1). According to Gietema (1999), ponds vary in size depending on their primary functions, i.e., for broodstock, nursery or on-growing (fattening). Broodstock ponds are used to hold the parent fish and usually range in size from 1 000 m^2 by 1 m deep. Nursery ponds are used for fry rearing and fingerlings and are usually 100-1 000 m^2 in area. On-growing ponds hold maturing fish until they have reached marketable size; they can range in size from 25 m^2 to larger than 100 ha.

In general, there are three main types of pond operations: extensive, semi-intensive and intensive. An extensive system has low inputs and low yields (0.1–0.3 $t \cdot ha^{-1} \cdot year^{1}$). A semi-intensive system requires some management and supplementary feeds to achieve higher outputs (1-5 $t \cdot ha^{-1} \cdot year^{1}$) than extensive systems. An intensive system requires high skill and high levels of inputs to achieve its high output (5-50 t·ha^{-1}·year^{1}) (Gietema 1999).

Figure 1. An example of a small-scale pond culture operation (from Coche 2000).

Bimbao and Smith (1988) summarized pond culture production systems in the Philippines reporting 0.4-1.5 t·ha^{-1}·year^{1}, although the level of intensification was not identified. For Israel, Sarig (1990) reports 3 t·ha^{-1}·year^{1}, 9 t·ha^{-1}·year^{1} and 20-50 t·ha^{-1}·year^{1} in extensive, semi-intensive and intensive ponds systems, respectively. Lazard et al. (1988) studied pond culture in Cote d'Ivore and found yields of 5.2–7.1 t·ha^{-1}·year^{1} depending on the feed type; yields of 15 t·ha^{-1}·year^{1} were also reported. ICLARM and GTZ (1991) report that in Africa yields of 0.1-0.5 t·ha^{-1}·year^{1} and 1.0-5.0 t·ha^{-1}·year^{1} are standard for extensive and semi-intensive systems, respectively.

As a system becomes more intensive, there is an increasing level of risk associated with the capital gains and losses. Capital is needed in the intensive system for infrastructure, processed feeds, skilled labor, higher stocking densities, disease control, fertilization, and machines for aeration and water circulation. Thus, the operation is less accessible to people without financing or expertise (ICLARM and GTZ 1991). In the intensive system there is also a corresponding risk associated with environmental degradation depending on how the inputs are obtained (e.g., stream diversion) and how wastes and other outputs are processed (e.g., downstream impacts) (Edwards et al. 2000). Depending on the design of the pond, possible environmental impacts include the disruption of the hydrological cycle, blockage of sediment transport, and the accumulation of effluents may cause high suspended solid counts and lack of oxygen in the water (ICLARM and GTZ 1991).

Pen and cage culture

Pen culture (Figure 2) refers to the use of framed net structures fixed to the substrate in open water environments (i.e., lake, river or ocean) and are widely used for rearing and fry production in marine "sea-ranching" industries in both Japan and North America (Piper et al. 1982). Cage culture (Figure 3) systems utilize a similar structure as pen culture, only in this case, the structure floats at the surface level and is anchored to the substrate.

Cage and pen culture is applicable where water cannot be drained (i.e., from a pond) or where harvesting a large area is inefficient. The overall costs of constructing a pen or cage is often lower than pond construction (ICLARM and GTZ 1991; Lazard et al. 1988) although finding a suitable site may prove difficult along high-energy shorelines.

Yields vary by a wide range in pen and cage culture systems around the world. Tantikitti et al. (1988) mention results of a pen culture growth experiment of *Tilapia* (*O. niloticus*) in Thailand at 5–17 t·ha^{-1} depending on the feed type. Morissens et al. (1988) report a production of 60 t·ha^{-1}·year^{1} in pen culture systems in brackish waters in coastal Benin. ICLARM and GTZ (1991) state that production can range from 25 to 220 t·ha^{-1}·year^{1} in African cage and pen systems.

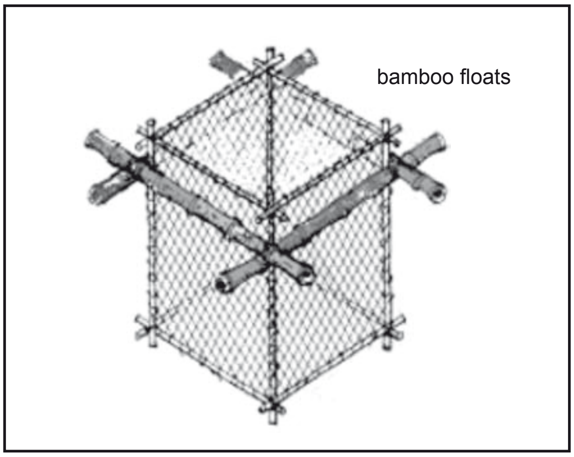

Figure 2. An example of a net cage (from Coche 2000).

While the construction costs of pen or cage culture suggest low start-up capital requirements, there is a risk of incorporating higher costs in other portions of the production cycle and in areas adjacent to the pen or cage itself. With an increase stocking density relative to many pond culture systems, disease management becomes a more

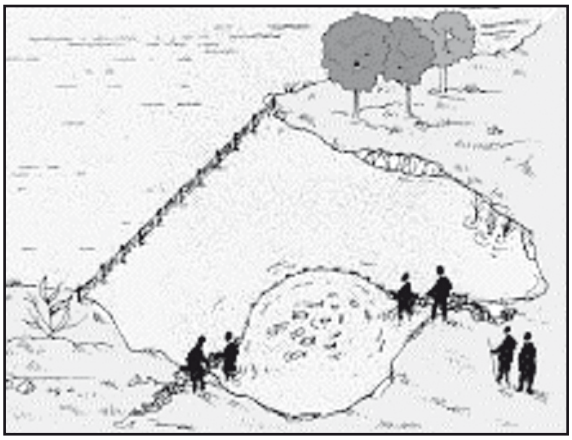

Figure 3. A shoreline fish pen (from Coche 2000).

prevalent issue limiting production and increasing the costs of maintenance (i.e., treatment). Muir et al. (2000) point out that in Israel 30-60% of *Tilapia* spp. aquaculture production is lost due to the *Streptococcus* bacteria in intensive systems. Such intensive systems can also cause anoxia in the benthos where circulation is inadequate, thus, limiting feed, oxygen and nutrient availability (ICLARM and GTZ 1991).

Management of pen and cage culture systems must address the cumulative impact of closely grouped operations or face reduced production in downstream users and other stakeholders in the aquatic resource (e.g., drinking water). Capture fisheries may also suffer if pens are sited in traditional fishing, fry rearing or breeding areas along the shoreline (ICLARM and GTZ 1991).

Tank and raceway culture

The most capital-intensive method of fisheries enhancement is the use of metal or concrete tanks with flow through water, high stocking densities (e.g., 50 $kg \cdot m^{-3}$), processed feeding, and control over physical and chemical water qualities. This system has been in use for *Tilapia* spp. in Kenya since 1975 and in other African countries such as Nigeria, Egypt, and Zambia (ICLARM and GTZ 1991). Productivity of the tank and raceway system is the most efficient means of producing fish protein at 2 000 $t \cdot ha^{-1} \cdot year^{-1}$ (ICLARM and GTZ 1991).

High capital costs for these systems make financing difficult and an ample market demand must be in place to make the venture profitable. The consumption of inputs such as freshwater and electricity (e.g., to operate pumps and quality control equipment) and the removal of waste outputs (i.e., effluents) require consideration in any environmental impact analysis. The suitability of the Chambo to this system is also questionable.

The prevailing view among aquaculture researchers is that the Chambo is difficult to grow to marketable size in captivity due to early maturation. Masuda et al. (2004) argue that if placed in suitable environmental conditions, then *Tilapia* spp. fishes can avoid early maturation and reach marketable size. Tank and raceway culture presents the best opportunity to deliver ideal conditions in intensive production systems as complete control over inputs is possible, unlike cage, pen or pond culture. The economic advantages of this approach must then be compared to ranching for which inputs are less intensive but with reduced productivity as well.

Habitat and fishery enhancement

Fish aggregation devices

Fish Aggregation Devices (FAD) are used in open water systems to attract prey species, target species and increase the production of the aquatic community. In freshwater environments this system is used widely in Mexico, Ecuador, Southern Asia and in some countries in Africa, namely Benin, Madagascar, Liberia, Cote d'Ivore, Sierra Leone, and Malawi (ICLARM and GTZ 1991). While these systems around the world with differ with various cultural and biophysical factors at play, the underlying principle of a FAD is the deliberate manipulation of sub-aquatic structures to attract target species. When it is time to harvest a net is encircled around or placed within the FAD, which is then removed to allow for the capture of the fish.

The main types of FAD in Africa are known as brushparks in West Africa, *acadja* in Benin and *vovomora* in Madagascar (ICLARM and GTZ 1991). In general, these systems utilize woody vegetation 2-2.5 m in length planted in the substrate to attract fish, and use some type of fence surrounding the brush to trap them. Thus, the start up capital is low for infrastructure, and, although supplementary feeding can be utilized, these systems are generally considered semi-intensive.

According to Balarin (1987) production rates from FAD, depending on the design, can range from 5 to 38 $t \cdot ha^{-1} \cdot year^{-1}$. Owing to the addition of brush wood over time, productivity of the brushpark increases as older vegetation decays and adds nutrients to the system. Experiments in Malawi with brushparks in Lake Chilwa (Jamu et al. 2003) and on fish farms (Chirwa 2004) have met with only minor or negligible increases in productivity compared to the control.

With a brush wood replacement rate of 30-75%, the demand for forest products to support the brushwood system is high, up to 60 t·ha^{-1}·year^{-1}(ICLARM and GTZ 1991). In coastal Benin where this practice is widely used, deforestation has become a serious problem and the subsequent siltation of the fishing areas has had further drawbacks to the productivity of this aquatic ecosystem. As with the cage/pen systems, occupation of the near shore areas by brushpark operations can reduce the availability of spawning and rearing habitat for capture fisheries.

Fish ranching

Fish ranching is an integration of aquaculture with capture fisheries in which the young are hatched and reared in a controlled environment such as a pond, net cage or pen until they reach a target size, and then they are released into open waters to grow to marketable size. This is a common enhancement technique used in marine fisheries such as the salmon fisheries of North America and the Baltic countries (Piper et al. 1982).

Because fish are released into open waters, productivity is low per unit area, approximately 0.05-0.3 t·ha^{-1}·year^{-1} (ICLARM and GTZ 1991). However, this does not reflect the overall productivity of the fishery as traditional capture fisheries using efficient harvesting technologies can be employed in the open water environment.

Conclusion

The choice of system to adopt must take into account the goals of the operation (i.e., profit, integration, or supplementary diet), availability of resources (i.e., expertise, labour, finances, raw resource inputs or waste disposal resources) and the suitability of the Chambo to be produced within a particular enhancement system. A comprehensive research plan that addresses the suitability of these enhancement systems to the Chambo production must be developed, including the analysis in both closed and open water systems. Furthermore, policy makers, donors and resource managers must carefully examine the impacts of each approach on the surrounding economies and environments where enhancement programs are planned. Lastly, each enhancement system requires a corresponding resource management strategy to ensure its sustainability and compliance with regulations from local communities and external investors. Benefits of enhancing the Chambo stocks in Malawi can be realized but these gains must be weighed against the environmental and socio-economic costs of intensifying production.

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Environmental impacts on the growth and survival of the *Oreochromis karongae* in captivity

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Abstract

The objective of the study was to determine the interactions of physico-chemical factors on the growth and survival of the *Oreochromis karongae* raised on low cost farm bio-resource inputs. The maximum yield of 618.3 $kg\cdot ha\cdot^{-1}\cdot 225$ $days^{-1}$ and the minimum yield of 237.0 $kg\cdot ha\cdot^{-1}\cdot 225$ $days^{-1}$ were recorded from inputs of chicken grower's mash plus grass, and grass only treatments. The survival was highest (55-71%) in treatments where morning-dissolved oxygen values were above 5.3 $mg\cdot l^{-1}$ and the lowest yields were obtained where dissolved oxygen was less than 4.5 $mg\cdot l^{-1}$. Multiple regression analysis showed that chicken mash, napier grass and poultry manure inputs accounted for 72.5% (adjusted r^2=0.72, P=0.038) of the growth variation. In low input treatments, however, the water quality was variable and this adequately explained this growth variation. Phosphorus (adjusted r^2=0.56, p=0.015) explained significant growth variations. The pH and electrical conductivity (adjusted r^2=0.71, p=0.0030) explained growth variations in high input treatments suggesting a general nutrient deficiency in the system. Ammonia, pH and temperature explained variations observed in fish survival (adjusted r^2=0.56, P=0.010). Dissolved oxygen significantly explained variations observed in both growth and survival (r^2=0.76, P=0.002). To confirm these observations, the *Oreochromis karongae* was raised at two sites of different water quality variables: in relatively soft water (pH=6.50, total hardness=70.90 $mg\cdot l^{-1}$, total alkalinity=20.00 $mg\cdot l^{-1}$) and hard water (pH=8.96, total hardness=120.90 $mg\cdot l^{-1}$ and total alkalinity=150.00 $mg\cdot l^{-1}$). The base saturation in soil at the two sites was low (30-70%) and high (80-100%), respectively. Fish growth increased from the average weight of 7-10 g to 80 g and 300 g, respectively, in 290 grow-out days. This growth response translated to specific growth rates of 0.93 and 1.47%. Water quality factors could not explain 27.5% of the growth variations, suggesting a potential for genetic improvement of the *Oreochromis karongae* once environmental and genetic interactions are exploited.

Introduction

Msiska and Costa-Pierce investigated successfully reproduction in captivity of the *Oreochromis karongae* (subgenus *Nyasalapia*) (Msiska and Costa-Pierce 1997). The use of cage nets or "hapas" and exogenous hormones resulted in consistent spawning success. These results might be applied on a larger commercial scale. On the other hand, results of growth performance have been inconsistent (Msiska and Costa-Pierce 1996; Maluwa et al. 1995).

Previous studies have isolated some of the environmental factors vital to fish growth and mortality in both wild and captive populations (Mann 1992, 1993; Mann and Drinkwater 1994) and in fish ponds (Boyd 1990; van Dam 1990a; Prein et al. 1993). Generally, high natural variability of environmental factors and multicollinearity make it difficult to estimate their respective contributions to growth and survival. Pauly (1980) was able to demonstrate a strong relationship among several factors: mortality, growth constant, length and average annual surface water temperature in natural fish populations. This finding has found worldwide application and acceptance (FAO 1993). However, the influence of environmental factors on the performance of the *O. karongae* has yet to be quantified, although high growth rate was demonstrated in ponds (Msiska and Costa-Pierce 1996; Msiska 1998).

The growth rates of wild populations in Lake Malawi and Lake Malombe of the endemic tilapias species of the Chambo group, *Oreochromis lidole*, *Oreochromis squamipinnis*, and *Oreochromis karongae*, are relatively high (Lowe 1952). The mean total lengths of 9-13 cm are attained in the first year, 17-23 cm in the second year, 24-28 cm in the third year and 26.5-30.0 cm in the fourth year. When transferred into ponds and stocked at low densities and fed good quality feeds, the *O. karongae* and *O. squamipinnis* grew to a large size of $L\infty$=23.6-31.3 cm and $W\infty$=537-891 g in 275 days (Msiska and Costa-Pierce 1996). In polyculture, however, there was a significant depression in growth (Maluwa et al. 1995). On average, the *O. karongae* grew from 54 g to 104 g in 112 days. This shows a significant discrepancy in growth performance. The species is naturally pelagic and inhabits open waters of relatively high alkalinity (2.45 $meq \cdot l^{-1}$), pH (7.8-9.0), electrical conductivity (215-230 $\mu S\ cm^{-1}$) and water temperatures of 22.0-29.0°C (Fryer and Iles 1972; Menz 1995). Could water quality factors hold the answer to observed differences in fish growth?

Boyd pointed out that investigating environmental factors can be complicated by the fact that interactions are along both biological and chemical lines (Boyd 1990). For this study, multiple regression analysis determined the critical predictor variables in the growth of captive *O. karongae*. Prein et al. (1993) applied this technique to explain fish growth and showed its robustness in capturing multiple factors implicated in what Pauly and Hopkins (1983) referred to as the "black box".

Alteration of water quality through the addition of lime, fertilizers or manures, feeds or combinations thereof affects tilapia production in ponds (Miller 1975; Boyd 1990). Many studies have shown positive simultaneous effects of environmental factors on the performance of the *Oreochormis niloticus* under various conditions. Boyd (1990), Prein et al. (1993) and van Dam (1990a) conducted the most notable studies. Similar studies were thought to be appropriate for the *Oroechromis karongae* because of the open water preference in lakes of its origin where growth performance is comparable to the best growing tilapia, *Oreochromis niloticus* (Msiska and Costa-Pierce 1996). The study may also enhance knowledge about the most suitable aquaculture system for this fish.

Materials and methods

Source of fry and fingerlings

The parent stocks of *O. karongae* were caught from Lake Malawi and Lake Malombe between September 1989 and March 1990. Since immature fish of three species, namely *O. squamipinnis*, *O. lidole*, *O. karongae*, occur in the same habitat and are difficult to separate, captured fish were left to grow to over 100 g to allow nuptial colors to develop in order to aid identification. Taxonomic characteristics for separating these fish have been outlined by Turner et al. (1989). First generation offspring raised on the farm were used in these experiments. Each pond of 200 m^2 and 0.8 m depth was stocked with 100 fish weighing 14.2±3.8 g (mean and standard deviation).

Bio-resource inputs into fish ponds

The experiment covered 24 ponds. Combinations of bio-resource inputs comprised: chicken grower's mash; and napier grass and poultry manure were added into the ponds at equivalent rates of 0.04 $kg\ N \cdot day^{-1} \cdot pond^{-1}$, 1.36 $kg\ N \cdot day^{-1} \cdot pond^{-1}$ and 0.23 $kg\ N \cdot pond^{-1}$, respectively. Each treatment was replicated twice using a completely randomized design. The experiment lasted for 225 days.

Sampling of fish

The growth rate was estimated from the average weights obtained from a random sample of at least 15 fish from each pond fortnightly. Every fish was weighed and had its total length measured in centimeters to the nearest one decimal point. Multiple regression analysis was conducted on fish growth and water quality variables.

Determination of water quality factors

Selected water physico-chemical factors were measured from each pond at 05h00-08h00 every fortnight. Values for each treatment were compiled from the replicates. An YSI meter measured the electrical conductivity. Analytical methods were according to APHA (1995). The total hardness and total alkalinity were determined titrimetrically using ethylenediam inetretraacetic acid (EDTA), phenolphthalein and methyl red. The Nessler method estimated the ammonia while phosphorus required the molybdenum complexiometric technique. Both elements were absorbed on a spectrophotometer. A Horiba meter determined the pH. Within one hour of sampling all analyses were completed to minimize *ex situ* changes.

Comparison of fish growth at two sites: Domasi and Kasinthula (southern Malawi)

In order to confirm differences in fish growth under varying environmental conditions, the growth performance was compared in two unreplicated ponds located at Domasi and Kasinthula, respectively, at a stocking density of one fish (7-10 g mean weight) per 1 m^2. Kasinthula is located in the Lower Shire Valley, which is a wetland extension of the Zambezi River, at 80 m above sea level. It has a mean air temperature of 25°C and a maximum of over 40°C. Soils are of the calcimorphic alluvial type with a base saturation of 80-100%. The pH of the soils is between 7.0 and 8.5. The second site at Domasi is 750 m above sea level. The mean air temperature is 22.1°C with a maximum of over 33°C. The soils are classified as latosols of the ferrallitic type with a base saturation of 30-70%. The pH of the soils varies between 4.0 and 4.5. The two sites are 75 km apart.

The experiment lasted from March 1991 to February 1992. Owing to the distance between the sampling sites, physico-chemical analyses for electrical conductivity, pH, dissolved oxygen, total alkalinity, total hardness, nitrogen and orthophosphate were conducted at the beginning, middle and end of the experiment. The data were sparse and not included in a multiple regression analysis.

Data analysis

The fish growth was calculated by the formula given by Gulland and Holt (1959) as follows:

$$\Delta L/\Delta t = L\ (t + \Delta t)\text{-}L\ (t)/\Delta t$$

Multiple regression analysis was conducted according to Zar (1984). In order to verify whether the assumptions of linear regression (zero mean error, constant error variance, independent error) were indeed satisfied, residual plots were examined for structural patterns (i.e. plots of residuals against every X and the estimated Y), and the Durbin-Watson statistics (Durbin and Watson 1951; Zar 1984). The Durbin-Watson statistics were compared with dL and du to test autocorrelation.

Growth data of fish from the unreplicated experiment conducted at the two sites were calculated according to the following formula:

$$\text{SGR \%} = \{(\ln W_t\text{-}\ln W_o)/t\} \times 100$$

where W_t = final body weight, W_o = initial body weight, and t = time interval.

All statistical tests conducted used Microstat Software (Ecosoft Inc., USA).

Results

Table 1 provides a summary of the fish yields, growth and survival, while water quality results for Domasi and Kasinthula are presented in Table 2.

As expected, the lowest growth rate was recorded in the no input treatment (control) while the highest growth rate was achieved in the grass plus grower's mash treatment (Table 1). A mixed suite of all inputs did not necessarily produce the best production. Instead there was a significant drop ($P<0.05$) in yield from 618.3 to 280.0 $kg \cdot ha^{-1} \cdot 225\ days^{-1}$ when poultry manure was added. When the value of chicken grower's mash input was raised from 2.5% to 5.0% of the fish body weight, yields increased from 320.0 to 431.1 $kg \cdot ha^{-1} \cdot 225\ days^{-1}$.

The overall ANOVA test did not show any significant differences in the fish yield among the treatments ($F_{ratio}=4.05$, $P=0.059$).

A correlation matrix was constructed to identify multicollinearity (Table 3). A cutoff point (±0.499) was included as a factor in the model.

This criterion indicated that the following factors were significantly correlated: initial body weight and ammonia levels; chicken grower's mash and ammonia levels; grass and ammonia levels; poultry manure and alkalinity; poultry manure and dissolved oxygen; poultry manure and phosphorus levels; alkalinity and ammonia levels; initial body weight and dissolved levels; initial body weight and phosphorus levels; final body weight and phosphorus levels; and dissolved oxygen levels and growth rate.

Table 1. Yield and survival of the *Oreochromis karongae* raised at the NAC, Domasi, Malawi, using various inputs. Fish were stocked at 10 000 fish·ha^{-1} in all treatments.

Treatments	Replicate	Initial weight (g)	Final weight (g)	Survival	Net yield (kg·ha^{-1})
No input (control)	1	22.0	45.90	36.5	307.5
	2	10.2	25.5	74.5	260.0
	Average	16.6	35.7	55.5	283.0
Chicken grower's mash (2.5% BWD)	1	15.1	35.1	99.5	430.0
	2	13.4	49.4	42.5	210.0
	Average	14.3	42.3	71.0	320.0
Chicken grower's mash (2.5%)+ grass	1	10.7	64.3	31.5	312.5
	2	13.8	57.1	35.0	250.0
	Average	12.3	60.7	33.3	281.3
Poultry manure	1	11.8	112.9	17.5	190.0
	2	4.0	54.2	48.0	290.0
	Average	7.9	78.6	24.0	240.0
Poultry manure + grass	1	10.9	84.6	26.0	280.0
	2	15.7	77.6	29.0	340.0
	Average	13.3	81.1	27.5	310.0
Chicken grower's mash (2.5%BWD) + Poultry manure	1	13.3	77.3	22.0	200.0
	2	10.1	69.0	56.5	390.0
	Average	11.7	73.3	39.3	295.0
Grass + Poultry manure + Chicken grower's mash (2.5% BWD)	1	6.6	66.7	13.5	11.0
	2	13.0	38.3	47.0	450.0
	Average	9.8	52.2	30.3	280
Grass	1	9.1	37.7	63.5	280.0
	2	23.1	40.4	47.5	195.0
	Average	16.1	39.1	55.5	237.5
Chicken grower's mash (5% BWD)	1	15.8	66.8	46.0	377.5
	2	21.1	198.8	23.5	485.0
	Average	18.5	132.9	34.8	431.3
Chicken grower's mash (5% BWD)	1	16.7	100.9	56.5	570.0
	2	20.4	87.5	72.5	666.5
	Average	18.6	94.2	64.5	613.3
Grass + Poultry manure	1	19.9	70.9	39.5	230.0
	2	18.2	116.7	41.5	455.0
	Average	19.1	93.8	40.5	367.5
Chicken grower's mash (5%) + Poultry manure + Grass + grower's mash (5%)	1	9.2	73.5	27.5	245.5
	2	29.2	88.9	13.5	210.0
	Average	19.2	81.2	20.3	227.3

Table 2. Summary of water quality parameters recorded in *Oreochromis karongae* ponds at Domasi and Kasinthula, southern Malawi. Values are means and standard deviations.

Parameter	Domasi	Kasinthula
PH	6.50	8.96
Orthophosphate (mg·L^{-1})	0.80±0.12	0.50±0.08
Total nitrogen (mg·L^{-1})	1.30±0.28	0.94±0.20
Total hardness (mg·L^{-1})	70.90±0.70	120.9±03.10
Total alkalinity (mg·L^{-1})	20.00±0.99	150.00±5.90
Electrical conductivity (μmho·cm^{-1})	94.60±6.18	163.30±10.50
Calcium (mg·L^{-1})	34.30±2.22	51.70±2.16
Magnesium (mg·L^{-1})	36.60±3.05	68.30±5.70

Table 3. Correlation matrix to identify multicollinearity. Number of cases (12) and number of variables (14).

	sgr	ibw	fbw	rec	mash	grass	manure
sgr	1.000.00						
ibw	-0.39334	1.000.00					
fbw	*0.7522	-0.37233	1.000.00				
rec	-0.28934	0.16304	-0.11086	-0.28421	0.3416	1.000.00	
mash	0.30461	0.27543	0.20654	-0.28421	0.03416	1.000.00	1.000.00
grass	0.05372	0.28949	-0.03949	-0.36996	0.03416	0.16903	*0.57616
manure	0.48609	-0.18161	0.10937	*-0.68188	-0.03835	0.16903	1.000.00
cond	0.26404	0.54129	0.11464	-0.52896	0.48229	0.37497	-0.02814
ammonia	0.21571	*0.70553	0.2093	*-.80201	*0.66073	0.41621	-0.41208
pH	-0.1529	-0.50807	0.10185	0.39091	*-0.08285	-0.53402	-0.52264
alk	0.24621	0.52826	0.13469	0.44361	-0.39567	-0.31809	*-0.73818
do	-0.45679	-0.38918	-0.0936	*0.57132	-0.39567	-0.31809	*-0.73818
temp	0.40074	-0.12812	0.31092	-0.39942	0.01827	0.3489	0.47633
phosph	0.21656	0.33808	0.00658	-0.52326	0.41611	0.06051	*0.628251
	ammonia	**pH**	**alk**	**do**	**temp**	**phosph**	
ammonia	1.000.00						
pH	-0.4194	1.000.00					
alk	*0.70569	*0.59599	1.000.00				
do	*-0.56863	*0.712674	*-0.83692	1.000.00			
temp	-0.19995	0.13086	0.15083	-0.35822	1.000.00		
phosph	0.40435	-0.6152	*0.88242	*-0.81862	0.0341	1.000.00	

Footnotes: 5% Significance > -0.574 or < -0.574.
* denotes significant correlations.
Key: ibw=initial fish body weight (g); fbw=final fish body weight (g); rec=fish recovery (%); mash=chicken layers mash (g); cond=electrical conductivity (µmho·cm^{-1}); do=dissolved oxygen (mg·l^{-1}); alk=alkalinity (mg·l^{-1}); temp=water temperature (ºC); phosph=total phosphorus (mg·l^{-1}).

Table 4. Multiple regression models of specific growth rate as the dependent variable using various inputs in *Oreochromis karongae* ponds.

Independent variables	B		SE	Beta
Initial Body Weight (g)	-0.0178		0.01092	-0.3619
Final Body Weight (g)	0.00347		0.001288	0.51117
Recovery (%)	0.006244*		0.003394	0.5286
Grower's mash (kg/week)	0.0175*		0.008038	0.4692
Napier grass (kg/week)	0.06309*		0.005173	2.4402
Poultry manure (kg/week)	0.02502		0.008562	0.7017
Constant (a)		0.17		
Adjusted R^2		0.72		
F Value		5.661		
Probability		0.0384		
Durbin-Watson		1.2885		

Table 5. Multiple regression models for recovery percentage.

Independent variables	b		SE	Beta
Grower's mash	-2.395		0.962	-0.756
Napier grass	-0.661		0.686	-0.301
Ammonia	72.568**		23.387	1.1352
PH	56.778*		46.241	0.455
Alkalinity	-1.274		1.139	-0.4266
Temperature	-24.17		12.583	-0.4266
Constant		140.171		
Adjusted R^2		0.563		
F Value		3.357		
Probability		0.01035		
Durbin-Watson Test		2.1142		

Table 6. Multiple regression models of the Gulland-and-Holt function as the dependent variable in the grower's mash (5% BWD), poultry manure and grass treatment.

Independent variables	b		SE	Beta
Conductivity	0.021**		0.00507	0.3125
Ammonia	0.212**		0.9	-0.215
Temperature	0.08		0.25	0.0516
Constant		-3.048		
Adjusted R^2		0.652		
F Value		7.232		
Probability		0.015		
Durbin-Watson Test		2.0174		

Table 7. Multiple regression models for grass and chicken grower's mash (5% BWD) inputs.

Independent variables	b		SE	Beta
Dissolved oxygen	0.939**		0.161	1.9556
Phosphorus	-0.247		0.75	1.1023
Constant		-0.507		
Adjusted R^2		0.755		
F Value		16.406		
Probability		0.0015		
Durbin-Watson Test		2.0987		

Table 8. Multiple regression models for chicken mash (5%) and poultry manure treatment.

Independent variables	b		SE	Beta
Dissolved oxygen	0.163**		0.04	0.4013
Phosphorus	-0.018		0.039	-1.013
Constant		0.078		
Adjusted R^2		0.596		
F Value		8.387		
Probability		0.0109		
Durbin-Watson Test		2.1234		

Electrical conductivity was correlated to several physico-chemical parameters (ammonia, pH, alkalinity, dissolved oxygen and phosphorus).

Multiple regression results (Table 4) showed that the fish growth rate was explained mostly by inputs of chicken grower's mash, napier grass and poultry manure (adjusted $r^2=0.72$, $P<0.0384$). Mortality was significantly and positively correlated with inputs of napier grass, poultry manure, and negatively correlated with ammonia, pH and dissolved oxygen levels (adjusted $r^2=0.563$ $P<0.0104$). In the treatment where 5% of the body weight of chicken grower's mash was added to the poultry manure and grass, conductivity, ammonia, and temperature significantly explained the fish growth (adjusted $r^2=0.652$, $P<0.0150$) (Table 7). When the same treatment was repeated with reduced input of chicken grower's mash to 2.5% of the body weight (Table 8), dissolved oxygen was the main predictive variable (adjusted $r^2=0.74$, $P< 0.006$). The addition of poultry manure and 5% of the body weight chicken grower's mash led dissolved oxygen to be a significant predictive variable (adjusted $r^2=0591$, $P<0.0259$).

Results of unreplicated growth comparisons of the *O. karongae* in two different environments at Kasinthula and Domasi are presented in Figure 1. These results show that the specific growth rate at Domasi was lower (0.93%) compared with that of Kasinthula (1.47%).

Discussion

Considering that relatively high level of inputs of bio-resource inputs were added, the results of fish yields were inferior to experiments done elsewhere (Boyd 1990; Pullin et al. 1989; Pullin et al. 1996). The growth of the *Oreochromis*

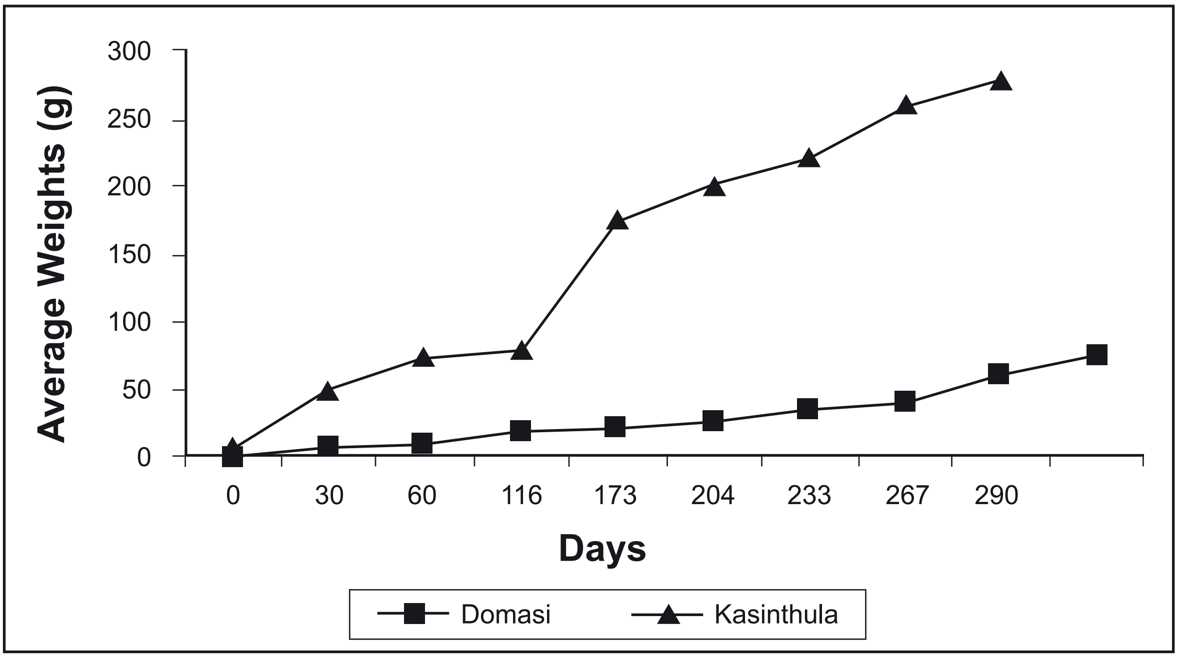

Figure 1. Plot of measures of population variation; mean±se observed (na) and effective (ne) number of alleles for individual Chambo populations.

karonage in the chicken grower's mash treatment was adversely affected by the addition of poultry manure and Napier grass while mortality was affected by dissolved oxygen levels.

Water quality factors were generally lower than optimum values reported for other tilapia species (Boyd 1990). Electrical conductivity, total alkalinity, and pH were low at the Domasi site despite high inputs of bio-resources. This may be attributed to low ion exchange capacity in the soil, which has been reported by Jamu (1990) and Jamu and Msiska (1996).

Dissolved oxygen was negatively correlated to specific growth rate, demonstrating that water quality deterioration adversely affected fish growth. The linkage between fish mortality, poultry manure levels and dissolved oxygen confirmed this finding. Phosphorus and electrical conductivity positively influenced fish growth in the low input treatment, indicating a general nutrient deficiency. Phosphorus was negatively related to pH because P is fixed by Al^{3+} under low pH conditions (Boyd 1990). Furthermore, these parameters were attributed to unfavorable water conditions, which were in turn influenced by soil exchange acidity (Boyd 1990). Thus pH differences between the two field stations of Domasi (pH=6.5) and Kasinthula (pH=8.96) were sufficient to elicit significant changes in fish growth. If these results are extrapolated onto the national scale, they offer opportunities for assessing the suitability of sites for fish production and location of facilities for aquaculture for different species and management systems.

Ammonia, pH and dissolved oxygen levels were directly responsible for poor fish survival. It is noteworthy that relatively small ion increases were quantitatively expressed in fish performance. For instance, a change of ammonia concentrations from 0.47 to 1.25 $mg \cdot l^{-1}$ significantly affected growth although they are sub-lethal levels for most tilapias (Boyd 1990). Depending on the species, acute toxicity (96-hour-LC_{50}) for ammonia ranges from 0.08 $mg \cdot l^{-1}$ for salmon to 3.8 $mg \cdot l^{-1}$ for channel catfish (Russo and Thurston 1991). Chemically, the toxicity of ammonia is compounded by factors such as dissolved oxygen and pH.

Considering that 5-10% mortality was reported for the *Oreochromis shiranus* and *Tilapia rendalli* in the same ponds (Chikafumbwa et al. 1993), values of up to 61% recorded in this experiment indicate that this fish is more sensitive to water quality factors. While mortality could not be attributed to one factor, dissolved oxygen was one of the most important factors according to multiple regression analysis. This is inferred from the fact that 4.5-5.0 $mg \cdot l^{-1}$ and 5.3-5.8 $mg \cdot l^{-1}$ dissolved oxygen were associated with 59-61% and 29-45% mortalities, respectively. This further suggests that it is one of the most important ecosystem-induced factors. That this species prefers high dissolved oxygen may be explained by its pelagic lifestyle in Lake Malawi (Turner et al. 1991). Except for the sub-thermocline region, lake water has more that 5 $mg \cdot l^{-1}$ dissolved oxygen values (Msiska 2001).

The effect of water quality variables on fish growth was best illustrated by data obtained at both sites (Domasi and Kasinthula). The two sites were shown to differ in terms of water and soil chemistry. The Domasi site whose soil is classified as acidic resulted in corresponding low water nutrient while Kasinthula soils are alkaline and have high exchange capacity and the water has high alkalinity. The fish growth rate was slower at Domasi than at Kasinthula. The growth differences between the two sites has not been recorded on any commonly cultured Malawian species, the *Oreochromis shiranus* and *Tilapia rendalli*. Environmental factors explained only about 72% growth variation. According to Tave (1995), when phenotypic variation is large, the environmental component of variance is usually larger than the genetic component, indicating that there was unrealized growth potential in the *Oreochromis karongae*. Further research should confirm this.

The best farming potential for this fish appears to lie in sites of high alkalinity, hardness and pH. This finding could assist the drawing of national zonation maps for farming the fish. Previous studies recommended the adoption of exchange acidity as an indicator in selecting soil suitability for aquaculture (Jamu and Msiska 1996).

In summary, satisfactory growth and survival of the *Oreochromis karongae* were achieved in relatively high concentrations of dissolved oxygen, total alkalinity, and hardness and low levels of ammonia. Thus, use of any pond inputs should be carefully considered so as not to cause water quality deterioration of these factors. While this was also true for other tilapias (Pullin and Lowe McConnell 1983), the influence of adverse effects of ammonia and DO appear to be greater for the *Oreochromis karongae*. The tolerance limits for this fish species require further investigations. The study suggests that systems that deliver high levels of dissolved oxygen would be suitable for *Oreochromis karongae* farming.

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