Inland Fisheries Enhancement in Sri Lanka: Opportunities and Constraints

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Abstract

Early attempts of fisheries enhancement in Sri Lankan freshwaters were aimed at establishing commercial fisheries and consequently, exotic cichlid species were introduced during the second half of the last century. The major inland fisheries enhancement strategy practised in Sri Lanka is the development of culture-based fisheries (CBF) in village reservoirs. CBF combines elements of aquaculture and capture fisheries and relies entirely on the natural productivity of the water body for growth of fish, and on artificial stocking as a means of recruitment.

The aquaculture extension officers of NAQDA and several NGOs have been conducting awareness programmes to educate rural farmers on CBF management. This state-sponsored extension mechanism considerably facilitates inland fisheries resources enhancement in the country. However, due to inadequacies in extension mechanisms in the fisheries authorities of provincial councils and their lack of coordination with the central government, in some instances there is a conflict of interest between the provincial authorities and the central government. Although there has been a significant policy level advancement providing legal provisions for fisheries and aquaculture development in small reservoirs, in some parts of the country, CBF activity is still considered as a secondary use of reservoirs with low priority.

Introduction

Sri Lanka (5°55'–9°55' N; 79°42'-81°52' E) is a continental island of about 65,621 km^2 in monsoonal Asia with rich water resources. There are 103 perennial rivers in Sri Lanka, most of which radially drain into sea from the central highland area into the western, southern and eastern coasts. These river basins cover over 90% of the land area. Floodplains, lagoons and estuaries also form natural inland water resources of the island (NSF 2000). In most countries with rich water resources, dam construction, transfer of water across river basins and water withdrawals for irrigation and hydroelectricity are worldwide enterprises. In some Asian countries like Sri Lanka, reservoir construction was an integral part of ancient civilization. The sovereignty of ancient hydraulic civilization in Sri Lanka is witnessed by extant reservoirs some of which have been as old as 2000 years (Fernando and De Silva 1984; De Silva 1988). The hydraulic civilization in Sri Lanka has possibly evolved from early rain fed shifting agriculture into small-scale irrigation that has in turn led to establishment of major irrigation systems, as evident from many landmarks which runs throughout more than 2500 of country's written history (Brohier, 1934, 1937). The multitude of reservoirs of the country includes ancient irrigation reservoirs and recently constructed multipurpose reservoirs (De Silva 1988; Fernando 1993). These reservoirs have been constructed primarily for irrigation and/or generation of hydroelectricity and as such, fisheries development in these reservoirs is essentially a secondary use.

Small-scale water conservation systems referred to as village/small reservoirs, created by constructing earthen bunds across natural drainage basins are a distinctive feature of the dry zone of Sri Lanka. These reservoirs in Sri Lanka depend entirely on direct rainfall and runoff water from their own catchments areas. Nevertheless, they are not randomly located but are formed to occur in the form of distinct cascades that are positioned either well defined small cascade or meso-catchment basins (Panabokke 2001; Udawattage 1985). Organization of small reservoirs into a cascading sequence connected to another micro-catchment allowed greater efficiencies of water use. A cascade, according to the definition by Madduma Bandara (1985), is a connected series of tanks organized within the meso-catchments of the dry zone landscape, storing, conveying and utilizing water from an ephemeral rivulet. These reservoirs irrigate paddy fields along channels by way of a sluice (Panabokke et al. 2002). There are over 10,000 small, village reservoirs in Sri Lanka but most of them are less than 100 ha in surface area and are distributed across the undulating landscape of the dry zone. The total extent of small village reservoirs of Sri Lanka is about 39,300 ha (Mendis 1977). Drainage from the paddy fields in the upper parts of the cascade flows into a downstream reservoir for reuse in the paddy fields below.

The inland reservoirs in the dry zone were utilized by ancient people as source of animal protein (Siriweera 1986; Ulluwishewa 1996). A stone inscription (Perimiyankulama stone inscription) located in Anuradhapura ancient city indicates that during the reign of King Vasabha (67 – 111 AD), the inland fish catches from the reservoirs were distributed within the village. According to another stone inscriptions established by King Nissankamalla (1187 - 1196 A.D.), taxes levied from inland fishing in reservoirs were abolished (Siriweera, 1994). During ancient times however, fish production from inland reservoirs has been based on indigenous species and there has been no commercial scale inland fishing industry in ancient Sri Lanka.

Inland fisheries enhancement

Inland fisheries in the tropics are important means of providing food and nutritional security to the people. However, most major inland fisheries in the world are reported to be in decline due to habitat deterioration and overfishing (Welcomme 2001). Inland fisheries enhancement is therefore suggested to be an effective intervention to increase the biological production from inland waters (FAO 1997). According to FAO (1997), fisheries enhancements are defined as technical interventions in existing aquatic resource systems, which can substantially alter environmental, institutional and economic attributes of the system. Accordingly, five types of inland fisheries enhancement are recognized to be practiced.

1. Species introduction;
2. Culture-based fisheries;
3. Environmental enhancement;
4. Habitat rehabilitation; and
5. Fisheries management

Early attempts

During the British colonial period in the early part of twentieth century, there had been some suggestions to utilize the multitude of inland reservoirs for increasing fish production. For example, Willey (1910) and Pertwee (1913) have advocated introduction of exotic herbivorous fish species into Sri Lankan reservoirs in order to increase inland fish production. Various herbivorous fish species were introduced to Sri Lankan freshwaters during the first half of the twentieth century, but none of them established as commercially viable fisheries (De Silva 1988). The commercial scale inland fishery is a relatively recent development after the introduction of exotic cichlid species, *Oreochromis* *mossambicus* (Peters) into Sri Lankan freshwaters in 1952 (Fernando and Indrasena 1969; De Silva 1988; Amarasinghe and Weerakoon 2009).

Introduction of *O. mossambicus* into Sri Lankan freshwater was based on the recommendations by fisheries authorities. Fernando (1956) has strongly criticized introduction of *O. mossambicus* into Sri Lankan freshwaters and mentioned that as there were herbivorous fish species in indigenous fish fauna, it was not necessary to introduce another herbivorous fish species such as *O. mossambicus*. However, subsequently he had been exponent in praising the role of *O. mossambicus* in Sri Lanka to produce high fish yields from reservoirs (Fernando 1971; 1977; 1993). These incidents suggest that attempts of the fish introductions during the first half of the twentieth century were not based on scientific reasoning but can be considered as "ad-hoc" introductions (Amarasinghe 1998a). However, Introduction of *O. mossambicus* into Sri Lankan reservoirs in 1952 was responsible for increased inland fish production and establishment of commercial scale inland fishery.

There are different opinions on the success of *O. mossambicus* in Sri Lankan freshwaters. Fernando and Indrasena (1969) mentioned that due to the extensive availability of shallow littoral areas in reservoirs in Sri Lanka, *O. mossambicus* can successfully reproduce in reservoirs. Fernando and Holčik (1982, 1991) indicated that as there were no lacustrine fish species in indigenous fish fauna of Sri Lanka, they were unable to support productive fisheries in reservoirs and that *O. mossambicus* which was pre-adapted to lacustrine conditions, could successfully colonize reservoir habitats and produce high yields. Costa and Abeyasiri (1978) have mentioned that as *O. mossambicus* is capable of digesting blue green algae, they can successfully colonize reservoir habitats where blue green algae are abundant. De Silva (1985) has shown that *O. mossambicus* in Sri Lankan reservoirs, changes feeding habitats from season to season depending on the availability of food items and that the nutritive quality of these food items is adequate for its average growth. De Silva (1985) based on these findings mentioned that due to elasticity in feeding habits of *O. mossambicus*, it can colonize successfully within reservoir habitats in Sri Lanka.

In 1975, *O. niloticus* was also introduced into Sri Lankan reservoirs. Presently in most reservoirs, these two exotic cichlid species form over 90% of total landings (Chandrasoma 1986; Amarasinghe 1997). Reservoir fishery of Sri Lanka is essentially a cheap source of animal protein for rural communities.

Government's support to the inland fisheries sector was first provided in the 1950s with the establishment of two fish breeding stations which were set up by the government, one in Polonnaruwa and the other in Colombo. As part of this development activity, the exotic cichlid *Oreochromis mossambicus* was introduced into reservoirs in 1952. This was responsible for dramatic increase of inland fish production and the trends in the growth of the fishery during the second half of the twentieth century, have been described by Fernando and Indrasena (1969) and De Silva (1988). The historical trends were such that fishing effort increased gradually in early 1950s as a result of migration of marine fishers to inland reservoirs.

An increase in efficiency of fishing sector took place in the late 1950s due to introduction of nylon gillnets by the government instead of less efficient cotton gillnets (Indrasena 1965). With the introduction of exotic cichlid together with support through extension services by the government, fish production in the reservoirs increased dramatically. Total fish catch of 1200 t in 1956 rose to 8200 t by the year 1970

(Amarasinghe and De Silva 1999). There had been a gradual increase of inland fish production in 1971, 1974 and 1977. In 1977, under a five year development plan, several strategies were introduced to increase inland fish production. For example, in 1979, the government introduced a 90% subsidy scheme to provide fiberglass out-rigger canoes and gillnets. Since these subsidies were given through fisheries cooperative societies, almost all fishing communities in the perennial reservoirs of the country organized into co-operative societies to get the benefits of state sponsored subsidy scheme (Amarasinghe 1995; 1998b; Amarasinghe and De Silva 1999). Due to these state-sponsored inland fisheries development activities, the country's annual inland fish production increased from 13,000 t in 1977 to 39,750 t in 1990. However, as a result of various religious and political reasons, state patronage for the inland fisheries and aquaculture was discontinued during 1990-1994 (Amarasinghe 1998b; Amarasinghe and De Silva 1999). As a result of over- fishing of the two major cichlid species in the reservoir capture fishery of Sri Lanka in the absence of state-sponsored monitoring procedures, inland fish production dropped from 39,750 t in 1990 to 12,000 t in 1994 (Amarasinghe 1994; Amarasinghe and De Silva 1999).

Failure to monitor reservoir fisheries by the government resulted over-exploitation of the resource, causing production to decline, thus indicating the ineffectiveness of a top-down approach for implementing management strategies (Amarasinghe 1998b). It was also evident that in reservoirs where there were well-organized fishing communities with their own fishery regulations to mange fish stocks, there was no over-exploitation even after withdrawal of state patronage (Amarasinghe 1998b; Amarasinghe and De Silva 1999).

The policy of the government on inland fisheries reversed in 1994 and the support of government to develop inland fisheries was revived (Amarasinghe and De Silva 1999). Learning bitter lessons from the past, the government now places great emphasis on mobilizing local communities for planning and implementation of all inland fishery and aquaculture development programmes. Lack of community participation in the development programmes has been identified as a major constraint as proposed by Amarasinghe (1988) so that government pays more attention to promote participatory approaches for the development of the inland fishery (Jayasekara 1997). Pomeroy et al. (1996) showed that in most Asian fisheries, participation by fishermen in planning and implementation processes facilitated effective co- management.

Fish stocking in perennial reservoirs: How effective?

Stocking of fish fingerlings is a commonly practised strategy to mitigate loss of stocks, enhance recreational or commercial catches, restore fisheries or create new fisheries (Cowx 1994). In Sri Lankan reservoirs, stocking of fish fingerlings is carried out to enhance commercial catches. De Silva (1987) reviewed the stocking practices in inland reservoirs of Sri Lanka and recognized two phases.

- First phase: stocking with giant gourami, *Osphronemus goramy* commencing in the 1940s followed by *Oreochromis mossambicus* in 1950s and *O. niloticus* in mid 1970s.
- Second phase: stocking with Chinese major carps beginning in the late 1970s followed by Indian major carps in the early 1980s.

Chandrasoma (1992) reported that in three reservoirs namely, Giritale (308 ha), Kandalama (777 ha) and Udawalawe (3374 ha), *Labeo rohita* that was intensively stocked in 1980s produced high yields.

However, stocking of exotic carps did not result in high yields in majority of reservoirs (De Silva 1988; Amarasinghe 1998a). Fish yields of exotic carp species showed negative curvilinear relationship with the reservoir area indicating that high fish yields through stocking can only be achieved in small (<800 ha) reservoirs (Amarasinghe 1998a). Such negative curvilinear relationships between yields of stocked fish and reservoir area are evident in reservoir fisheries in many parts of the world such as Mexico, China and India (De Silva et al. 1992; Sugunan 1995; Welcomme and Bartley 1998). As the number of fingerlings needed to ensure high recovery rates in larger reservoir is too high, there is a general tendency to stock fish at lower densities into larger reservoirs (Welcomme and Bartley 1998). Also, competition and predation will be greater in larger water bodies and therefore, survival rates of stocked fish will be reduced resulting in low recovery rates (Welcomme and Bartley 1998).

In Sri Lankan reservoirs, early stocking regimes were arbitrary and achieved poor results (De Silva 1987, 1988). The stocking in major perennial reservoirs of Sri Lanka has been less successful, as they are managed mainly for self-producing tilapias (Amarasinghe 1998a). Since recently, fisheries cooperative societies (FCS) in some reservoirs such as Chandrikawewa and Urusitawewa have started stocking of fish fingerlings using the funds raised in the FCS. The outcomes of these stocking regimes are however, needed to be evaluated.

Exotic carps in capture fisheries in perennial reservoirs

In Udawalawe reservoir in the Walawe river basin, fingerlings of Chinese and Indian major carps were stocked intensively in 1980s because this reservoir is situated in close proximity to a state-owned fish breeding station. In this reservoir, *O. mossambicus* and *O. niloticus* formed nearly 25% of the total landings whereas the contribution of Indian major carps (*Catla catla*, *Cirrhinus mrigala* and *Labeo rohita*) and an indigenous cyprinid species, *Labeo dussumieri* to the ladings was about 70% (Sricharoendham et al. 2008). The catch per unit effort (CPUE) expressed as kg per boat-day, in Udawalawe reservoirs was shown to be influenced by lunar phase and rainfall (Sricharoendham et al. 2008). During full-moon phase, majority of boats had lower CPUE whereas peak CPUE was reported during rainy seasons with very high proportion of *C. catla* (over 95%) in the landings. According to the information gathered from fishers, egg masses of Indian carps attached to submerged macrophytes could be observed in the inflow areas of the reservoir. This evidence suggests that self-reproducing populations of Indian major carps have been established in the Walawe river basin. Studies on the reproductive biology of Indian major carps in Sri Lankan inland waters are therefore necessary for defining reservoir fisheries management strategies.

Culture-based fisheries

The inland fishery of Sri Lanka has been essentially a capture fishery from perennial reservoirs. However, the small (< 50 ha) village reservoirs in the country can be utilized for the development of culture-based fisheries. This is also a fisheries enhancement strategy (Lorenzen et al. 2001) and the fisheries enhancement through the stocking of individuals or introduction of species is a practice frequently used by fisheries owners, managers and scientists throughout the world (Cowx 1994). Although fishery enhancement has received much attention, culture-based fisheries have not received their due attention in spite of their potential to contribute significantly to fish production and also in view of their potential impact on rural poor in most developing nations (De Silva 2003).

In culture-based fisheries, artificially propagated seed stocks are released into water bodies not primarily and traditionally used for fish production, and recaptured upon reaching a desirable size (Lorenzen, 2001). De Silva (2003) mentioned that as a rule, culture-based fisheries involve ownership either singly, as in the case of Vietnam where farmers lease out small reservoirs (Nguyen et al., 2001), or collectively, in the form of a cooperative, such as the case in oxbow lakes in Bangladesh (Middendrop and Balarin, 1999).

The small village reservoirs in the country, which are also known as seasonal reservoirs are highly productive due to the cattle manure accumulated in the draw-down areas from cattle grazing during dry season and residues of terrestrial vegetation. Small puddles in most seasonal reservoirs do not dry up completely so that they can harbour some of the indigenous carnivorous fish species with accessory respiratory organs such as snakehead (*Channa* sp.), climbing perch (*Anabas testudineus*), catfishes (*Macrones* sp.). These indigenous species, although harvested in some reservoirs, do not produce high yields. The potential of small village reservoirs for the development of culture-based fisheries was first pointed out by Mendis (1965). Accordingly, attempts were made in 1960s to utilize these seasonal reservoirs for the development of culture-based fisheries (Indrasena, 1965). Indrasena (1965) reported that in 1960s, some seasonal reservoirs were stocked with *O. mossambicus* fingerlings of 7.5-10.0 cm and that during 8-9 months of water retention period, they grew upto 25-30 cm in size.

Fernando and Ellepola (1969) reported that in February-March 1963, eight small reservoirs in the north-central province of Sri Lanka were stocked with *Chanos chanos* and *O. mossambicus*, which were harvested in September 1963. They also reported their observations in Dalukanawewa during fishing season in July-August 1964. Mendis (1977) has estimated the culture-based fisheries production potential of the small village reservoirs as 13,000 tonnes on the basis of mean fish yield of 330 kg ha^{-1} yr^{-1}.

Based on the recommendations by Rosenthal (1979) and Oglesby (1981), a programme was implemented to formulate a suitable strategy for the development of culture-based fisheries in seasonal reservoirs of Sri Lanka (Thayaparan, 1982). De Silva (1988) estimated fish yields of some seasonal reservoirs, mean survival rates and mean weight at harvesting of the stocked species in seasonal reservoirs, based on the data reported by Chakrabarty and Samaranayake (1983). These estimates indicate that fish yields in a culture cycle varied considerably from 18 kg ha^{-1} to 1961 kg ha^{-1}. The highest survival was reported for *O. mossambicus* whereas fast growth rates were observed for *Cyprinus carpio, Ctenopharyngodon idella and Aristichthys nobilis.* This experimental project was funded by FAO/UNDP (FAO/UNDP, 1980). As these studies have shown that there is a high potential for the development of culture-based fisheries in seasonal reservoirs, the Asian Development Bank financed a project on aquaculture development in Sri Lanka, the main activity of which was the utilization of seasonal reservoirs for culture-based fisheries development (De Silva, 1988). This project commenced in 1984 and it also involved the strengthening of 6 fish breeding centres and 8 fingerling-rearing centres, which were owned by the Ministry of Fisheries (Thayaparan, 1982).

The culture-based fisheries development trials were carried out in seasonal reservoirs in 1980s with rural community participation. Fingerlings of common carp, Chinese and Indian major carps of 5-8 cm size, produced in the fish breeding stations, were stocked in the reservoirs. At the end of the culture period of 7-10 months, fish stocked were harvested by the rural farmers using encircling nets. Chandrasoma and Kumarasiri (1986) reported that in 15 seasonal reservoirs, fish yields ranged from 220 to 2300 kg ha^{-1} (mean 892 kg ha^{-1}) within a single growing season.

As the culture period in seasonal reservoirs is 7-9 months, the species suitable for stocking in seasonal reservoirs should reach the marketable size in 6-8 months. These species should also be able to utilize the natural food resources available in the reservoirs. In Sri Lankan indigenous fish fauna, such species are not available. Exotic tilapias are not desirable because they tend to mature early in life in small water bodies. As such, culture-based fisheries in seasonal reservoirs exclusively rely on common carp, Chinese and Indian major carps. These species have been artificially spawned successfully in Sri Lanka (Weerakoon, 1979; Balasuriya et al., 1983; De Silva, 1988).

Water resources for culture-based fisheries development in Sri Lanka

According to a survey carried out by the Department of Agrarian Services (now named as Department of Agrarian Development), there are about 12,000 village reservoirs in Sri Lanka and about 10,000 of these are at present in working conditions. The district-wise breakdown of the distribution of village reservoirs is given in Table 1. Almost all of these small village reservoirs are situated in the dry zone of the country receiving less than 187 cm annual precipitation (Fig. 1). The dry zone of

Sri Lanka is located within the lowest peneplain of the island and it covers approximately 66% of the total land area of the country, which holds 33% of the country's population. Over 90% of the rural population is directly involved in farming and the peasant community is characterized by acute poverty and malnutrition (De Alwis 1983).

Strategies for sustainable culture-based fisheries

As previous culture-based fisheries trials in seasonal reservoirs indicated that there would be a high potential for their development, it has been suggested that at a stocking density of 2000 fingerlings ha^{-1}, an average yield of 750 – 1000 kg ha^{-1} could be achieved (Charkabarty and Samaranayake, 1983; Chandrasoma and Kumarasiri, 1986; De Silva, 1988). It is highly unlikely that fingerlings will ever be available in sufficient quantities to stock all seasonal reservoirs in Sri Lanka. As such, it is important that wise use of the available seed stock is made through a selection of reservoirs that are suitable for developing and sustaining culture-based fisheries.

Pushpalatha (2001) and Pushpalatha and Amarasinghe (2007) reported case studies of rural aquaculture in Sri Lanka for the production of fish fingerling in ponds and cages. In eight earthen ponds ranging in size from 136 to 540 m^2, fry of *Cirrihnus mrigala*, *Cyprinus carpio*, *Labeo dussumieri* and *L. rohita* were stocked and after the growing period of 62-78 days, survival rates of fingerlings were 33-86% (Pushpalatha, 2001). Pushpalatha (2001) also reported that in 8 perennial reservoirs, fish fry were reared up to fingerling size in net cages of 4 m x 2.5 m x 2 m size, made of 4 mm mesh nets and that with the stocking density of about 5000 fry per cage, high survival rates (55-92%) were achieved within the culture period of 58-80 days.

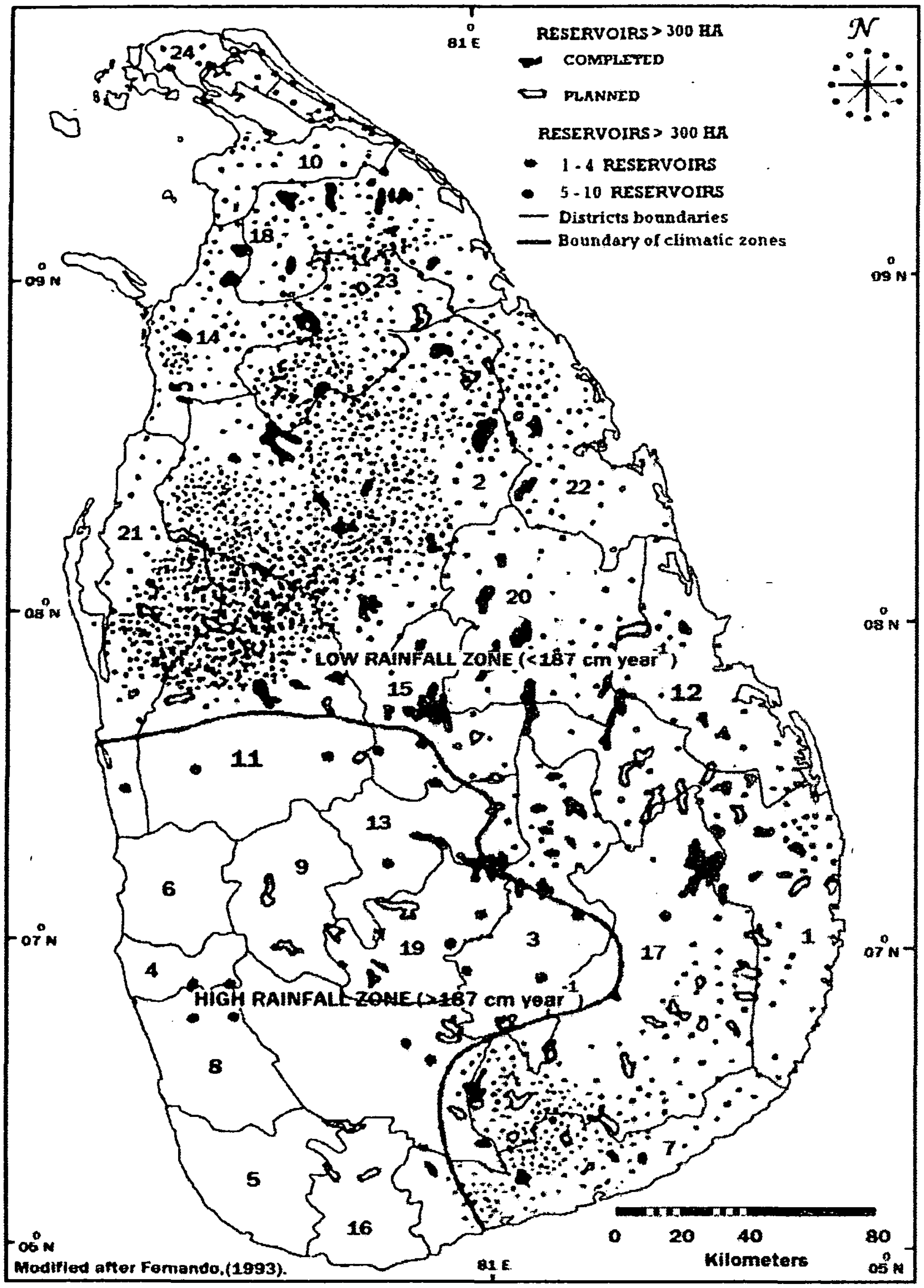
Table 1. Distribution of reservoirs in Sri Lanka (adopted from Kularatne et al., 2009).

District	Working tanks	Abandoned tanks	Total tanks
Ampara	181	87	268
Anuradapura	2,333	665	2,998
Badulla	259	128	387
Batticaloa	132	110	242
Colombo	03	02	05
Galle	00	00	00
Gampaha	24	33	57
Hambantota	446	23	469
Kalutara	06	01	07
Kandy	47	11	58
Kegalle	07	03	10
Kurunegala	4,192	77	4,269
Mannar	.61	51	112
Matara	24	03	27
Matale	278	33	311
Monaragala	285	151	436
Nuwara Eliya	54	17	71
Polonnaruwa	79	36	115
Puttalam	743	175	918
Ratnapura	59	08	67
Trincomalee	428	196	624
Vavuniya	453	101	554
Tatal	10,094	1,911	12,005

This case study indicates that in Sri Lanka, it is possible to introduce a strategy for rearing of fish fry to fingerling size in net cages and earthen ponds. However, low-cost feed for fry rearing, subsidy schemes to cover the initial cost of cage and pond construction etc. are needed for the sustainability of this strategy. As the fingerlings should be stocked in seasonal reservoirs just after the heaviest rainy season (November-January) in the dry zone of the country, correct timing of production of fingerlings is also necessary for successful implementation of culture based fisheries in seasonal reservoirs. Amarasinghe (1998a) has shown that in small (<800 ha) perennial reservoirs, where the fisheries based on cichlids are not productive, stocking of fingerlings of major carps might increase yields. Amarasinghe (1998a) however has further indicated that in planning fisheries development in small perennial reservoirs, they have to be treated individually, taking into consideration the biology of the reservoir ecosystem as well as the socio-economic aspects of the rural communities living around reservoirs.

Culture-based fisheries in minor perennial reservoirs

The demand for fish fingerlings for CBF development in seasonal reservoirs exists only after the peak rainy period in November-January in the dry zone of the country. As such, fingerlings that are produced during the seasons when not required for stocking seasonal reservoirs can be used for CBF development in minor perennial reservoirs. Water management in these reservoirs comes under the jurisdiction of either Irrigation Department (those with command area of over 80 ha) or Department of Agrarian Development (those with command area of < 80 ha).



DISTRICTS :

1. Ampara
2. Anuradhapura
3. Badulla
4. Colombo
5. Galle
6. Gampaha
7. Hambantota
8. Kalutara
9. Kegalle
10. Kilinochchi
11. Kurunegala
12. Madakalapuwa (Batticaloa)
13. Mahanuwara (Kandy)
14. Mannarama (Mannar)
15. Matale
16. Matara
17. Monaragala
18. Mullaitivu
19. Nuwara Eliya
20. Polonnaruwa
21. Puttalama (Puttalam)
22. Thirikunamalaya (Trincomalee)
23. Vavuniyawa (Vavniya)
24. Yapanaya (Jaffna)

Figure 1. Distribution of reservoirs in Sri Lanka (adopted from Kularatne et al., 2009)

In 2003, Ministry of Fisheries and Aquatic Resources of Sri Lanka initiated through the Asian Development Bank-funded Aquatic Resources Development and Quality Improvement Project (ARDQIP), a programme to introduce CBF in minor perennial reservoirs (< 250 ha). In most of these reservoirs, only subsistence level fisheries existed. There had been neither stocking nor proper management of fisheries in minor perennial reservoirs (Pushpalatha and Chandrasoma, 2010).

Pushpalatha and Chandrasoma (2010) listed the following physical, biological and socioeconomic criteria for selection on minor perennial reservoirs for fisheries enhancement.

i. Water spread at full supply level to be between 50-250 ha;
ii. Retention of sufficient water in the reservoirs to sustain CBF during dry seasons;
iii. Absence or low abundance of rooted or floating aquatic macrophytes;
iv. Absence or less abundance of impediments for fishing such as submerged decaying tree stumps;
v. Location of reservoir in the vicinity of the village community and close proximity to markets;
vi. Absence of major conflicts among water users;
vii. Concurrence of FO with fishers for CBF development; and
viii. Willingness of the community to be engaged in CBF.

Under the ARDQIP project, fisheries enhancement commenced in 15 minor perennial reservoirs in 2004. In these reservoirs community-based organizations (CBOs) were formed or re-organized and the members of CBOs were given training in basic aspects of CBF including community-based management, leadership, simple accounting, book keeping etc. The members of each CBO, with the assistance of aquaculture extension officers, prepared a plan for the development of CBF. This included agreements on fish species to be stocked (based on the consumer preferences and availability of seeds), stocking densities to be adopted, time for stocking, sources of fish seed, and CBF management measures to be adopted.

Species stocked were *C. catla*, *L. rohita* and *O. niloticus*. In some reservoirs, CBOs stocked *Macrobrachium rosenbergii* and *C. carpio*. According to the records maintained by CBOs in the 15 reservoirs for 2004-2007 period, annual stocking density (SD) ranged from 146 fingerings per ha in Mahagal wewa in 2004 to 2780 fingerlings per ha in Ranawa in 2006.

Unlike in seasonal reservoirs, harvesting of fish in minor perennial reservoirs is a year-round activity. Fishers working on non-mechanized canoes (2 fishers per canoe) use gillnets of stretched mesh sizes ranging from 8.5 to 20 cm. In all non-perennial reservoirs where CBF were introduced, *O. niloticus* was the most abundant species forming over 80 percent of the landings, prior to introduction of CBF. Other important species were *Channa striata*, *Clarias brachysoma*, *Anabas testudineus*, *Trichogaster pectoralis* and *Mystus keletius*. According to Pushpalatha and Chandrasoma (2010), *O. niloticus* continued to be the highest contributor to the harvest, even after the introduction of CBF. In the 15 reservoirs studied, mean annual contribution of *O. niloticus* to the CBF harvest was 47.4 percent (ranging from 19.7 to 66.5%). The overall mean contributions of three species of exotic carps namely *C. catla*, *L. rohita* and *C. carpio* were 27.2, 16.9 and 4.3 percent, respectively. Pushpalatha and Chandrasoma (2010) further indicated that in 11 reservoirs where *Macrobrachium rosenbergii* was also stocked, its mean contribution to the harvest was 0.7 percent.

Pushpalatha and Chandrasoma (2010) reported that the percent increase in mean annual fish production due to introduction of CBF ranged from 42.8 to 1344 percent, with an overall average increase of 263 percent. Prior to introduction of CBF, mean annual fish yield in the 15 reservoirs was 57.3 kg ha^{-1} and after introduction of CBF, it increased up to 208 kg ha^{-1}. Annual CBF production of minor perennial reservoirs as deduced from the available information is given in Table 2. The features of enhancement strategies and regulatory measures in the two types of reservoirs in Sri Lanka are given in Table 3.

Table 2. Annual CBF production of minor perennial reservoirs as deduced from the available information (adopted from Amarasinghe, 2010).

Category	2007	2008
Number of fingerlings stocked in minor perennial reservoirs ($x10^6$)[a]	4.61	5.70
Estimated total extent of minor perennial reservoirs stocked (ha)[b]	6,147	7,600
Estimated CBF production from minor perennial reservoirs (tonnes)[c]	1,279	1,581
Total inland capture fisheries production (tonnes)[a]	30,200	37,170
CBF production from minor perennial reservoirs as a percentage of total inland capture fisheries production	4.24	4.25

[a] Source – www.fisheries.gov.lk; [b] Estimated on the basis of average stocking density of 750 fingerlings in minor perennial reservoirs; [c] Estimated assuming average CBF production of minor perennial reservoirs as 208 kg ha^{-1} yr^{-1} (Pushpalatha and Chandrasoma, 2010).

Table 3. The features of enhancement strategies and regulatory measures in the two types of reservoirs in Sri Lanka (adopted from Amarasinghe, 2010).

	Non-perennial reservoirs	Minor perennial reservoirs
Ownership and jurisdiction of water uses	Agrarian Development Department; Farmer organizations	Irrigation Department or Agrarian Development Department; Farmer organizations
Responsible community group for CBF	Agricultural farmers (traditionally non-fishers)	Agricultural farmers (traditionally non-fishers) and/or fishers
Stocking density (nos/ha, yr)	2000 – 2500	217 – 870
Stocking size (cm)		
Major carps	5 - 6	5 - 6
Nile tilapia	6 – 8	6 – 8
Stocking frequency	After peak rainy season in November-January	Once a year when fingerlings are not needed for stocking seasonal reservoirs
Harvesting	During dry season; complete harvesting	Year-round harvesting of surplus biomass
Harvesting methods	Seining; gillnetting, cast netting	Gillnetting (8.5 – 20 cm mesh)
Management	Farmer organizations (FOs)	Farmer organization/ fishers
Funding for CBF	Revolving fund raised by the FO	Revolving fund raised by the FO/ fisheries society

Fisheries Management

In Sri Lanka, no strategies are in place for inland fisheries enhancement through environmental enhancement or habitat rehabilitation. However, Amarasinghe and De Silva (1999) have shown that fishing communities in reservoirs could be organized to introduce co-management where both the resource users and the government fisheries authorities would share the responsibilities of making decisions on resource utilization. Nathanael and Edirisinghe (2002) have also emphasized that institutional links are available for introduction of co-management in Victoria reservoir, Sri Lanka. Under the ARDQIP, National aquaculture Development Authority (NAQDA) has successfully implemented co-management in two major reservoirs of Sri Lanka, Senanayake Samudra and Mahawilachchiya (Kulatilake et al. 2010).

There are also untapped fishery resources in Sri Lankan reservoirs mainly due to low consumer preference and fishing gear limits imposed by fisheries regulations. However, De Silva and Sirisena (1989) and Amarasinghe (1990) have estimated the fishery potential of small indigenous fish species, termed as minor cyprinids to differentiate from Chinese and Indian major carps and common carp, in reservoirs of the country by comparing catch rates of cichlids with those of minor cyprinids in the experimental gillnet fisheries. According to their estimates, at least a four-fold increase in fish production (within the range of 441 – 907 kg/ha) in most reservoirs is possible by introducing a subsidiary gillnet fishery.

In reservoirs, cichlids exhibit habitat segregation with size, with the occurrence of juveniles in shallow (<1.5 m) areas and adults in deeper (>1.5 m) areas. As such, in the deeper, pelagic areas of reservoirs, small-mesh (15-52 mm stretched mesh) gillnets can be used to exploit minor cyprinids without harming juvenile cichlids, due to the reason that the gillnet selectivity curves of the two categories of fish do not overlap (Amarasinghe 1985; De Silva and Sirisena 1987). The introduction of a subsidiary gillnet fishery for minor cyprinids, which can co-exist with the tilapia gillnet fishery was therefore shown to be feasible in major reservoirs of Sri Lanka (Sirisena and De Silva 1988a, 1988b; Ajith Kumara et al. 2009).

Pet et al. (1996) have shown that in a Sri Lankan reservoir, although the minor cyprinid species, are abundant, are not exploited by the commercial fisheries. According to them, the fish yield dominated by cichlids was only 4.5% of the biological production but could be increased upto 10% of the biological production by exploiting small sized cyprinids. In fact, Moreau et al. (2001) have shown through a mass-balance modeling approach, that an exerting fishing mortality towards small pelagic fish species such as *Amblypharyngodon melettinus* would not harm existing tilapiine fishery in a Sri Lankan reservoir.

High abundance of these fish species, possibility of differential exploitation without harming the existing cichlid fishery and absence of negative impact on other commercially important species in terms of trophic interactions justify the introduction of a subsidiary fishery for minor cyprinids. Furthermore, there is an increasing tendency in consumer acceptability of these fish species mainly as dried fish, which is essentially a driving force for reservoir fishers to exploit these fishery resources.

Opportunities for inland fisheries enhancement

Over 39,000 ha of seasonal reservoirs are available in the dry zone of Sri Lanka and at least 25% of these reservoirs might be suitable for the development of culture-based fisheries. Seasonal reservoirs which could be considered as village ponds are present in large numbers, where the costly earthen work has already been done and very few improvements have to be effected for them to be used for CBF. Soil, water and other environmental conditions of the seasonal reservoirs are found to be generally quite suitable for fish culture. No costs are involved in fertilizing the seasonal reservoirs as they are being fertilized by the excreta of the animals grazing in the reservoir bed during the dry spell and by decaying terrestrial vegetation during inundation.

Major and medium perennial reservoirs can be used for installation of cages which are used to rearing of fry to fingerlings. Similarly, suitable lands in association with irrigation systems are available for the nursery pond for fry rearing. High survival rates can be obtained in rearing fingerling in cages and ponds. Fingerlings can be produced at a lower cost with the experience of farmers. Suitable fish species are available for rearing in cages and the ponds.

Technology for pond and cage culture could be made available through government aquaculture extension officers of NAQDA. Raw materials (agricultural and livestock wastes and cheaper fish feed ingredients) for fish feed preparation are locally available. At present there is a demand for fish fingerlings. Under the ARDQIP project, several mini-nurseries were established for rearing fish fry upto fingerling sizes. The initial capital investment was borne by ARDQIP on the condition that the CBOs must pay back the total amount in 60 instalments to

NAQDA (Anon. 2006a). Presently 21 mini-nurseries are fully operational.

The farmers could be easily trained on the techniques of aquaculture as they are already in possession of years of experiences in caring and tendering of agricultural crops. Co-operatively sharing of responsibilities has been a traditional practice in farming communities of Sri Lanka.

The aquaculture extension officers of NAQDA and several NGOs have been conducting awareness programmes to educate rural farmers on CBF management and development of business plans (Weerakoon 2007). Due to the creation of demand for fish fry and fingerlings through this process, normal market forces of demand and supply govern the process of seed supply for enhancement strategies. Seasonality of induced breeding in aquaculture development entres of NAQDA associated with the gonad maturity cycles of broodstocks however, restricts supply of fish fry in spite of peak demand. As mentioned by Weerakoon (2007), the legal framework applicable to sale of other products with a certain level of governmental intervention is applicable to sale of fish fry and fingerlings. The prices of fish fingerlings should not be controlled by the government, but with the pace of development, flexi-prices governed by demand could perhaps be envisaged.

There is already a government institutional setup to manage the seasonal reservoirs i.e. the Department of Agrarian Development with established farmer organization for their management. Also, under the Agrarian Development Act No. 46 of 2000, there are legal provisions to incorporate fisheries and aquaculture activities in small, village reservoirs (Table 4). A well structured institutional link has been developed between the NAQDA and the Department of Agrarian Development through which the field level coordination is considerably facilitated. As part of the profits from seasonal reservoir fish culture is siphoned to the improvement of the reservoir, such as strengthening of earthen bunds, there is a tendency to develop a strong cordial relationships between the aquaculture committees and the farmers organizations with respect to management of reservoirs activities.

Table 4. Provisions in Agrarian Development Act No. 46 of 2000 for community participation in fish culture activities in village reservoirs.

Community participation related to fisheries activities	Relevant provisions
Establishment of farmer organizations (FO)	Part V; Section 43
Examine accounts of FOs by the Agrarian Commissioner General / representative	Part V; Section 44
FOs power to obtain loan facilities	Part V; Section 45
Establishing small groups of farmers	Part V; Section 46
Appointing a member to the Agrarian Development Council	Part V; Section 47
FOs to assist ADC for agriculture and fisheries development	Part V; Section 48

Harvesting of the seasonal reservoirs is taking place during the period between two seasons of paddy harvests i.e., Yala (March-July) and Maha (October- February) which allows the community to gain monetary benefits through the sale of harvested fish, when they are most in need of such benefits.

As CBF falls within the realm of aquaculture (De Silva 2003), defining ownership of the CBF system is a prerequisite for sustainability. Under section 39 of the Fisheries and Aquatic Resources Act No. 2 of 1996 (Anon. 1996a) and amended act No. 22 of 2006 (Anon. 2006b), there is a provision for licensing aquaculture enterprises. Under these legal provisions, aquaculture management regulations were implemented in 1996 (Anon. 1996b).

Since there are minimal inputs for CBF, there are hardly any negative impacts on the environment. The CBF does not involve supplementary feeding and therefore, it is considered as an eco- friendly activity (De Silva 2003).

As the fish harvest is somewhat predictable with time and in quantities, forward sales agreements could be signed for the disposal of the harvest with selected buyer/s. Carp species are well accepted in most areas of the country and any surplus could be converted to dried fish as harvesting is carried out during the driest months of the year. Also simple post harvest technology development for processing of fish by National Aquatic Resources Research and Development Agency (NARA) Industrial Technology Institute (ITI) can be used to process surplus harvest.

Contract farming which is already in practice in agriculture for the cultivation of crops like tobacco and gherkins and in the livestock for the poultry raised under buy-back scheme could also be adopted to develop aquaculture in seasonal reservoirs with private sector participation.

Culture-based fisheries in seasonal reservoirs can be managed through co-management strategies due to the well established governmental setup and state sponsored strategy to mobilize and strengthen people's participation.

Constraints and problems associated with inland fisheries enhancement

Major technical constraints to the CBF development include lack of adequate supply of fish fingerlings at the correct time. Of the inland reservoirs numbering over 10,000 (Table 1), only 745 reservoirs (12.7 million fingerlings) in 2007 and 611 reservoirs (16.1 million fingerlings) in 2008 were stocked. This low percentage of reservoirs stocked was due to inadequate supply of fingerlings and probably insufficient extension mechanism. Presently, induced breeding of major carps is carried out at the AQDCs of NAQDA. Hitherto, breeding techniques of different fish species have not been introduced to rural farmers. With increased demand for fish fingerlings for fisheries enhancement, there is an urgent need for training rural farmers to establish mini-hatcheries. As selling of fish fry to mini-nurseries is a major source of income for AQDCs, introduction of breeding techniques of fish species to rural farmers on the other hand, would result in creating a competition for AQDCs.

In village reservoirs, which come under the jurisdiction of the Department of Agrarian Development (DAD) fisheries and CBF development is still not a high priority area. As CBF development is carried out by NAQDA under its mandate, DAD has less responsibility to get involved in CBF activities. Active involvement of Agrarian Research and Development Assistants of DAD in CBF activities would facilitate the process.

In addition, provincial councils are also involved in stock enhancement activities. The strategies that are adopted by fisheries authorities of provincial councils are quite different from those of the central government. Generally, establishment of CBOs is not practised by the fisheries authorities of provincial councils and as a result, CBF activities in reservoirs where provincial councils are involved are at a poor state. Active involvement of farmers' organizarions in CBF is an essential pre-requisite for its sustainability, because ownership of stocked fish is assured through this process. Stocking of fish fingerlings as part of political agenda of the provincial councils is not an effective means of CBF development.

In minor perennial reservoirs, fisheries enhancement is essentially carried out by professional fishers. NAQDA's involvement for mobilizing the fisher communities through preparation of CBF management plans helps significantly for its sustainability. As fishers have experienced socio-economic benefits of these enhancement strategies, continuous demand for stocking materials prevails in many minor perennial reservoirs of the country.

As inland fisheries enhancement is essentially based on exotic species, there may be negative impact of released animals on the genetic biodiversity of the natural populations. However, no attempts have been made in Sri Lanka to investigate such impacts. In Sri Lanka inland fisheries enhancement activities are conducted in quasi-natural water bodies. As De Silva and Funge-Smith (2005) mentioned, the impact of exotic species used in enhancement activities on the biodiversity of indigenous flora and fauna of these artificially created water bodies cannot be strictly considered to be serious. When the exotic species and indigenous species share food resources with great abundance, competition between exotic and native species is unlikely (Weliange and Amarasinghe 2003).

There are legislative barriers to exploit minor cyprinids in reservoirs because according to the existing gillnet mesh regulations, the minimum permissible mesh size is 8.5 cm. This prevents exploitation of minor cyprinids, for which the effective gillnet mesh sizes are 15 – 38 mm.

Conclusion

Fisheries enhancement in inland waters of Sri Lanka is successful in small village reservoirs and minor perennial reservoirs (< 250 ha). De Silva and Funge-Smith (2005) have shown that stock enhancement in large lacustrine water bodies has not been successful except in a few exceptions. The enhancement strategies should therefore be restricted to small, village reservoirs and minor perennial reservoirs. Fisheries enhancement in minor perennial reservoirs however, has not been studied in detail. Pushpalatha and Chandrasoma (2010) reported the results of CBF trials in 15 minor perennial reservoirs of Sri Lanka. Density-dependent growth and size-dependent mortality of stocked fish in CBF activities in small water bodies are shown to influence CBF yields (Lorenzen 2001). Further studies are therefore warranted for optimizing CBF yields in minor perennial reservoirs.

As there is an increasing demand for fingerlings for enhancement activities, expansion of fingerling production is necessary. Rural people are financially benefited from the mini-nurseries established for fingerling rearing. The present practice of production of postlarvae and fry in the AQDCs is needed to be extended to rural communities with adequate training. In most Asian countries backyard fish hatcheries are common for the propagation of Chinese and Indian major carps. As such, transfer of this technology would be useful for sustaining CBF in the small reservoirs of Sri Lanka. Furthermore, establishment of backyard hatcheries for propagation of major carps would provide rural communities with additional household income.

The genetic quality of fish species that are used for enhancement strategies is a poorly addressed issue. The genetic diversity of fish species is expected to be affected by inbreeding. Although it is unlikely that self-reproducing populations of Chinese and Indian major carps in Sri Lankan waters would be established, some evidence is found that there are self-reproducing populations of Indian major carps at least in one river basin (Amarasinghe and Nguyen 2009). As such, impact of stocking of exotic species on biodiversity should be a major concern in fisheries enhancement strategies.

Development of processing methods of the species commonly used for CBF is also an important subject for further investigation. It will help preventing flooding of market during a short period. Furthermore, it would increase consumer acceptability of the product.

Sustainability of CBF is undoubtedly dependent on the functional management structures which should be strengthened through various local level institutions. Although there has been a significant policy level advancement providing legal provisions for CBF development in village reservoirs in the Agrarian Development Act of 2000 (Anon. 2000b; Table 4), CBF activity is still considered as a secondary use of reservoirs with low priority. Quantification of benefits from multiple uses of village reservoirs might therefore be useful for convincing mid-level officials about the advantages of CBF development for improving livelihoods of rural communities. Also, as social traditions still prevail as integral parts of rural living, this sociological aspect should be a priority area to be considered in fisheries enhancement in village reservoirs. In some Sri Lankan rural communities, in spite of the obvious benefits from CBF, traditional practices among communities associated with religious beliefs, prevent CBF development.

For fingerling rearing in mini-nurseries established in many parts of the country, the feeds used are mainly rice bran. Due to the low quality of such feeds, optimal growth is not achieved in most mini-nurseries. Ariyaratne (2001) and Amarasinghe et al. (2002) have shown that minor cyprinids that are abundant in major reservoirs of Sri Lanka can be used for making feeds for fry rearing. Amarasinghe et al. (2009) have reported that in some reservoirs, profitable fisheries have been established for minor cyprinids. Development of low-cost feed from minor cyprinids using appropriate technology at affordable prices therefore encompasses two aspects. First, this approach supports economic viability of fingerling rearing for CBF development. Secondly, exploitation of hitherto unexploited fishery resource from Sri Lankan reservoirs will ensure more complete utilization of biological productivity, as mentioned by De Silva and Sirisena (1987), Amarasinghe (1990) and Pet et al. (1996). There is a need for revising the existing gillnet mesh size regulations to make it possible to exploit minor cyprinids.

The institutional coordination between provincial councils and central government should be streamlined through the policy levels. Multiple involvement of various stakeholders ranging from village level administration, provincial and central government fisheries authorities, irrigation and agricultural officials etc. make the *modus operandi* of enhancement strategies different from reservoir to reservoir. This dilemma is needed to be addressed for further expansion of CBF in small reservoirs of Sri Lanka. As there are different administrative bodies responsible for reservoir uses other than fisheries, there is a poor coordination of the stocking of fingerlings with water release schedules.

At least in one minor perennial reservoir (Kimbulwanaoya reservoir in Kurunegala district), with the permission from irrigation authorities, an effective netting structure is installed by fishers near the sluice gate to prevent the loss of stocked fish. According to fishers, this has considerably increased CBF yield in the reservoir (personal observations). However, no quantified data are available for evaluating impact of installation of such structures. It is worthwhile to attempt installation of structures near sluices to prevent escape of stocked fish. As practised in Kimbulwanaoya reservoir, fishers can bear the cost of installation.

In Sri Lanka, no information is available on the synergy between water management related to downstream activities and fisheries enhancement. As practised in China (De Silva and Funge-Smith 2005), fisheries enhancement activities in reservoirs can be coordinated with other downstream activities and water management, associated with agriculture and otheruses. This would help improving mutual benefits to the stakeholders and reducing user conflicts. Furthermore, there has been an increasing emphasis on the implementation of the FAO code of conduct for responsible fisheries through an ecosystem approach to fisheries and aquaculture (Staples and Funge-Smith 2009). This approach addresses both human and ecological well-being. As such, studies directed towards this direction in fisheries enhancement and conservation strategies are useful to combine two important aspects that are of ecological and societal interest. Here, a balance is achieved between conservation of biodiversity and ecosystem functioning, and improvement of livelihoods and provision of food through fishery resources enhancement.

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