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ENHANCING THE PRODUCTIVITY OF SMALL WATER BODIES

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A review prepared for the Challenge Program on Water and Food

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FOREWORD

Foreword

“Small Water Bodies”, though a nebulous inland fisheries resource, comprise a diverse set of natural and man-made aquatic ecosystems that contribute significantly to the livelihood and food security of millions of poor people in the developing world by producing fish and other harvestable aquatic organisms. These are often community-based and multiple-use water bodies, such as small irrigation reservoirs, ponds, canals, swamps and small streams, serving a variety of purposes like irrigation, livestock watering, household water storage, electric power generation, wildlife habitat, improved fish productivity, recreational fishing, and cage-based aquaculture. Like other inland aquatic ecosystems, the contribution of small water bodies to water productivity in the form livelihood support to the local communities does not receive the recognition it deserves.

Small water bodies are highly dispersed over large geographical areas with poorly organized fishing and marketing activities, as result of which, there is a gross under-reporting of the fish produced and the benefits accruing from them. Often, the potential benefits through fish and fisheries from such water bodies are ignored while planning water and land resources development. However, these water bodies are very important from a fisheries perspective as they are spread over an area of 750,000 km^2 with a fish production potential of 57 million t per year.

The small man-made impoundments created primarily for irrigation, cattle watering and multiple community use form the bedrock of small water bodies with fish production as a major economic activity them. In many countries, there is no inventory on these ubiquitous, but nondescript entities, and hence any attempt to assess their social and economic contribution becomes a very tedious task. Nonetheless, such studies are vital to the national and international efforts to find solutions to the problems related to management of these resources. Some small water bodies are assuming even greater significance by being biologically sensitive areas that provide vital links in the life cycle of organisms. Sometimes, these ecosystems provide shelter and grazing grounds for threatened species of fish during transient phases of their life cycle.

Our current interest in small water bodies derives mainly from their use in fisheries enhancement, which involves guidance on stocking, harvesting, species- and stock management. In view of the adverse environmental impacts of intensive aquaculture and the fast depleting marine and riverine capture fisheries, many developing countries are looking forward to newer areas for fish production with a view to obtaining optimum yields on a sustainable basis. In this context, small water bodies, which allow a suite of relatively enhancement-friendly fishery enhancement options, need special attention.

In this review, Randall Brummett provides an overview of the small water bodies as an important inland fishery resource and analyses the global trends in their utilization. He also assesses the opportunities for enhancing fish production from these water bodies based on the strengths and weaknesses of the different management options. This review is targeted mainly at the researchers who need background information to formulate research projects on key issues related to small water bodies. This will also serve as a useful reference material for students, researchers, planners and policy makers, who deal with water, ecosystems and fisheries in general.

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INTRODUCTION

Introduction

Small waterbodies are found all over the world and although no accurate estimates for their number are available, they most likely number in the millions. Kapetsky (1998) estimated that total global surface area of small waterbodies larger than 1 km^2 (100 ha) is in the region of 750,000 km^2. Of course, most small waterbodies are much smaller than 1 km^2. Using rainfall data as a proxy, Kapetsky (1998) went on to estimate that 23% of the total global surface is very suitable for small waterbody construction, including some 20-30% of Africa, Asia and Latin America. Verheust (1998) has documented over 14,000 small waterbodies in relatively dry Southern Africa. Sugunan (1997) reported some 19,000 small reservoirs in India, 10,000 in Sri Lanka and over 70,000 in Brazil. Huang et al. (2001) document over 84,000 small dams in China. Using Sugunan's (1997) figures, the production of fish from small waterbodies under varying (but mostly very low) levels of management ranges between 49 and 200 kg/ha with an average of 91 kg/ha. If this can be extrapolated globally, then the current total production of small waterbodies greater than 100 ha must be more than 7 million tons, equivalent to 14% of total global aquaculture production reported to the Food and Agriculture Organization of the United Nations in 2002 (FAO 2000). If the value of 743 kg/ha reported by De Silva (2001) for managed small waterbodies in China exemplifies the potential for improvement, then these resources could be producing something on the order of 57 million tons of fish per year.

What constitutes a «small waterbody» has been the subject of considerable debate. To the Committee for the Inland Fisheries of Africa, a small waterbody is less than 1,000 ha, including lakes, ponds, marshes, swamps and rice paddies (CIFA 1986). Song (1980) uses the 1 km^2 also used by Kapetsky (1998). The WorldFish Centre regards any waterbody of less than 200 ha as small, but in reality, this type of definition is artificial because the key feature that differentiates small waterbodies from fishponds and from other, larger, waterbodies is their degree of manageability.

Virtually all aspects of fishpond productivity are controllable to one degree or another by the farmer. For larger waterbodies, the level of control is restricted to capture fisheries management and, possibly, stocking of certain species. Small waterbodies, lying somewhere in-between, are likewise intermediate in their amenability to management. Usually, small waterbodies can be at least partially drained, they are normally small enough to be effectively fertilized, water quality can be reliably monitored, catches can be regulated through controlled access, and reasonably precise mixed-species stocking programs are feasible. In addition to size, other key features of small waterbodies include fluctuating water levels, seasonal thermoclines and seasonally or permanently flooded marginal vegetation (Figure 1).

Figure 1. Flooded trees are a common feature of small waterbodies constructed in river valleys

In terms of water management, most small waterbodies were built for capturing and/or holding surface water, but have also been shown to replenish water tables, decrease the severity of flash-flooding, reduce soil erosion and increase vegetative cover, especially trees (Roggeri 1995). Small waterbodies are generally of two types:

1) reservoirs created by damming a river and,

2) ponds built on watersheds to collect surface runoff. The main objectives of small waterbody management include:

- Irrigation
- Livestock watering
- Household water storage
- Electricity generation
- Wildlife habitat
- Improved productivity (of capture fisheries)
- Recreational (sport) fishing
- Opportunities for cage-based or other aquaculture

This review will address the main opportunities for enhancing the last three; those related to fish. Optimisation of (economically) fish production from small waterbodies requires managed stocking, nutrient loading and harvest.

STOCKING

In Burkina Faso, stocking small waterbodies in the Sahel with 20 kg (800 fingerlings @ 25 g) of *Oreochromis niloticus* per hectare increased production from 23 to 269 kg/ha (de Graaf & Waltermath 2003). India reports up to 10 fold increases in yield from stocking programs (Sugunan 1995). Five-fold increases have been reported from Thailand, Indonesia, the Philippines and Malaysia (Fernando 1977 as cited in Welcomme & Bartley 1998). Stocking of oxbow lakes in Bangladesh has increased yields up to nearly 600 kg/ha, while stocking of shallower floodplain lakes has yielded 2 800 kg/ha (Welcomme & Bartley 1998). Introduction of the largemouth bass, the red swamp crayfish (*Procambarus clarkii*) and two tilapia species into Lake Naivasha, Kenya have increased the production of food and sport fish from virtually zero prior to the introduction up to 300 tons (under very poor management). Stocking of centrarchids (especially largemouth bass, *Micropterus salmoides*) and salmonids (especially rainbow trout, *Onchorynchus gairdnari*) is widespread in the United States, Europe, South America and Southern Africa. Australia has an extensive stocking program for indigenous sport fishes (Petr 1998).

There are two basic strategies for stocking: 1) the establishment of reproducing, balanced, populations and, 2) unbalanced put-and-take fisheries. Reproducing populations can either be internally or externally balanced. In externally balanced systems, forage fish species that feed low on the food chain (e.g., carps and tilapia) are periodically or continuously removed by fishers.

This is the type of system that is most commonly observed in developing countries where stocking programs are undertaken to address problems of food insecurity or declining capture fisheries. Properly managed, these systems can be highly productive and beneficial to human communities. The majority of the examples cited above are of this type of stocking program. Inappropriate fishing (e.g., overfishing, taking fish that are too small or fishing in the breeding season) can ruin such fisheries and poses a major threat to sustainable management.

Internally balanced systems are comprised of reproducing mixed predators and forage species and are most popular for sport fishery enhancements, where the predatory species are the most sought after. As for externally balanced systems, if the exploitation is properly regulated, the fishery is self-sustaining and does not require restocking. However, the ratio of predator and prey species is critical to success and is often difficult to achieve, particularly in areas where food insecurity and poverty create incentives to poach or violate bag limits. Examples include the widely successful stocking programs for mixed centrarchid sport fisheries in the US and Europe (Davies 1973).

Unbalanced, or put-and-take fisheries, are based on species that cannot spawn in the lake or dam environment. The silver and bighead Chinese carps are examples of such species. Trout populations stocked in dams that have no access to streams are unbalanced. Weed control programs involving grass carp (*Ctenopharyngodon idella*) are another example. The advantage of these systems is that they do not rely on any particular level of fishing pressure to maintain balance. However, they must carefully monitored and restocked regularly as fish die or are removed through capture.

Naturally occurring species, both of fish and other aquatic fauna or flora, can complicate stocking programs. Indigenous species compete for food, disrupt nesting/breeding behaviour and can predate stocked fish. By muddying water and uprooting plants, common carp can disrupt foodwebs and render ineffective the stocking of planktivorous species. Stocking of tilapias in Lake Nasser, Egypt to increase production was foiled by the Nile Perch (*Lates niloticus*), which ate the bulk of the stocked fish, often at the point of stocking. In any case, stocking with forage species in cases where natural reproduction occurs, is often superfluous (Welcomme & Bartley1998).

Fingerlings or broodfish for stocking come from two sources, the selection of which depends upon the objectives of management and the type of system (balanced or unbalanced). Hatchery-reared stocks, either of local or exotic origin, require careful genetic management to avoid inbreeding and other deleterious genetic effects. Skibinski (1998), for example, showed that introduction of hatchery-produced populations into existing populations of fish generally results in declines in the native stock, often ruining the fishery entirely. On the other hand, hatchery stocks can be manipulated to provide exactly the number and size of fish required at the time when they are wanted. Likewise, options exist for genetic enhancement of hatchery-based stocks used specifically for small waterbody enhancement (Penman & McAndrew 1998).

Wild-caught fingerlings may only be available at certain times of year, and then only in certain sizes and numbers. These can, however, be very useful in ensuring that any accidental fish escapes will have minimal impact on surrounding aquatic ecosystems. Also, reliance on wild stocks facilitates genetic management by always having a pool of wild fish from which to select new broodfish when restocking.

Knowledge of a fish's reproductive strategy and seasonality contributes substantially to success rates in stocking programs. Programs to enhance the production of red drum (*Sciaenops ocellatus*) in the US have increased the capture of stocked fish from 0.005% to 4.1%, depending upon the season of release (Bert et al. 2001). Introduction of Chinese carps has often failed because stocking programs did not take into consideration the fact that these fish can only reproduce in large rivers. In this latter case, the failure to reproduce can be a good thing, if escape of stocked species into other natural waterbodies is deemed undesirable.

Stocking rate is also a critical factor in success and is generally based on estimates of productivity generated through ecological studies. In general, production rises with increasing stocking density up to a limit determined by the abundance of food organisms, the carrying capacity (Welcomme & Bartley 1998). The number and sizes of fish to stock is based on estimates of carrying capacity, expressed in terms of weight/unit area (see Harvest, below). Within a given carrying capacity, the total weight of fish can either be in the form of many small fish or fewer larger fish. Typically, the number of fish to stock is calculated on the basis of desired fish size and the productivity of the waterbody, simply put:

$$\text{Number to Stock (per ha)} = \frac{\text{Carrying Capacity (kg/ha)}}{\text{Minimum Average Weight Desired (kg)}}$$

If natural mortality and growth rates are known, inversion of the standard mortality formula can give a more precise estimate (Welcomme & Bartley 1976):

$$\mathbf{N_O = N_C{}^{(z\ (c-o))}}$$

Where N_O = number to stock, N_C = number of fish desired at age of capture c, o = age at stocking, z = total mortality.

Stock Assessment

Monitoring and evaluation are critical aspects of management. Without knowledge of the fish stock structure and trophic status of the waterbody at any given time, rational choices about stocking, fertilization, feeding and/or harvest are impossible. Substantial technical knowledge is available on the subject of fish stock assessment, but this generally needs to be adapted to specific conditions (Fjalling & Furst 1991). Multi-mesh gill nets (Degerman et al. 1988), beach seining (Elrod 1971) and mark-and-recapture (Burnham et al. 1987) systems have been effective tools for estimating total fish biomass and population structure. These require a certain amount of equipment and expertise on the part of those charged with biotechnical management. On the other hand, fish stock assessment data can be combined with quantitative knowledge of other trophic levels (e.g., benthos, macrophytes, zooplankton, etc.) can be used to develop new and highly specific management systems (Christensen & Pauly 1993).

A system that cannot give accurate data on stock structure, but which can provide general guidance on whether or not a waterbody is overfished, is the catch per unit of effort (CPUE). The CPUE can be obtained by on-shore monitoring of catches at a central landing point or through creel surveys and questionnaires (i.e., hours fished, type of gear, catch rates) and is thus much easier for non-technical persons than test-fishing. Over time, trends in CPUE can identify trends in fish population structure.

The importance of practical experience in small waterbody management cannot be over-estimated. Stock assessment tools can give an experienced manager a snapshot of what is happening under the water, but understanding and balancing interaction among the innumerable factors that can influence fish population dynamics, requires in-depth knowledge of how a particular waterbody responds to various and changing externalities.

Stock Structure

Structured populations can increase productivity by taking advantage of the multiple food resources available in most waterbodies. For example, Tang (1970) characterized the feeding habits of the main species available for small waterbody culture in Taiwan:

Species	Food Habit	Stocking Rate/h
Silver Carp (*Hypothalmichthys molitrix*)	Planktophagic	400
Grey Mullet (*Mugil cephalus*)	Detritophagic	200
Bighead Carp (*Aristichthys nobilis*)	Zooplanktophagic	15
Grass carp (*Ctenopharyngodon idella*)	Macrophytophagic	80
Common Carp (*Cyprinus carpio*),	Benthophagic	200 or
Black carp (*Mylopharyngodon piceus*)	Benthophagic	200
Sea perch (*Lateolabrax japonicus*)	Nektophagic	50

In general, adults of these species overlap by less than 10% in terms of dominance within the diet of an individual food item (Tang 1970). From a quantitative comparison of the main food items and biomass of fish produced over a period of years, Tang estimated where food items could be added and/or fish species abundance manipulated to optimise productivity. Likewise, Huet (1972) described a subjective indicator, the biogenic capacity, based on the composition of a waterbody's biota. This is a relative value that can provides general guidelines for extrapolation and comparison.

A practical method used to manage small impoundments was developed by Brummett (1996). This is a three-step process for matching the fish with the environment. The first step is to characterize the pond in terms of available foods. The second step is to characterize the diet of the fish, and the third step is to make meaningful comparisons between various fish combinations and production/economic constraints. Categorization of food resources is based on the intrinsic traits of the foods that effect their «selectivity» by consumers (Ivlev 1961):

I. Plankton (phyto + zoo)
II. Macrophytes + Filamentous Algae
III. Benthic Invertebrates and Detritus

To give an indication of how well a particular fish species might fit into the environment; the frequencies of materials from these basic food groups in the stomach and in the waterbody are compared on a dry matter basis:

	Plankton	Macrophytes	Benthos/Detritus
Waterbody (without fish)	0.02	0.56	0.42
Barbus paludinosus	0.93	0.07	0.00
Lethrinops furcifer	0.02	0.06	0.92
Oreochromis shiranus	0.67	0.28	0.05
Tilapia rendalli	0.01	0.88	0.11

The average of the absolute value of the difference between food available and food eaten for each food group is calculated to give a general indication of the fishes «food fit» (Ff) within the dam. Data from Malawi give a general indication of the Ff for some of the main species:

B. paludinosus: (0.02-0.93) + (0.56-0.07) + (0.42-0.00)/3 = 0.61
L. furcifer: (0.02-0.02) + (0.56-0.06) + (0.42-0.92)/3 = 0.33
O. shiranus: (0.02-0.67) + (0.56-0.28) + (0.42-0.05)/3 = 0.43
T. rendalli: (0.02-0.01) + (0.56-0.88) + (0.42-0.11)/3 = 0.21

A perfect fit using this method would be represented by an average Ff of 0.0. A perfect mismatch would give an Ff of 0.66. In this case, *T. rendalli* would be the best candidate. In addition to guiding species selection for use in various culture systems, the categorization and comparison of food groups also permits the manager to make systematic guesses about strategies for various species. For example, polycultures might be evaluated by generating a group stomach from pooled stomach content data. If 100 O. shiranus were stocked together with 100 *T. rendalli*, the polyculture, would have an Ff of 0.32. If the stocking ratio or average weight of the polyculture were altered so that the standing stock in the pond was 25% O. shiranus and 75% *T. rendalli*, the Ff becomes 0.27 as shown below:

	Plankton (g dry wt/m2)	Macrophytes (g dry wt/m2)	Benthos/Detritus (g dry wt/m2)	Food Fit (Ff)
Waterbody (without fish)	0.02	0.56	0.42	-
O. shiranus Stomach	0.67	0.28	0.05	0.43
T. rendalli Stomach	0.01	0.88	0.11	0.21
50:50 Polyculture Stomach*	0.34	0.58	0.08	0.32
25 O. shiranus: 75 T. rendalli	0.18	0.73	0.10	0.27

$$\textbf{Polyculture Stomach Content Frequencies} = \frac{[(W_{os} \text{ x } F_{fos}) + (W_{tr} \text{ x } F_{ftr})]}{(Wos + Wtr)}$$

W_{os}= weight of *O. shiranus*, W_{tr}= weight of *T. rendalli*,
F_{fo}= food frequency *O. shiranus*, F_{ftr}= food frequency *T. rendalli.*

It would also be possible to improve the Ff for a species or a polyculture by modifying the environment. For instance, a qualitative examination of imbalances between food needs and availability might be used to design management regimes. Weeding to decrease macrophytes to 0.33 and increase the relative frequency of dry matter in the form of plankton to 0.25, improves the Ff for O. shiranus to 0.28. Removal of unwanted species can be as important as addition of desired species in managing stock structure. Competition for food or space with low-value species or size/age classes can seriously undermine stocking programs (Meronek et al. 1996). In some cases, partial removal of particular age-classes through the selective application of fish poisons (Table 1) to specific habitats (e.g., spawning beds) within a waterbody can be effective (Figure 2). The active ingredient in most of fish poisons is either a saponin or rotenone, the effects of which are generally temporary and the fish killed are safe for human consumption.

Figure 2. *Fish poisons, such as rotenone, can be effectively used to remove unwanted species from managed small waterbodies.*

Table 1. Plants used as fish poisons on several continents (Kritzon 2003)

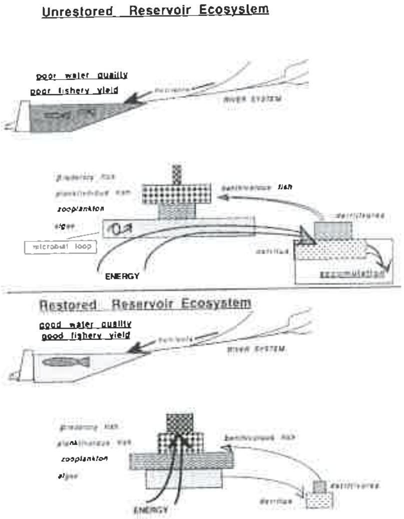
North America	**Pacific Islands**
Black Walnut *(Juglans nigra)*	Fish poison tree *(Barringtonia asiatica)*
Devils Shoestring *(Symphoricarpos orbiculatus)*	Auhuhu *(Tephrosia purpurea)*
Horse Chestnut *(Aesculus hippocastanum)*	Akia *(Wikstroemia uva-ursi)*
Pokweed *(Phytolacca americana)*	**Australia**
Turkey-Mullein *(Eremocarpus setigerus)*	Pituri *(Duboisia hopwoodii)*
California Buckeye *(Aesculus california)*	Austral Indigo *(Indigofera australis)*
Soap Plant *(Chlorogalum pomeridianum)*	Wild Indigo *(Austral Indigo)*
Indian Hemp *(Apocynum cannabinum)*	Fish Killer Tree *(Barringtonia asiatica)*
Pokeweed *(phytolacca americana)*	Fish Poison Tree *(Acacia ditricha)*
Indian Turnip *(Arisaema triphyllum)*	Fish Poison Tree *(Barringtonia racemosa)*
Wild Cucumber *(Marah fabaceus)*	Fish Poison-wood *(Barringtonia vitiflora)*
South America	Soapy Wattle *(Acacia holosericea)*
Lechuguilla *(Agave lechuguilla)*	**India**
Soapberry *(Sapindus drummondii)*	**Indian Beech *(Pongamia pinnata)***
Mexican Buckeye *(Ungnadia speciosa)*	Fish Berries *(Anamirta cocculus)*
Barbasco *(Jacquinia sprucei)*	Swallowwort *(Asclepias curassavica)*
Barbasco *(Tephrosia toxicofera)*	**Africa**
Barbasco *(Lonchocarpus nicou)*	Pencil tree *(Euphorbia tirucalli)*
Acariquara *(Minquartia guianensis)*	Ironwood, *(Prosopis africana)*
Fish Poison Leaves *(Euforbia cotinifolia)*	

Likewise, the use of selective fishing gears can help to reduce competition with desired species. Drawing down the water level, when feasible and if carefully timed, can target the removal of certain species when they are on their spawning or nursing grounds. When partial measures are not sufficiently effective, more drastic measures such as complete poisoning or desiccation can be considered.

Another way to structure populations is to give selective advantage to certain species through environmental modifications. The placement or cleaning (of sediment) of gravel beds can enhance production of char (*Salvelinus* spp.) and largemouth bass (*Micropterus salmoides*). Construction of shallow marginal areas can increase reproductive success of tilapias and carps. Fish aggregating devices or brush-parks can be installed to provide cover and grazing for desired forage species.

Trophic Cascades

Figure 3. *Example of a trophic cascade model of a percid-regulated food web in Eastern Europe (Zalewski 1992).*



Managing stock structure through manipulation of predators has potential to dramatically modify productivity, but will generally emphasize water quality (i.e., reduction of phytoplankton turbidity) and the production of larger, carnivorous species at the expense of the forage fish most commonly consumed by the rural poor. For example, the stocking of predatory species to remove competitors has been used in Israel (Leventer 1981). Another example comes from Zalewski (1992) who showed how phytoplankton density could be managed by stocking carnivorous percids. Stocking the zooplanktivorous perch (*Perca fluviatilis*) reduced zooplankton, increasing phytoplankton and lowering water quality. Conversely, stocking the piscivorous zander (*Stizostedion lucioperca*) reduced the number of zooplanktivorous perch and bleak (*Alburnus alburnus*), thus reducing the number of forage species that eat larger zooplankton, which in turn increases zooplankton grazing on phytoplankton, increasing water quality (Figure 3).

Another example comes from Lake Naivasha, Kenya where Mavuti et al (1996) developed a trophic model showing how lack of a zooplankton predator (Lake Naivasha contains only alien species stocked by man) substantially reduces the productive capacity of the fishery. Actually, these relationships are quite complex, involving important differences in plankton size, zooplankton predator avoidance and, as mentioned below, nutrient recycling as a result of changes in fish foraging pattern (Ramcharan et al. 1996). In a similar vein, Berlanga-Robles et al. (2002) showed how introduction of alien species (*C. carpio, O. niloticus, M. salmoides*) can disrupt food webs and create imbalances in feed utilization and, subsequently, the stability of the lake ecosystem.

NUTRIENTS

Nutrients

Since productivity is generally a function of food organism density, fertilization to increase planktonic and benthic prey species can substantially improve catches (Biro 1995). Sources of nutrients can be in the form of organic inputs such as manures or leaves, inorganic (chemical) fertilizers or waste materials such as agro-industry by-products (e.g., brewery waste) or treated/untreated sewage. Due to the nature of small waterbodies, nutrients in the watershed (e.g., from animal grazing or fertilization of crops can strongly influence water fertility.

There are two principal mechanisms through which nutrients enter the food web: 1) dissolved forms (often inorganic fertilizers) are taken up by primary producers which then convert them into usable food, or 2) organic matter in the form of feeds, mulches or manures is either eaten directly and then partially excreted, or are decomposed by bacteria, releasing their nutrients into the water column.

In China, yields have been increased by nine times up to 540 kg/ha through the application of inorganic fertilizers (Lu 1992). Fertilization rates for small waterbodies are on the order of 3-6 kg/ha of phosphorus and 10-20 kg/ha of nitrogen. In Russia, these rates have been shown to increase the density of food organisms by 5 times (Berka 1990). Maximum carbon fixation in the sub-tropics and tropics is on the order of 10 g C/m^2/day, but other factors such as turbidity and temperature limit productivity to an average of about 4 g C/m^2/day (Schroeder 1980). To approach maximum fertility without polluting the water, Boyd (1979) recommends maintaining 0.5 mg/l P and 1.4 mg/l N dissolved in the water, obtained from regular applications of 9 kg/ha of N, 9 kg/ha of P_2O_5 and 2.2 kg/ha of K_2O. Schroeder (1980) recommends that manures be applied at a rate of 120 kg/ha/day of dry organic matter (2.5-4% fish biomass/day). Such nutrient input levels, if properly matched to appropriate fish stocking levels, can produce up to 7,000 kg/ha of fish.

When waters are exceedingly soft, carbon can become limiting, rendering nitrogen and phosphorus fertilization ineffective. In these cases, the application of lime, generally in the form of agricultural limestone (CaCO3), at rates sufficient to raise total alkalinity above 20 mg/l can more than double fish production (Boyd 1979).

The source of nutrients makes little difference to the food web (Schroeder 1980) so the choice of which inputs to use depends upon other factors. Although price and availability are important considerations, especially in developing countries, it is clear that the use of chemical fertilizers is more efficient in terms of labour and transportation than bulky and smelly organic fertilizers. Moving and applying whatever nutrient source is a critical factor in usability in small waterbody fertilization. For example, Gupta et al. (1996) found that in Bangladesh, chemical fertilizers were often used in excess, while manures were generally applied at below recommended levels, because of problems of manipulation. Timing of application also differs among fertilizers. Manures are typically spread on the dry bottom before filling (Biro 1995) while chemical fertilizers can be applied in a slurry or on a platform (Boyd 1979) to avoid direct contact with bottom sediments.

Depending upon the chemical composition of the water, large amounts of nutrients can be tied up in sediments. This is especially true of phosphorus, typically the most limiting factor in pond fertility, which adsorbs onto aerobic muds, especially under acidic conditions or situations where the mud contains high concentrations of calcium carbonate (Boyd 1979).

The introduction of benthic detritivores to these systems such that adsorbed mud is either re-suspended by foraging activity (in the case of common carp, for example) or by the digestion and excretion of food particles, can result in recycling of phosphorus back into the water column where it is again available to phytoplankton (Prikryl 1990). Such a phenomenon has been shown to increase dissolved P levels by up to three times (Havens 1993).

Interactions between the bank and the water of small lakes are important determinants of productivity. For example, a major source of nutrients in some small waterbodies is the epiphytic algae, bacteria and invertebrates that grow on the surface of submerged woody vegetation, particularly trees, which effectively increases the shore-line/water interface that to a large extent regulates productivity in natural ecosystems (Lowe-McConnell 1975).

Figure 4. *Livestock benefit from small waterbodies while improving nutrient profiles.*

According to Karenge & Kolding (1995) substantial nutrient inputs result from regular draw-down and refilling, thus flooding the seasonally vegetated and/or grazed marginal (draw-down) zone and exposing accumulated nutrients to decomposition (Figure 4). The draw-down zone of Lake Chad, for example, produces grass yields of more than 2 tons/ha, forming an important dry season resource for herders. In addition, harvesting of seasonally planted crops from the draw-down zone of reservoirs (e.g., 10 tons/ha of Cassava from the margins of Lac de Guiers, Senegal) is another economically important option for riparian communities (Roggeri 1995).

Draw-downs can also have negative consequences, particularly when a fish stock is near carrying capacity. As most reservoirs occupy v-shaped (ex-riverine) valleys, the total surface area, and hence the area of the air-water interface through which much of the oxygen needed for fish respiration is diffused, declines sharply when water levels are lowered, effectively decreasing the size of the waterbody and driving and pushing the existing fish stock over carrying capacity (Costa-Pierce 1997).

Flushing and water retention times are often key determinants of small waterbody productivity (Nissanka & Amarasinghe 2001). As dams are generally put up in river channels or at the bottom of drainage basins where water tends to collect during heavy rainfall, they are vulnerable to overflowing. Any rate of overflow that replaces the productive part of the water column more than once a month will be impossible to effectively fertilize (Boyd 1979).

Another important aspect of nutrient management in small waterbodies is the role of the thermocline. Decaying organic matter from upper levels descends through the water column and accumulates below the thermocline where they are more or less captured until such time as the thermocline is upset, either due to changes in season or due to activities related to dam management. The subsequent exposure of large quantities of reduced organic matter to oxygen can either provide a big boost to productivity or, if excessive, use up all the dissolved oxygen in the reservoir and cause catastrophic fish kills (Costa-Pierce 1997). Dam design, particularly the location of outlets, can be critically important in management of these turnovers. In situtiaons where nutrients are not limiting, bottom (below the thermocline) outlets can help to reduce build-up of organic matter during periods of high risk for thermocline disruption, increasing the oxygenated portion of the water column and increasing fish production (Costa-Pierce 1997). Use of mechanical aerators has been effective in mediating problems associated with rapid declines in dissolved oxygen due to turnovers or algal blooms (following die off and subsequent oxidation of organic matter), but this is expensive and generally limited to very small or very high-value waterbodies.

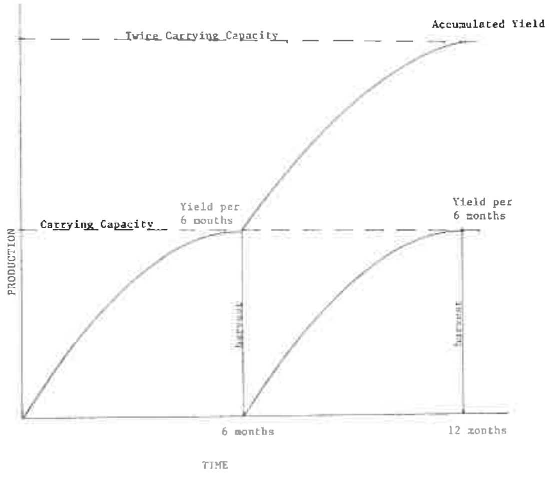
HARVEST

Harvest

Managing the removal of fish may be the most important, and is certainly the most used, method of regulating productivity from both large and small waterbodies. The idea is to optimise individual size and numbers removed for the benefit of fishing communities. In smaller waterbodies or those that are completely drainable, managed strategies for stocking, harvest and restocking are used. In larger or undrainable reservoirs, harvest management generally involves the imposition of bag limits, size restrictions and regulation of fishing gear with or without restocking. Cage aquaculture is a relatively new management option, but in certain cases can present useful options for increasing fish production under minimal management arrangements.

To effectively manage harvest, one needs to understand the concept of carrying capacity. The carrying capacity is the total weight of fish that a waterbody can maintain, determined by nutrient loading, species combinations, etc. For any given waterbody at any point in time, there is a fixed carrying capacity, which can be manifested by a large number of smaller fish or a smaller number of large fish. When a reservoir is first filled and stocked, the fish are small and the total stock is far from carrying capacity. As the fish grow and/or multiply, the fish stock approaches carrying capacity. Once carrying capacity has been reached, fish growth essentially stops. Some system of fish removal will be necessary if the waterbody is to continue producing new or larger fish. Conversely, when the fish stock is much below carrying capacity, nutrients are only being partly exploited for fish growth. The ideal is to keep the pond near carrying capacity, but still growing for as much of the production cycle as possible.

Figure 5. *Complete harvesting of a small waterbody twice a year doubles the yield within a fixed carrying capacity*



The simplest system is to harvest the total stock all at once and then restock as soon as possible thereafter.

Although easy to manage, this system does not effectively take advantage of the waterbody's carrying capacity, as for most of the production cycle, the waterbody is below carrying capacity.

Also, having a large quantity of fish all at once complicates fish marketing or consumption. Figure 5 illustrates the yield from such a system, completely harvested twice per year. Partial harvesting offers more flexible marketing opportunities, while increasing overall yield.

Figure 6. *Yield for a system from which part of the fish stock is removed as the population approaches carrying capacity to permit those remaining to continue growing.*

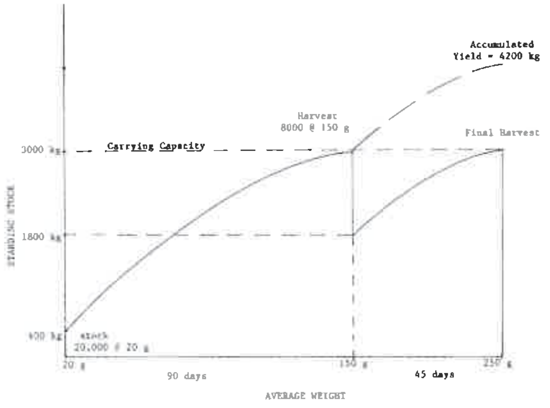


Figure 6, for example, illustrates a common system whereby stocking occurs once per year, but part of the fish biomass is removed at some point (as the total approaches carrying capacity) in order to let the remainder continue growing. This method is useful in cases where there are markets for smaller as well as larger fish.

The most efficient systems involve stocking mixed sizes of fish, harvesting each size class as it reaches market size (Figure 7) and/or restocking after each partial harvest (Figure 8).

Figure 7. *Yield for a system stocked with mixed-size fingerlings. As each group reaches market size, and the population as a whole approaches carrying capacity, it is harvested so the remaining fish can continue growing.*

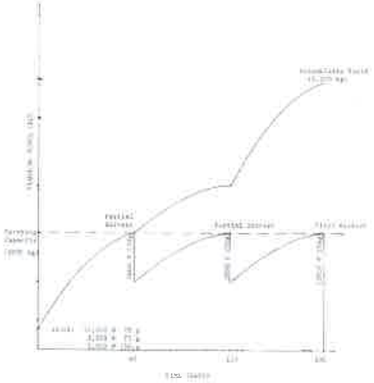
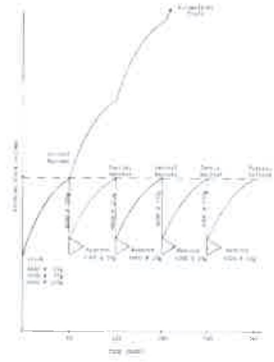


Figure 8. *Accumulated yield from a system restocked after each partial harvest with small fingerlings in order to keep the production system going. This type of system would only work if the fish do not reproduce in the lake.*



This has the effect of keeping the pond as close as possible, but just below, carrying capacity at all times.

In waterbodies for which complete harvest is not an option, stocks must be managed through the establishment and enforcement of bag and size restrictions on the catch.

This is complicated and generally species-specific, the basic idea being to only remove fish after they have reproduced at least once, thereby protecting the stock from over-exploitation. Such methods as net mesh size limits are common.

For example, Amarasinghe (1988) developed a regression model of gill net mesh sizes that permits the harvest of *Oreochromis mossambicus* only after they have achived sexual maturation and spawned at least once:

$$\mathbf{Y = 3.4763 + 2.023\ X\ (r = 0.992)},$$ where Y = average TL of sexually mature fish (cm); X=stretched mesh (cm)

However, applying inordinate pressure on just larger size classes can have the negative consequence of selecting for earlier maturing, and thus smaller, individuals within the population ultimately reducing the individual sizes of fish captured even while increasing total catch (Gwahaba 1973). For some species, such as sturgeon, window size limits are used, whereby only fish above and below certain total lengths can be retained. Often, it is necessary to restrict certain gear types or fishing methods during certain seasons.

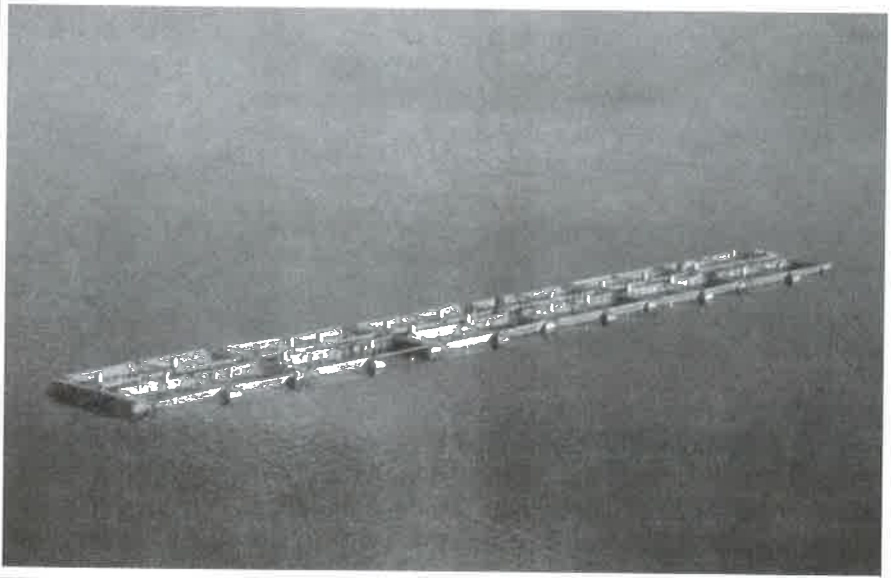
For example, Amarasinghe & Samarakoon (1988) found that economically important cichlids in Lake Parakrama Samudra, Sri Lanka were relatively invulnerable to gill netting during the spawning season when they are guarding nests. However, water-beating to chase fish dramatically increases catch rate. Likewise, as fish move into the re-flooded draw-down zone to feed on the abundant decomposing marginal vegetation at the beginning of the rainy season, they become more vulnerable to capture, which might deserve consideration in setting harvest strategy depending upon the goals of management (Amarasinghe & Samarakoon 1988).

Recreational fishing is increasing in popularity worldwide, particularly in more industrialized countries, where value added by sport fishing is generally much higher than for foodfish. State managed stock enhancement programs in the United States have increased catches by almost 12 times (Davies 1973).

Management of small waterbodies for sport can, however, be complicated and requires substantial knowledge of fish ecology to be effective (Elrod 1971). Often, sport fish stocking is accompanied by weed control and/or introduction of fish attracting devices (i.e., brush piles) or the enforcement of exclusion zones to increase success rates among rod and reel fishers (Hill & Shell 1975).

An increasingly popular approach to fish production in both small and large waterbodies is the introduction of aquaculture cages (Figure 9). Provided there is sufficient water movement (e.g., currents, wind) the carrying capacity of cages within a reservoir can approximate that of the entire waterbody while maintaining the fish in easy-to-harvest units (Beveridge & Stewart 1998). Usually, the use of cages is constrained by availability of the more or less complete feeds needed to replace natural production of food organisms to which caged fish have little access.

Figure 9. *Common carp cages placed in the Tishreen Dam, Syria.*



However, in highly eutrophic waterbodies, such as Laguna del Bay in the Philippines, feeds may not be needed. Theft can be a significant problem for cage-based aquacultur Although typically in the range of 5-10 kg/m^3, very high yields are possible from these cages. In lake Kariba, Zimbabwe, for example, tilapia are being cultured in 500 m^3 cages at a stocking density of 50 kg/m^3. Costa Pierce (1997) reports standing stocks of 200 kg/m^3 of carp and tilapia in cages in Saguling Reservoir, West Java, Indonesia. Zainal (1998) reported that three reservoirs (19,600 ha total) in West Java contained 31,277 fish cages for 3,848 cage operators and produced 45,210 tons of fish in 1996. In China, cage aquaculture has proven very useful in dams with high water level fluctuations (Hu 1998).

It should be noted that feed inputs to fish cages will result in increasing fertility in the surrounding water. Hu (1998) found that introduction of cages to Lake Jinyang in Shanxi Province, doubled total fish yield. This can be a good thing when capture fisheries are suffering from inadequate nutrients or a bad thing if water quality for domestic or other uses is a critical consideration.

Economics

Welcomme & Bartley (1998) reviewed the economics of managing small waterbodes. In essence, the objective is to balance the costs of management (stocking, feeding, fertilization, removeal of unwanted species, etc.) against direct (financial) benefits accruing to local communities and macroeconomic benefits accruing to society as a whole.

The major cost in most management programs (40-70% of the total) is for fingerlings to stock. The most easily identified benefit of managing a small waterbody is the cash that returns to local communities or management entities through license fees and the sale or cost savings from harvested fish. When other economic criteria are added, the picture becomes less clear. In the case of recreational fisheries, for example, the value of the fish must include such things as tackle and equipment sales, hotel and restaurant revenues and guide services (Figure 10). In Queensland, Australia a 2-3 kg fish harvested by commercial fishers adds between A$6-22.00 to the economy, whereas the same fish harvested by a recreational fisher adds about A$150 (Welcomme & Bartley 1998). Overall, Petr (1998) found that 5.5 million (30%) of 18 million Australians are sport fishers, spending some A$3.5 billion per year on licenses, equipment and travel alone.

Figure 10. *Recreational fishing can add substantially to local economies while removing relatively few fish from the ecosystem.*

Management of forage fisheries can also be profitable. For example, the stocking of approximately 42.2 million carps into Thai reservoirs at a cost of $ 118,000 contributes substantially to a fishery worth over $ 2 million. Likewise, stocking of oxbow lakes in Bangladesh has a cost-benefit ratio of 0.56 on a 266% increase in fish yield (Welcomme & Bartley 1998).

NON-FISH
OUTCOMES

Non-Fish Outcomes

In addition to producing fish, small waterbodies can provide additional benefits to communities (Figure 11). Many dams have irrigation, power generation and livestock watering as design features, but mud turbidity, plankton blooms, incorrect stock structure or weed infestations can impair function and reduce access and lifespan.

Figure 11. *Wildlife can benefit from the availability of water and forage associated with small waterbodies.*

Unplanned usage often includes extraction for household management, particularly laundering. Contact between humans (often children) and stagnant water creates ideal conditions for disease transmission. The regulation of water quality in general is a desirable outcome of small waterbody management. The other main, non-fish outcomes are weed and disease vector control.

Water Quality

Water quality is generally defined in terms of turbidity. Turbidity can be of two general types: **1)** phytoplankton and, **2)** suspended solids. Problematic phytoplankton blooms are normally the result of excessive nutrient loading. Suspended solids are the result of sediment entering the water column through erosive runoff from the watershed, or the activities of fish and livestock, which stir up bottom sediments.

Phytoplankton can be managed with applications of copper sulphate, but this chemical is dangerous to the environment and, anyway, expensive applications need to be repeated as long as excess nutrients exist in the system (Leventer 1981). More durable is phytoplankton management through trophic manipulations. Although complex, such manipulations can work as demonstrated by Zalewski (1992) and Ramcharan et al. (1996). Conversely, sediments contain 100-1000 times the concentration of nutrients as the water column (Biro 1995) and Prikryl (1990) found that most changes in phytoplankton abundance were associated with re-suspension of benthic nutrients rather than direct predation on plankton.

On the other hand, Lu et al. (2002) showed that high concentrations of filter-feeding silver carp can significantly reduce phytoplankton concentration, albeit not as efficiently as zooplankton. However, since zooplankton is seldom of interest as a commercial or food crop, the introduction of more planktivorous fish as opposed to just a few (which in fact appear to increase phytoplankton abundance), might be a way to increase fish and decrease phytoplankton biomass.

A number of different species have been used to influence various water quality parameters in the management of water quality in the Israeli national water carrier system (Leventer 1981):

Species	**Introduced to control:**	**Reproducing?**
Oreochromis aureus	*organic matter in sediments*	Yes
Liza ramada (Mugil capito)	*organic matter in sediments*	No
Aristichthys nobilis	*zooplankton*	No
Hypophthalmichthys molitrix	*phytoplankton*	No
Sarotherodon galilaeus	*phytoplankton*	Yes
Ctenopharyngodon idella	*aquatic weeds*	No
Mylopharyngodon piceus	*snails*	No
Cyprinus carpio	*snails*	Yes

Within their extensive system of reservoirs and canals, three basic types of small waterbody have been described:

> **A. Reservoirs with low storage capacity, continues flow through and stable water levels.Main biotic forms include: attached algae, submerged plants, snails, shrimps and insect larvae.**
>
> **B. Reservoirs with frequent discharge and refilling and highly variable water levels. Main biotic forms are: attached algae, snails and insect larvae.**
>
> **C. Reservoirs in which water is held for long periods and only replaced annually, thus water levels rise and fall slowly but significantly. The upper layers of these reservoirs are rich in zoo and phytoplankton. Lower layers are thinly populated and often anaerobic.**

Each type of reservoir has slightly different water quality problems and so for each type a different fish stock management strategy has been implemented. For type A reservoirs *O. aureus, L. ramada, C. idella, M. piceus and C. carpio* are stocked to control the abundant benthic fauna. In type B reservoirs, *L. ramada, H. molitrix, C. idella, M. piceus and C. carpio* (males only) are stocked to control snails and aquatic plants. In type C reservoirs, *A. nobilis* and *H. molitrix* control plankton.

An interesting variant of trophic manipulation of water nutrients was presented by Gliwicz (1992), who hypothesized that the use of alarm substances such as purines, pterines or histamine-like compounds that are released by fish when their skin is ruptured, might be introduced to certain parts of a lake, thus «chasing» forage fishes that target algae-grazing zooplankton and in turn reducing phytoplankton blooms. In a study in Lake Ros, zooplanktivorous smelt density in areas where «alarm substances» were splashed were reduced to 25% of pre-treatment levels. Likewise, the introduction of chemical signals that influence the dormancy of certain types of algae might be useful in direct prevention of noxious blooms. Abundant macrophytes compete with planktonic algae for both light and nutrients and can significantly improve water clarity (Boyd 1979, Hanson & Butler 1994).

Weed Control

As many dams were build for irrigation, evapotranspirative water losses and clogging of intake pipes as a result of heavy aquatic macrophyte infestation are major issues. Water losses due to evapotranspiration by emergent weeds can double total evaporation, reaching 500 m^3/ha/day in the tropics. Heavy weeds can also limit the accessibility to sport fish and decrease the usability of reservoirs for other recreational uses such as swimming and boating. Common macrophyte weed species in reservoirs include (Applied Biochemists 1979):

- **Water hyacinth** *(Eichornia crassipes)*
- **Water lettuce** *(Pistia stratioties)*
- **Cattails** *(Typha* spp*)*
- **Water lily** *(Nymphaea* spp*)*
- **Bulrush** *(Scirpus* spp*)*
- ***Salvinia*** spp
- **Water primrose** *(Polygonum* spp*)*
- **Pondweed** *(Potamogeton* spp*)*
- **Naiad** *(Najas* spp*)*
- **Duck weeds** *(Lemnaceae)*
- Water Millfoil *(Myriophyllum* spp*)*
- Coontail *(Ceratophyllum demesum)*
- *Elodea* spp
- *Hydrilla* spp
- *Utricularia* spp
- *Hydrilla* spp
- Filamentous algae *(Spirogyra,*
- *Cladophora, Rhizoclonium,*
- *Mougeotia, Zygnema, Hydrodictyon)*
- Attached algae *(Chara, Nitella)*

Weed control is a major objective of reservoir managers. Methods include:

- stocking of herbivorous fishes such as grass carp&red-breasted tilapia *(T.rendalli)*
- chemical spraying (Table 2)
- mechanical control by hand or with floating weed harvesters.
- periodic draw-down to dessicate marginal weed beds.
- Use of biological control agents, the most notable of these being the weevils that have been introduced all over the globe to constrain the growth of water hyacinth.

Table 2. *Common aquatic herbicides and their application rates (Applied Biochemists 1979).*

Chemical	Rate	Comments
$CuSO_4$-$5H_2O$	0.25-3 mg/l	Depends upon alkalinity
Simazine	0.5-3 mg/l	Apply as slurry
Diquat	0.25-2 mg/l	Inject below surface
Endothol	2-5 mg/l	Inject below surface or broadcast
2,4-D (granules)	25-50 kg/ha	Broadcast on growing weeds
2,4-D (liquid)	5 kg/ha	Spray on foliage
Dichlobenil	7.5-10 kg/ha	Broadcast pellets
Dalapon	6-25 kg/ha	Spray on foliage
Roundup / Rodeo	3-5 kg/ha	Apply to foliage, not to water

None of these methods is without negative consequences. The use of chemical methods can effect the usability of both water and fish by humans or for irrigation, most often necessitating delays between application and use of between 1 and 365 days. The most commonly used aquatic herbicides are based on copper which kills all plant life, including beneficial phytoplankton that form the basis of the food web (thus lowering overall productivity) and forms carbonates in water that accumulate in sediments and can render them sterile for aquatic life. In addition, both chemical and mechanical controls require frquent and repeated treatment and so are expensive.

Grass carp are alien in most of the places where they are introduced and thus risk the negative environmental impacts of escapement. To address this problem, some agencies employ only sterile triploid grass carp, produced through pressure treatment of eggs and subsequent screening, making this technique quite expensive. *Tilapia rendalli is* another useful weed-eating fish (Caulton 1976), but only becomes actively herbivorous after reaching a relatively large size (Brummett 1995).

Drawdown can not only kill marginal weeds, but can also negatively affect fish reproduction which often occurs in shallow water, particularly among weed beds. In addition water losses from the irrigation system due to draw down can be substantial. On the other hand, drawing down the lake level can allow access by livestock, which can leave behind substantial amounts of nutrients in the form of dung (Kolding 1994, Skarpe 1997).

Phytoplankton can also be weedy, creating problems primarily with water quality leading to either massive fish kills during deoxygenation events or dynoflagellate blooms (red tides), and off-flavours in foodfish. High concentrations of cyanophytes *(e.g., Anabena, Anacystis, Aphanizomenon, Nostoc, Nodularia, Gleotrichia, Gomphosphaeria)* have been associated with deaths among watering livestock, and may also be dangerous for humans. Phytoplanktivorous fish species such as bighead carp *(Aristichthys nobilis)*, silver carp *(Hypothalmichthys molitrix)* and Galilee tilapia *(Sarotherodon galilaeus)* have been successfully used to reduce phytoplankton in Israel (Leventer 1981).

Disease Vector Control

Disease vectors, especially mosquitoes (malaria, yellow fever) and snails (bilharzia) are common in some standing waters and theoretically can pose serious health risks to humans in cases where lakes and reservoirs are in proximity to villages or towns (Figure 12). Chemical control with natural or synthetic insecticides or molluscicides is common and can be effective, but is also expensive and can damage natural food webs, lowering overall productivity (Ndamba & Chandiwana 1992). Preferred in many places has been the introduction of fish that eat mosquito larvae such as members of the poecilidae, especially mosquito fish (*Gambusia affinis*) and guppies (*Poecilia reticulata*).

Figure 12. *Small waterbodies in urban areas are important recreation and food resources for human populations, but can pose significant threats of public, if poorly managed.*

On the other hand, studies in India, Sri Lanka, Tanzania and West Africa have shown that, though communities living near small waterbodies suffer from very high mosquito densities, they enjoy lower than average malaria transmission (Klinkenberg et al. 2003). According to Teuscher (pers. comm., Bouake, Côte d'Ivoire, 1999) this is due to the stability of predator:prey relationships within the ecosystem. In seasonally wet areas, mosquitoes and their main predator, dragonflies (Odonata), die back during the dry season. When rains begin, mosquitoes rapidly increase in number ahead of the dragonflies resulting in a peak in malaria. As the wet season wears on, dragonfly populations catch up to the mosquitoes and eventually reach a density where they effectively shorten the mosquito's life span to less than the required two weeks for malaria transmission. In areas where permanent water protects the natural balance between predators and prey, the overall density of insects remains high throughout the year, but their individual life spans are shorter, thus reducing malaria.

In addition to snails, bilharzia transmission depends upon contamination of waterbodies with human urine and/or faeces. This disease could be easily controlled through public education and health campaigns, with available drug therapy (Blas et al. 1992). Surveys conducted in the Lake Chilwa floodplain of Malawi, where bilharzia is a major public health problem, found that managed waterbodies contain large numbers of snails, but when the local population was not discharging human waste into the water, none of these contained cercariae (Chiotha 1994).

Attempts to introduce snail-eating fishes such as the black carp (*Mylopharyngodon piceus*) to control bilharzias-transmitting snails has been attempted in a number of places without much success, due largely to the snailsí habit of sheltering amongst aquatic weeds where they are generally inaccessible to fish predation. When weeds are not a major problem, black carp can be effective. For example, within the Israeli national water carrier system, snail densities of 237 per m^2 were reduced to zero (Leventer 1981). Suppression of bilharzia intermediate host snails by a competitor snail, *Thiara granifera*, has been observed in the Caribbean (Sodeman 1992), while red swamp crayfish (*Procambarus clarkii*) have been shown to effectively control schistosome transmitting snails in Kenya (Loker et al. 1992, Mkoji et al. 1992), although the translocation of this highly invasive alien species should only be considered in extreme cases (Lokker et al. 1992).

MANAGEMENT

Management

Typically, dams and other water control structures are created by governments and allocated to communities for collective management and use with little or no fish management strategy (Sugunan 1997). Ignoring the high potential for managed fisheries in small dams has lowered overall productivity and efficiency of resource use. In Zimbabwe, for example, over 10,000 dams have been constructed for irrigation, domestic water supply and stock watering. The vast majority of these are currently unmanaged for fisheries, but have the potential to produce over 12 million kilograms of fish per year (Ersdal 1994). If properly managed, the runoff holding and groundwater recharge capacity of these dams is sufficient to supply water to a population some 4-6 times the current level (Sugunan 1997). Low incentives to maintain the physical infrastructure of water control structures can be attributed to low returns on investment and conflicts over ownership of benefits. Enhanced fish production and organized management, optimised around stated objectives of landowners and/or communities, could resolve many of these problems and return substantial benefits to local communities (Vallet 1993).

In general, management is much easier and more effective in smaller lakes and reservoirs (Quir.s 1998). Fertilization, for example can increase production from the typical 10-500 kg/ha up to 1000-5000 kg/ha, but is generally not practical in large reservoirs. Likewise, control of illegal fishing becomes more difficult as the size of the reservoir increases. Managed dams have been shown to produce substantial quantities of fish and revenues if their management can be balanced against the needs of irrigation and other uses (Renwick 2001).

Typical problems with achieving this balance were noted by Barbosa and Hartmann (1998):

- **Ambivalence of government towards user participation;**
- **Lack of legal backing for co-management system;**
- **State preference for generally applicable rules rather than locality-specific regulations;**
- **Inadequate rule enforcement.**

Nevertheless, a number of successes have been recorded for improved management of small waterbodies. A 10-year effort in Bangladesh to introduce community-based fisheries management of waterbodies (40-500 ha) has produced improvements in productivity of between 25 and 70%, and new institutional arrangements that have been used to implement season closures, access restrictions, installation of fish aggregating devices and the establishment of protected areas for the benefit of local communities (Thompson et al. 1999). Exclusivity of ownership, transferred from government (public) to local management entities that are comprised of, and operate on behalf of, fishing communities, was found to be a critical factor in success.

In a review of traditional inland fisheries management systems in Africa, COFAD (2002) identified exclusivity of access and a locally evolved and collectively owned cognitive base and established, accepted and functioning local institutionsî as key elements of success.

In NE Nigeria, Neiland & Ladu (1998) found that there are many advantages of using traditional management strategies and structures as the basis for improved institutional arrangements (Table 3). Likewise, COFAD in a review of African institutional arrangements for fisheries management, found that co-management (a mixture of traditional and modern strategies) produced the best results overall (see box).

Table 3. *Management systems and their outcomes in NE Nigeria (adapted from Neiland & Ladu 1998).*

Management System	Description	Number of Villages (%)	Case Study	Outcomes
Traditional	Fisheries managed by traditional government administration through village and district heads.	31 (58)	Dagona: District head has jurisdiction over local fisheries in Hadejia River & floodplain; fisheries managed for community benefit; regulations implemented by village master fisher, including gear & access restrictions; fishers (mostly migrants) pay fee to fish; proceeds redistributed to community; poachers fined & have catch confiscated; some floodplain pools owned by local families; fishers pay fee & give part of catch to district head.	• Management objectives achieved. • No conflicts over fishing. • Owners of privatge pools among wealthiest members of the community.
Modern	Fisheries managed by government administration through federal, state and local officers.	5 (10)	Wuro Bokki: Fishing Benue River monitored by officers of State Fisheries Department posted in the village; management objectives to conserve fisheries resources & sustain fisher livelihoods; methods include mesh-size restrictions as part of «good fishing» campaign; fishers obtain license to fish and pay fee to State; fishers found not complying have gear & catch confiscated; traditional management has broken down as village has enlarged & become commercially active in trade with nearby Cameroon.	• Fishery has assumed a state of open access. • Fishing has decreased in importance. • Fishers are poor. • State management objectives have not been met. • Limited compliance. • Conflicts over fishing rights.
Mixed	Traditional & modern government administrations participate together in management of fisheries, either intentionally or inadvertently.	17 (32)	Kwatan Dawashi: Fishing Lake Chad floodplain under jurisdiction of village head, mainly during low water in isolated pools & channels; two management objectives: generate revenue & avoid conflict; site fees for each fishing traps negotiated between fishes and village head, a proportion being passed to local government and district head.	• Management objectives achieved. • Revenue generated. • Conflict avoided.

Workers in Burkina Faso found that simple management strategies for seasonal dams could increase fish standing stock from 60 to over 600 kg/ha (Baijot et. al 1994). Training and group formation for fisheries management committees helped to develop flexible mangement plans for a range of small waterbodies (de Graaf & Waltermath 2003). In Malawi, local management entities have proven themselves capable of managing seasonal waterbodies for fish production (Chikafumbwa et al. 1998). What started as a micro-project with two villages has, over the last five years, expanded to over 12 villages with no additional external input and has been so successful that demand for fingerlings to stock the ever-increasing number of com nity lakes in the area has become a serious constraint.

Co-management Vs Community-Based Management
(adapted from COFAD 2002)

Central government is usually not capable of taking and enforcing adequate management decisions for a specific waterbody. The involvement of stakeholders, in particular local institutions and traditional authorities, appears to be the only way to manage inland fisheries.

Options include community-based management (CBM) or co-management of resources. Both entail the involvement of communities, but differ in that community CBM gives full responsibility to a community, while co-management creates a partnership arrangement between government and one or more communities. As the degree of government involvement in co-management varies, CBM can be seen as a form of co-management with minimal direct government participation.

Co-management appears to be the most suitable option where larger waterbodies are concerned, where a sizeable number of stakeholders have access to a resource, where different ethnic groups or nations are involved or where the state has a particular interest in a resource (e.g., biodiversity conservation). Where resources are delimited and utilised by only one or a very few stakeholder groups, CBM appears to be the better option.

In African inland capture fisheries, it is usually traditional communities that represent most stakeholders. To devolve management functions to these communities has several advantages:

Institutions exist and can be «utilised» with little or no cost.
Their acceptance is generally high.
They have appropriate methods to mediate in case of conflicts.
They have effective mechanisms of enforcement.

However, to rely solely on traditional communities for resource management is, in most cases, neither viable nor realistic.

Successful co-management requires government support, in particular by providing an appropriate legal framework and officially acknowledging traditional institutions. Also, community management could require the adaptation of existing, or the creation of new, institutions and/or management bodies. If traditional authorities and institutions are fully integrated into such structures, the advantages of traditional management could be maintained.

Communal management of reservoirs in Kerala, India has brought internal rates of return of 24% to hatchery operators and 32% to fishers (Peters & Feustel 1998). In Zimbabwe, people engaged in community-based small dam management initiatives have succeeded in putting in place comprehensive management structures and regulations, but have confronted ownership/control issues that have diminished expected fish productivity impacts (Chimbuya & Ersdal 1994).

Some of the key issues in regard to the development of sustainable local management strategies are shown in Table 4, the main finding being that exclusive access is a critical component of improved management.

Table 4. *Management issues for a range of small waterbodies in Burkina Faso (de Graaf & Waltermath 2003).*

Large (20-700 ha)	Medium (5-20 ha)	Small (1-5 ha)
Management & ownership by more than one village.	Management & ownership by only one village	Management & ownership by one (extended) family group.
People view management as the business of the government.	Local management is possible in cases where legal framework exists.	Distribution of benefits regulated locally through traditional mechanisms.
Difficult to obtain exclusive access for local management entities.	Exclusive access can be organized	Access rights are normally exclusive to the family group.
Impact of investments in management are difficult to monitor	Impacts of investments are relatively easy to monitor.	Impacts of investments obvious to owners.
Inequitable distribution of benefits among stakeholders.	Benefits more equitably distributed among stakeholders.	Benefits distributed according to family norms
Management generally not sustainable outside of a project context	Can be sustainable if developed under a proper legal framework.	Highly sustainable

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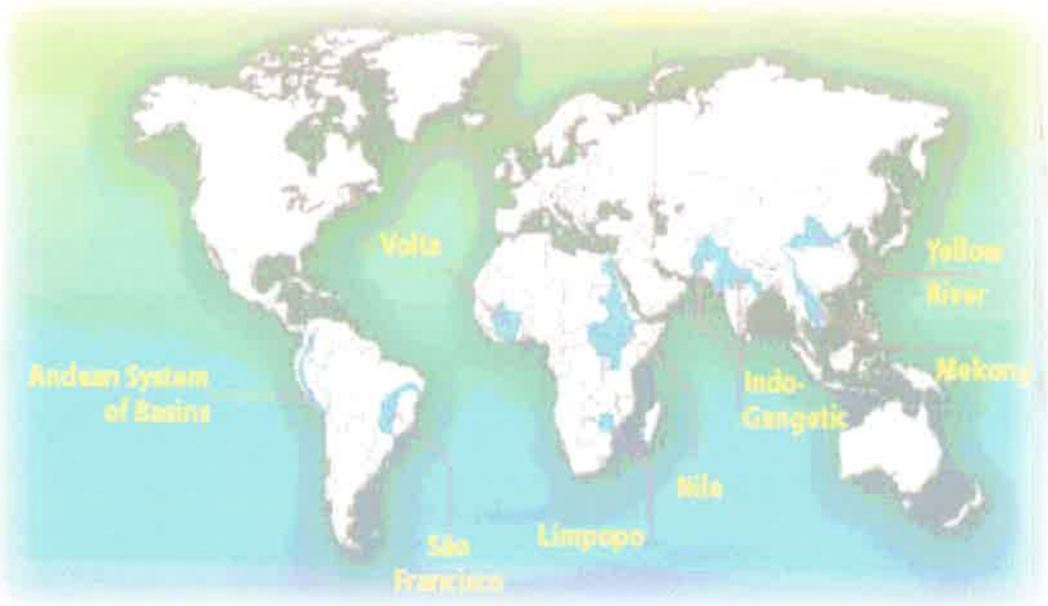

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