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REVIEW

New paradigm for inland fisheries development in Sri Lanka: a transdisciplinary approach for addressing food and nutritional security

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Summary: Globally, inland fisheries make a significant contribution to sustainable development across dimensions of food security, livelihoods, economic value and biodiversity. Nevertheless, aquaculture is generally considered to be environmentally unfriendly. As such, environmentally friendly approaches of increasing fish production such as fisheries enhancement receive increasing attention. Culture-based fisheries (CBF) are seen as a way forward for inland fisheries development in most Asian countries. Due to the extensive availability, reservoirs of Sri Lanka, which have been constructed in the past for irrigation, can secondarily be utilized for inland fisheries development. The reservoir fishery of Sri Lanka has been a relatively recent development during the second half of last century after the introduction of exotic cichlid species, *Oreochromis mossambicus* and *O. niloticus*. The trends in inland fish production until the 1990s suggested that under the socio-economic milieu that prevailed, for the management of reservoir fisheries, state sponsored monitoring procedures or centralized management systems was essential. Due to the concerted efforts to develop CBF in Sri Lankan reservoirs after 2000, through regular stocking of fingerlings of tilapia, Chinese carps and Indian carps, a significant development in the inland fisheries sector has been achieved. Recent attempts at stocking *Macrobrachium rosenbergii* postlarvae in inland reservoirs as part of CBF contributed to significant elevation of rural income. Also, 'human capital' in the rural institutions (i.e., famer organizations and fisheries societies) has a high potential to be mobilised for CBF development. Introduction of co-management strategies for CBF is useful for its sustainability. CBF development in Sri Lankan reservoirs should essentially be a transdisciplinary approach, which would take into account the biological productivity favouring growth of stocked fish, institutional linkages for supporting different stages of the strategy, social attitudes for adopting CBF within the realm of participatory development, and market forces driving the entire process.

Keywords: Biological sustainability, blue revolution, inland fisheries enhancement, socioeconomics, tropical reservoirs.

INTRODUCTION

As many fisheries and aquaculture development strategies aim at ensuring biological sustainability and economic efficiency of fisheries, their potential contribution to improve food and nutritional security is not fully appreciated (Béné *et al*., 2015). Furthermore, inland fisheries are crucial for many socially, economically and nutritionally vulnerable groups of people around the world (Welcomme, 2001). Nevertheless, a complete understanding of the magnitude of contribution of inland fisheries to food security is often not fully recognized, mainly due to the reason that greater interest is vested in marine fisheries and ocean management (Funge-Smith & Bennett, 2019). There is widespread expert opinion that much of the catch from inland fisheries is unrecorded, bringing about underestimates of inland fishery catches (FAO, 2020). Nevertheless, there is a

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significant contribution of inland fisheries to sustainable development across dimensions of food security, livelihoods, economic value and biodiversity (Funge-Smith & Bennett, 2019).

Intensification of aquaculture practices has led to use of artificial feeds, prophylactics for disease prevention, drugs of varying sorts for disease control, growth promoters and other ways and means of increasing yields, essentially reflecting comparable developments in land–based agriculture and animal husbandry. This paradigm shift was termed as "blue revolution", which is analogous to "green revolution" to intensity agricultural food production (Cunningham *et al*., 2004). Green revolution and blue revolution are initiatives that have been adopted to increase food production to meet the demand of ever-increasing global human population. Nevertheless, adoption of environmentally unfriendly approaches in aquaculture such as increased use of antibiotics, eutrophication, consumptive uses of water etc. made "blue revolution" far from green (Costa-Pierce, 2002). As such, environmentally friendly approaches of increasing fish production such as fisheries enhancement (Lorenzen *et al*., 2001; De Silva, 2003; Taylor *et al*., 2017) receive increasing attention.

The significant growth in aquaculture in recent times has also been subjected to a higher degree of close monitoring by the public, particularly in the wake of the establishment of the convention on biological diversity (CBD, 2018). There has been no generally accepted notion that all major aquaculture development activities should be sustainable (De Silva & Davy, 2010). Overall, sustainability of intensive aquaculture is often questioned on many grounds (Naylor *et al*., 2001; De Silva *et al*., 2006) but the growth of the sector has to be considered in the context of food security and nutrition (Committee on World Food Security, 2014). Béné *et al.* (2016) have shown that the influences of major drivers (decentralization, climate change, demographic transition) on the contribution of aquaculture for poverty alleviation are still insufficiently documented and therefore poorly understood. Recently, inland fisheries enhancements, such as culture-based fisheries (CBF), have been increasingly adopted and seen as a way forward for inland fisheries development in most Asian countries (De Silva & Funge-Smith, 2005). As strategies for enhancement of inland fisheries are essentially multi faceted paradigms, this synthesis is aimed at providing a comprehensive review of inland fisheries in Sri Lanka, within the purview of transdisciplinary approaches for their sustainability.

Reservoirs of Sri Lanka and their fisheries

Sri Lanka is endowed with large number (>12,000) of irrigation reservoirs (Figure 1). In Sri Lanka, reservoir construction and use have been an integral part of ancient civilization, with some major reservoirs being more than 2,000 years old. Most of these reservoirs are concentrated in the dry zone receiving 125 – 190 cm annual rainfall. The total reservoir extent of the country is around 206,000 ha (Jayasinghe & Amarasinghe, 2018). On average, size of these reservoirs ranges from a few hectares to 7,000 hectares. Depending on their hydrological regimes these reservoirs are broadly categorized into seasonal and perennial reservoirs. These reservoirs with a few exceptions (i.e., recently constructed hill country hydroelectric reservoirs, some drinking water reservoirs and a few reservoirs of aesthetic value) are irrigation reservoirs and are very diverse in age, hydrology and catchment features (Amarasinghe *et al*., 2002). Perennial reservoirs of Sri Lanka (around 200,000 ha in extent) are divided into three broad categories: major (>800 ha), medium (200 – 800 ha) and minor (< 200 ha) based on the water spread at full supply level. These irrigation reservoirs have been secondarily used for the development of inland fisheries.

Historical evidence indicates that inland fish were exploited from reservoirs and irrigation canals during the time immemorial (Siriweera, 1986; 1994). Inland fisheries have been a significant source of food since pre-historic times. Hooks, harpoons and fish remains were found in many archaeological sites, and many early river-based civilizations. In Sri Lanka, some historical evidence is found about the fisheries in inland waters of the country (Amarasinghe, 2018). Perimiyankulam rock inscription made during the latter part of the first century refers to the revenue from fish caught in the channels of two reservoirs were used to meet expenses to spread deer skins in meditation halls of Buddhist monks (Paranavithana, 1958), indicating that inland fishing was an important economic activity during that period.

However, prior to 1950's, fish yield in Sri Lankan reservoirs was reported to be very low (Fernando, 1984, 2000). The reason for these low yields was said to be due to the inability of indigenous riverine fish species to sustain high population densities in the lacustrine habitats of reservoirs (Fernando & Holčik, 1991). Development of inland fisheries in Sri Lanka commenced with the introduction of exotic tilapia, *Oreochromis mossambicus*, in 1952 and the trend of inland fisheries in perennial reservoirs of Sri Lanka following this introduction is well documented (Indrasena, 1965; Fernando & Indrasena, 1969; Mendis, 1977; Fernando & De Silva, 1980; De Silva, 1983, 1988; Amarasinghe, 1992, 1998; Fernando, 1993, 2000; Amarasinghe & Weerakoon, 2009).

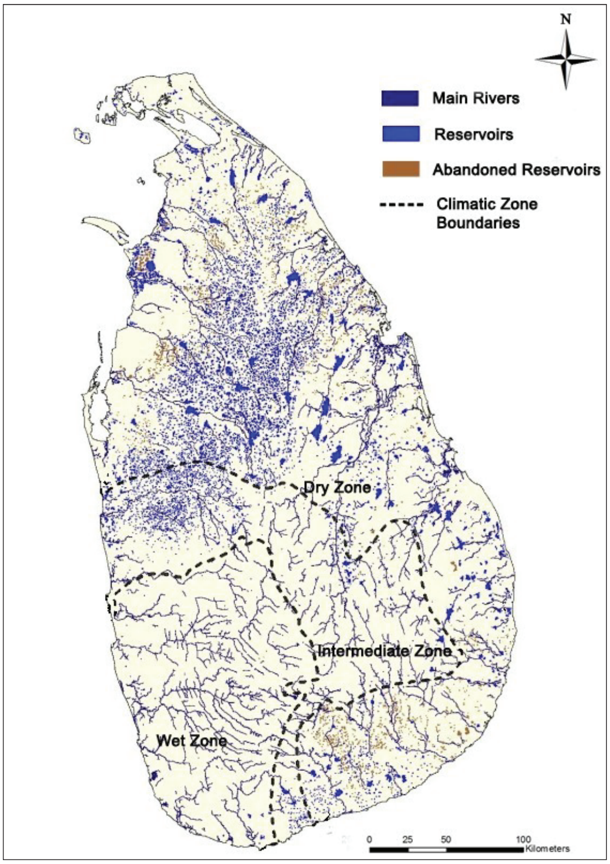

Figure 1: Distribution of reservoirs in Sri Lanka (adopted from Jayasinghe & Amarasinghe, 2018)

The impact of introduction of *O. mossambicus* into Sri Lankan reservoirs is best exemplified by the dramatic increase in fish production in Parakrama Samudra, a major perennial reservoir from <10 kg ha^{-1} yr^{-1} prior to its introduction in 1952 to 180 kg ha^{-1}yr^{-1} subsequently in 1967 (Fernando, 1984). According to De Silva (1988), *O. mossambicus* became the most dominant species in the fishery of inland perennial reservoirs contributing over 70 percent of the total landings. Various reasons have been suggested to be attributed to the success of this species in Sri Lanka. Among them are breeding success in the intensive littoral zones of reservoirs (Fernando & Indrasena, 1969), ability to digest blue green algae dominant in Sri Lankan reservoirs (Costa & Abeysiri, 1978), lack of lacustrine species in the indigenous fauna capable of colonizing the reservoir habitats (Fernando & Holčik, 1991), and ability of *O. mossambicus* to change its dietary habits from season to season depending on the availability (Maitipe & De Silva, 1985). In 1975, another exotic cichlid species, Nile tilapia, *Oreochromis niloticus* was introduced to Sri Lankan freshwaters and by 1980s, it became the dominant species of the inland fisheries in perennial reservoirs following heavy stocking (Chandrasoma, 1986; Amarasinghe, 1997; Amarasinghe & De Silva, 1992a). In recent years, exotic carps, particularly catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) also have been contributing significantly to fish production of perennial reservoirs of Sri Lanka. Until late 1990s, the inland fisheries of Sri Lanka had essentially been capture fisheries in perennial reservoirs.

Inland fisheries production trends from 1978 to 1999

During 1978-1989 period, there were several strategies adopted by the government of Sri Lanka to develop the inland fisheries in the country. They included providing fishers with fibreglass canoes and gillnets under a subsidy scheme. As a result, fishing effort in reservoirs increased considerably (De Silva, 1988). At the same time, the fisheries authorities have also imposed fisheries regulations to control fishing effort and size of the fish (especially exotic cichlids) landed. Use of mechani*s*ed boats and any kind of shore seine nets are forbidden in perennial reservoirs and the minimum permissible mesh size for the gillnet fishery is 8.5 cm. However, gillnets of mesh sizes smaller than minimum permissible size (<8.4 cm) and beach seine, which were also illegal were operated in some reservoirs sporadically (Amarasinghe & De Silva, 1992b). Also, some fishers increased efficiency of gillnetting by beating water with wooden poles or weighted ropes to drive fishes towards gillnets (Amarasinghe & Pitcher, 1986; Amarasinghe & De Silva, 1992b).

During the early 1980s, fishers in inland reservoirs became members of the fisheries cooperative societies (FCS) because only the active members of FCS were eligible to receive boats and gillnets under the state-sponsored subsidy scheme. From the point of view of reservoir fisheries management, this trend was conducive for fishers to arrive at collective agreements regarding resource exploitation such as complete curtailing of beach seining and increasing the minimum mesh size of gillnets upto 10.2 cm. This resulted in a considerable increase in inland fish production in the country with a reported peak of 39,300 tonnes in 1989 (Amarasinghe &

De Silva, 1999). However, in 1989, the government has made a politically inspired policy decision to discontinue state patronage for inland fisheries and aquaculture development. As a result of this abrupt policy decision, during 1990-1994 period, inland fish production declined markedly (Amarasinghe & De Silva, 1999). This was due to interruption of government funding for monitoring and stocking programmes. In the absence of monitoring by fishery officers, fishers began using smaller meshed (<7.5 cm) gillnets that resulted in "growth overfishing" of the cichlid species, which were dominant in the fishery. However, inland fisheries tended to recover since the state restored its support in the mid-1990s. Trends in Sri Lanka's inland fish production from 1978-1999 are shown in Figure 2.

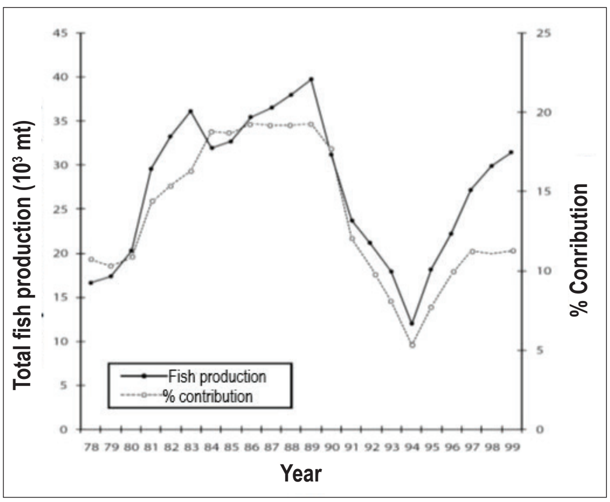

Figure 2: Trends in the inland fish production in Sri Lanka during 1978–1999 (adopted from Amarasinghe & Weerakoon, 2009). Percent contribution of the inland fishery to the total fish production is also indicated here.

These trends in inland fish production until mid-1990s suggest that under the socio-economic milieu that prevailed, for the management of reservoir fisheries, state sponsored monitoring procedures or centralised management systems was essential. In two reservoirs namely Maduru Oya and Muthukandiya reservoirs, where fishing communities were actively involved in making decisions for management of the fisheries, even in the absence of centralized management system, overexploitation of fish stocked was not evident (Amarasinghe & De Silva, 1999). In both reservoirs, fishers arrived at collective decisions on fisheries management and environmental protection through the FCS. This indicated that co-management procedure in which the centralised administration authority (i.e., Ministry of Fisheries) and fishing community share the responsibilities of making decisions for fishery resource management (Berkes, 1994; Pomeroy, 1995; Sen & Raajaer-Nielsen, 1996) had been useful for preventing over-exploitation of fishery resources even during the period of absence of state-sponsored monitoring procedures from 1990 to 1994 (Amarasinghe & De Silva, 1999). A similar community-based management system has also been in operation in Senanayaka Samudra (7,680 ha), the largest reservoir in Sri Lanka in terms of water spread area, where fishing trips are also regulated by the fisheries co-operative society (Kulatilake *et al*., 2010).

Inland fisheries production trends during 2000-2020

Realising the national need for sustainable development of inland fisheries in Sri Lanka, Deakin University, Victoria, Australia, University of Kelaniya, Sri Lanka and National Aquaculture Development Authority of Sri Lanka (NAQDA) developed a collaborative research project under the auspices of Australian Centre for International Agricultural Research (ACIAR) for scientific management of reservoir fisheries of Sri Lanka. Also, there was a subsequent project named as "Aquatic Resources Development and Quality Improvement Project" (ARDQIP) for the development of inland fisheries in the country, which was funded by the Asian Development Bank. The scientific inputs from both these projects have been responsible for spectacular increase

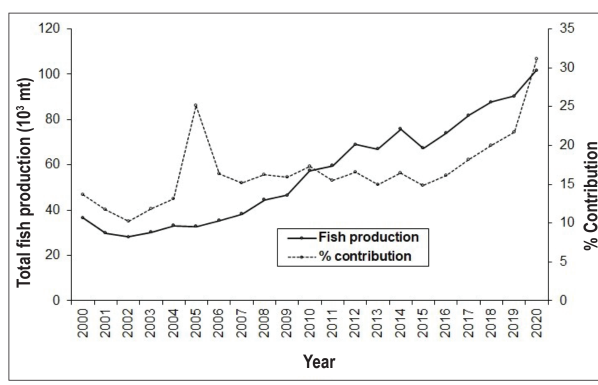

Figure 3: Trends in the inland fish production in Sri Lanka during 2000–2020 (source: NAQDA). Percent contribution of the inland fishery to the total fish production is also indicated here. Note: Increased percentage contribution of inland fishery to the total fish production in 2005 was due to drastic decline of marine fishing fleet causing decreased fish production due to tsunami on 26 December 2004.

of inland fish production in the country (Figure 3). In the ensuing section, strategies that have been adopted so far for achieving success up to now are reviewed, and the way forward for sustainability of the inland fishery of Sri Lanka is emphasized.

Culture-based fisheries

The major fisheries enhancement strategy for dramatic increase of country's inland fish production after 2001 was development of culture-based fisheries in reservoirs. In the wide array of fisheries enhancement strategies, the common feature is human intervention in the life cycle of the aquatic organism that is used for fisheries enhancement (Lorenzen *et al*., 2001), and 'culture-based fisheries' and 'capture-based aquaculture' are two major terminologies in this context. In culture-based fisheries, artificially propagated seed stocks are released into water bodies, which are not primarily and traditionally used for fish production, and recaptured upon reaching a desirable size (FAO, 1997; De Silva, 2003). As such, this is essentially 'aquaculture-driven.' In contrast, 'capture-based aquaculture,' which involves capture of aquatic organisms from the wild and rearing them in various aquaculture systems such as cages (Ottolenghi *et al*., 2004), is "fishery-driven."

As culture-based fisheries (CBF) are aimed at stocking of different species which are able to optimally utilise available food niches, they often share features of polyculture (Bardach *et al*., 1972). As a rule, culture-based fisheries involve ownership (De Silva, 2003) 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 & Balarin, 1999).

Culture-based fisheries in small village reservoirs

The small village 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. Nationally, CBF development in irrigation reservoirs is of particular importance due to the fact that Sri Lanka has a long tradition of irrigation water management in reservoirs dating back to the first century AD. 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* spp.), climbing perch (*Anabas testudineus*) and catfishes (*Macrones* spp.). These indigenous species, although harvested in some reservoirs, do not produce high yields. The potential of small village reservoirs for the development of CBF was first pointed out by Mendis (1965). Accordingly, attempts were made in 1960s to utilise 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 during 8–9 months of water retention period, they grew upto 25–30 cm in size. Fernando & 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 has been implemented to formulate a suitable strategy for the development of culture-based fisheries in non-perennial reservoirs of Sri Lanka (Thayaparan, 1982).

In Sri Lankan reservoirs, irrigation of agricultural lands is essentially based on pre-planned schedules and water is not freely available on demand to the farmers. CBF can also be incorporated as a community-based activity during the planning stage of an irrigation schedule for the two cultivation seasons in a calendar year in the command areas of each reservoir. These community-based water management strategies and CBF in village reservoirs are essentially facilitated by the Department of Agrarian Development and the NAQDA respectively, under the legal provisions of Agrarian Development Act No. 46 of 2000.

As the culture period in seasonal reservoirs is 7-9 months, the species suitable for stocking in these reservoirs should reach the marketable size in 6-8 months. These species should also be able to utilise 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 carps and Indian major carps. These species have been artificially spawned successfully in Sri Lanka (Weerakoon, 1979; Balasuriya *et al*., 1983; De Silva, 1988).

Hormone induced captive breeding of major carps in government-owned hatcheries and fingerlings rearing in mini-nurseries maintained by rural agricultural farmers are the sources of seed material for stocking in the seasonal reservoirs. These species utili*se* the natural food resources available in these reservoirs. The efforts to develop CBF in non-perennial reservoirs in the dry zone of Sri Lanka in the 1980s (Thayaparan, 1982; Chandrasoma & Kumarasiri, 1986) were, however, not successful due to lack of a proper selection method for the identification of suitable reservoirs. Recent efforts for the CBF development in seasonal reservoirs have taken a momentum (Amarasinghe & Nguyen, 2010). A transdisciplinary approach having both resource component and social component that makes use of the resource component made it possible to achieve a considerable success in the CBF efforts in small village reservoirs of Sri Lanka.

Culture-based fisheries in minor perennial reservoirs

As fingerlings are required for stocking in non-perennial reservoirs only after the peak rainy period in November-January in the dry zone of Sri Lanka, fingerlings produced during other periods can be used for CBF development in other types of inland water bodied such as minor perennial reservoirs. In 2003, NAQDA initiated through ARDQIP, a pilot-scale programme to introduce CBF in minor perennial reservoirs (<200 ha), where only subsistence level fisheries existed. Pushpalatha and Chandrasoma (2009) reported the results of this CBF initiative in 15 minor perennial reservoirs. In these reservoirs, community-based organisations (CBOs) were formed and members were given training on basic aspects of entrepreneurship planning such as leadership, simple accounting, book keeping etc., together with aspects of community-based management of CBF. The stocking density in CBF in minor perennial reservoirs ranged from 146 fingerlings/ha to 2780 fingerlings/ha. Unlike in non-perennial reservoirs, where harvesting is done at once during the dry season, CBF harvesting in minor perennial reservoirs is a year-round activity using gillnets of mesh sizes ranging from 8.5 to 20 cm. Before introduction of CBF in minor perennial reservoirs, mean annual fish yield was reported to be 57.3 kg ha^{-1}, with *Oreochromis niloticus* being the most abundant species forming over 80% of the landings. However, after introduction of CBF, annual fish yield increased up to 208 kg ha^{-1} and *C. catla*, *L. rohita* and *C. carpio* formed major proportions of the landings. The contribution of *O. niloticus* to the landings reduced to 47.4% (range 19.7–66.5 %) (Pushpalatha & Chandrasoma, 2009; Amarasinghe, 2010).

Pushpalatha *et al.* (2020) also reported that in 3 medium and 2 large reservoirs, after introduction of CBF, fish species composition in the landings changed with the occurrence of stocked species in the landings, resulting remarkably elevated fishers' income ranging from 194% to 2187%. According to the analysis of Pushpalatha *et al.* (2020), economic gains of fishing communities were due to socioeconomic characteristics having improved leadership qualities and empowerment fishers for management decision-making, which were achieved through participatory development approaches of NAQDA. However, CBF production in these reservoirs was found to be further increased through more efficient management of inputs such as increased number of fishers, increased mean number of fishing days per year and increased stocking density (Pushpalatha *et al*., 2021).

Influencing strategies for CBF development

After the re-establishment of state patronage for inland fisheries and aquaculture development in the country in 1994, the government has taken several steps to revive inland fishery. Some of the major steps taken were establishment of NAQDA and rehabilitation of state-owned fish hatcheries which were responsible prior to 1990, for induced breeding and fingerling rearing of Chinese and Indian major carps, and stocking of inland reservoirs. As small village reservoirs are managed by the rural institutions called farmer organisations (FOs), which have legal power under the Agrarian Development Act, these rural institutions were chosen to implement influencing strategies for CBF development. Meetings of FOs were held before the agricultural cultivation period ("*Kanna Meeting*"), under the supervision of Agrarian Research and Production Assistants (ARPAs) employed by the Department of Agrarian Development. These meetings provided an opportunity to discuss and place before the FOs about the possible nutritional and financial benefits that would be generated from CBF in their reservoir if they were to embark on CBF. This approach was further developed by NAQDA and the aquaculture extension officers of NAQDA, closely worked with the members of FOs in each village reservoir to develop an "entrepreneurship plan" for CBF development.

Transdisciplinary approaches for CBF development in non-perennial reservoirs

Selection of suitable village reservoirs for CBF development is needed for its sustainability in the country. Carrying out extensive surveys for selecting reservoirs is prohibitive due to limitations in terms of manpower and funding. However, 'human capital' in the rural institutions (i.e., FOs) has a high potential to be mobilised for CBF development. As such, for defining a better practice model, both biological aspects related to productivity of water bodies and socioeconomic aspects of rural communities should be considered (De Silva *et al*., 2006).

Biological and technological aspects

Carlson's trophic state index (TSI), a diagnostic approach that can be used to monitor status of lentic waters (Carlson, 1977), was employed in non-perennial reservoirs (Jayasinghe *et al*., 2005). They determined TSI (SD), TSI (Chl) and TSI (TP) according to the following definitions.

TSI (SD) = 60 – 14.41 ln Secchi depth (metres)
TSI (Chl) = 9.81 ln Chlorophyll-a (mg/m^3) + 30.6
TSI (TP) = 14.42 ln Total Phosphorus (mg/m^3) + 4.15

Jayasinghe *et al.* (2005) further showed that CBF yields were positively correlated to TSI (Chl). In non-perennial reservoirs with similar trophic characteristics, CBF yield could be predicted from shoreline/reservoir area ratio (Jayasinghe *et al*., 2006). In rural villages of dry zone of Sri Lanka, buffalo and cattle keeping is one of the economic activities. Nutrient enrichment in village reservoirs through cow dung also positively influences the CBF yields (Jayasinghe & Amarasinghe, 2007; Jayasinghe *et al*., 2018).

In village reservoirs, which do not completely dry up during the dry season, carnivorous fish species such as *Channa striata*, *Glossogobius giuris* are drawn from the associated river basins. Hence, stocked fish fingerlings are vulnerable to predation by such piscivores, resulting in low returns from the CBF efforts (Wijenayake *et al*., 2005). As suggested by De Silva (1988), this could be prevented by stocking large-sized (>10 cm) fingerlings as predator-prey relationship is usually size-dependent. However, cost-effectiveness of stocking large fingerlings in reservoirs has not yet been evaluated. Also, our experience is that when freshwater prawn (*Macrobrachium rosenbergii*) post-larvae are stocked, night stocking (after 19:00 hr) ensures higher survival. This might be due to the reason that prawn post-larvae can move to the bottom of the reservoir so that they can avoid predation by fish species such as *Rasbora daniconius* and *R. caverii* which are essentially visual feeders in the water column during twilight periods of the day (De Silva *et al*., 1996; Weliange *et al*., 2006).

Species combination of stocked fingerlings is also an important aspect in CBF because optimal utilisation of food resources in the water body is a key to achieve optimal harvests from polyculture systems (Bardach *et al*., 1972). Although not scientifically confirmed, the species combination that is commonly used (30% common carp and mrigal, 30% bighead carp/catla; 30% rohu and 10% Nile tilapia/freshwater prawn (Wijenayake *et al*., 2005, 2007), appeared to be reasonable because CBF harvests based on this species combination were generally high.

In non-perennial reservoirs, the relationship between stocking density (SD) and CBF yield showed a second order curve (Wijenayake *et al*., 2005), conforming to those that were reported from Bangladesh (Hasan & Middendrop, 1998) and India (Sugunan & Katiha, 2004). Accordingly, the optimal stocking density was determined to be 3,500 fingerlings per ha (Wijenayake *et al*., 2005). Here, it must be noted that effective area for CBF planning was considered as 50% of the area at full supply level (FSL) because extents of non-perennial reservoirs at FSL during the rainy season gradually shrink to almost zero during the dry season.

Socioeconomic aspects

As mentioned above, the community meeting of FOs held at the beginning of the cultivation season, the *Kanna meeting*, is meant for planning agricultural activities through collective decisions. At these meetings, FOs also make decisions whether CBF activities should be incorporated in the agriculture-related economic activities. As these community-based initiatives are backed by the legal provisions of Agrarian Development Act of 2000, in most instances, FOs establish Aquaculture Management Committees (AqMCs), which are responsible for stocking fish fingerings, guarding the stocked fish, harvesting and marketing. The members of AqMCs arrive at agreements with FOs on sharing of CBF profit between the AqMC and FO. In many instances, a levy of about 5 % of the net profit is paid to FOs. The group size of AqMC generally varied between 5 and 20. There are rare instances where the entire FO acts as the AqMC and as a result, all members of FO take part in the CBF activities. After payment of the levy to the FO, the profit is equally shared by the members of AqMC. Kularatne *et al.* (2009) have shown that communities with small AqMCs with satisfactory participation in group activities and those belong to the same caste expressed high 'willingness to pay' for CBF activities.

Also, socioeconomic homogeneity with regard to kinship and political ideology of the farming communities as well as education level and good leadership qualities of group members in AqMCs had a positive influence on the attitudes towards adoption of CBF in village reservoirs (Kularatne *et al*., 2009). Accordingly, socioeconomic characteristics in rural agricultural communities are important aspects to be considered for selecting suitable reservoirs for CBF development. Wijenayake *et al.* (2021) presented a simplified scheme of decision making to select suitable reservoirs for CBF development taking into account both technical and socioeconomic aspects (Figure 4).

Multi-criteria decision making

Wijenayake *et al.* (2015) employed a multi-criteria decision-making procedure known as Analytic Hierarchical Process (AHP; Saaty, 1977). In this approach, criteria that are important for CBF development in village reservoirs such as water quality parameters, catchment land-use characteristics and socioeconomic factors, under which there were several sub-criteria with varying relative importance were considered. The AHP approach equated sets of heterogeneous criteria into a common denominator, and as such, it was a powerful decision-making tool for selection of reservoirs for CBF

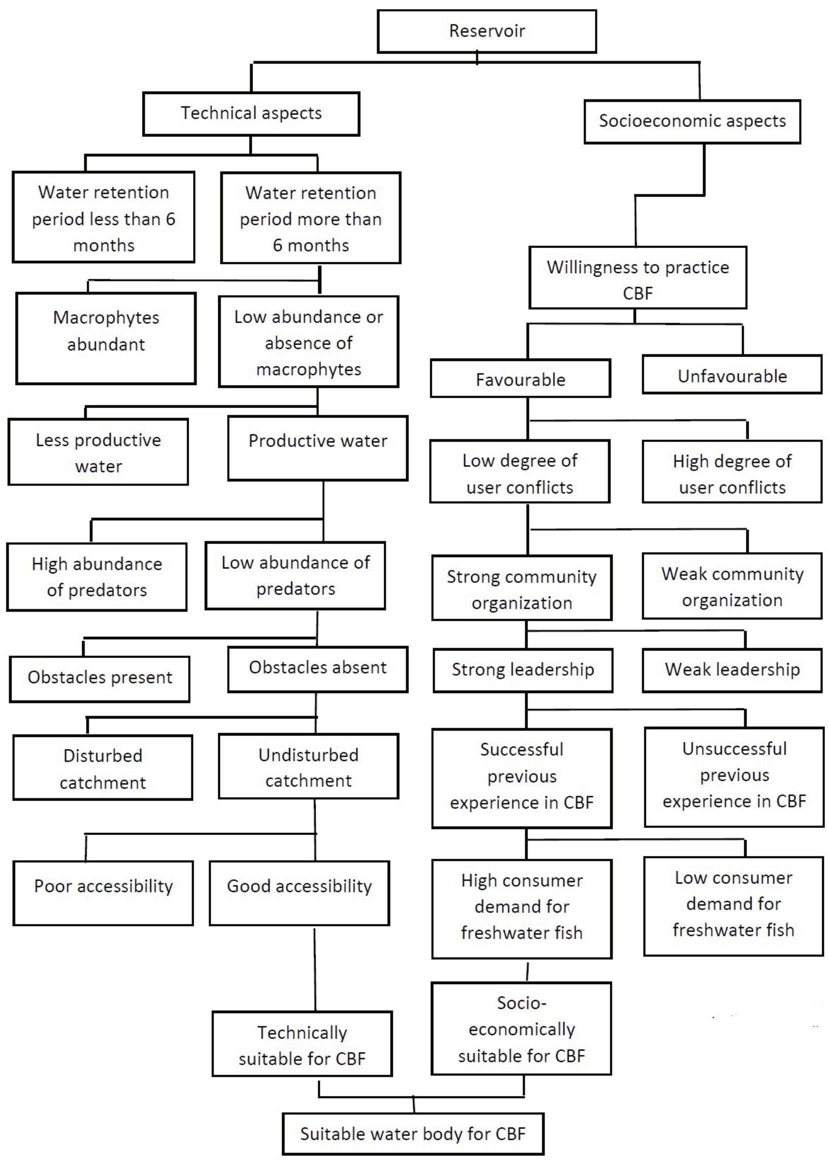

Figure 4: Technical and socioeconomic feasibility to select suitable village reservoir for CBF development (adopted from Wijenayake *et al*., 2021).

based on their ranking through relative weighting of multiple criteria.

Science into practice for CBF development

During 2004-2007, the Asian Development Bank funded ARDQIP has taken many initiatives for the CBF development in Sri Lanka. The initiatives of ARDQIP included infrastructure development in state-owned fish breeding centres (i.e., aquaculture development centres; AqDCs), capacity building through training field officers in the inland fisheries and aquaculture sector, introduction of an effective strategy for social mobilization for adoption of CBF in reservoirs (i.e., preparation of entrepreneurship plan in each reservoir through community participation), setting-up of a procedure for more accurate recording of fisheries and aquaculture production data, and establishment of mini-nurseries for fingerling rearing through community participation. The strategy of fingerling production in mini-nurseries is shown in Figure 5, from which it can be seen that there are three stages in the CBF strategy. First, induced breeding of exotic carp species and nursing of post larvae to fry stage are performed in the state owned AqDCs, secondly, community-based fry-to-fingerling rearing in mini-nurseries and in net cages installed in some irrigation reservoirs, and finally stocking fish fingerlings in small village reservoirs (mostly non-perennial) and minor, medium and major perennial reservoirs. Although, fry-to-fingerling nursing is performed in state-owned AqDCs, the maximum capacity of production is limited to 50 million fingerlings per year, which is not sufficient to stock most reservoirs of the country.

Due to these concerted efforts to increase inland fish production through development of CBF, there had been a dramatic increase in the total inland fish production from about 36,700 tonnes in 2000 to 57,410 tonnes in 2010 and then to 101,810 tonnes in 2020 (Figure 3).

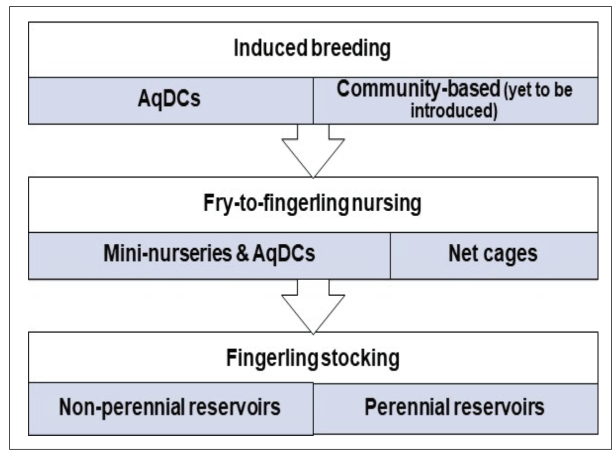

Figure 5: Institutional linkages for different stages of production of stocking material

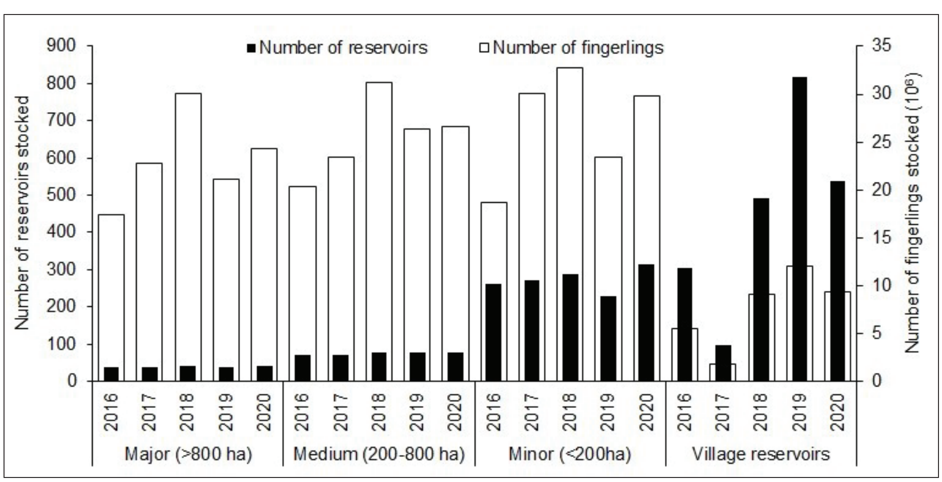

Figure 6: Number of reservoirs of different categories and number of fingerlings stocked during 2016–2020. White bars: number of fingerlings stocked; dark bars: number of reservoirs stocked. (source of data: NAQDA)

Fingerling production in mini-nurseries

CBF development in different kinds of reservoirs has become a regular inland fisheries development strategy in the country, and the greatest potential for CBF development exists in non-perennial reservoirs (Amarasinghe & Nguyen, 2010). Hence, availability of sufficient number of fingerlings for stocking non-perennial reservoirs at the correct time is a major constraint to CBF development in the country. When fingerlings are required for stocking one category of reservoir (e.g., minor perennial reservoirs), fingerling requirement for CBF development in non-perennial reservoirs is severely constrained due to their limited supply (Figure 6).

Under the ARDQIP, this issue had been addressed and there were initiatives to establish mini-nurseries through community-based organizations (CBOs) to fulfil the demand for fingerlings for CBF. Through this initiative, initial capital investment was borne by ARDQIP on the condition that CBOs must pay back the total amount in 60 instalments to NAQDA (Anon., 2006). At present, there are about 29 mini-nurseries in different parts of the country. They have been established by rural CBOs, mainly AqMCs. Almost all these mini nurseries are established as earthen pond systems, for which technical advice was provided to CBOs by NAQDA. Fish fry purchased from AqDCs of NAQDA are reared up to fingerling size in these mini-nurseries, which in turn are sold to CBF farmers. As the profit that the owners of mini-nurseries can earn is very significant, this strategy is bound to continue.

Freshwater prawn stocking

NAQDA's freshwater prawn hatchery, established in 2008 at Kahandamodara in southern Sri Lanka under the assistance of FAO, has a production capacity of 17 million post larvae per year. In addition, freshwater prawn breeding centre established in 2017 in Kallarawa, eastern province, has a capacity to produce 25 million post larvae per year. In the freshwater prawn hatchery in Pambala, north-western province, 13.5 million post larvae were produced in 2020. Although aquaculture technology of *M. rosenbergii* is well-developed elsewhere, such technology has not yet been effectively transferred to Sri Lanka. As a result, there is an over-supply of *M. rosenbergii* post larvae from the NAQDA's hatcheries. Freshwater prawn post larvae were therefore stocked in different kinds of reservoirs.

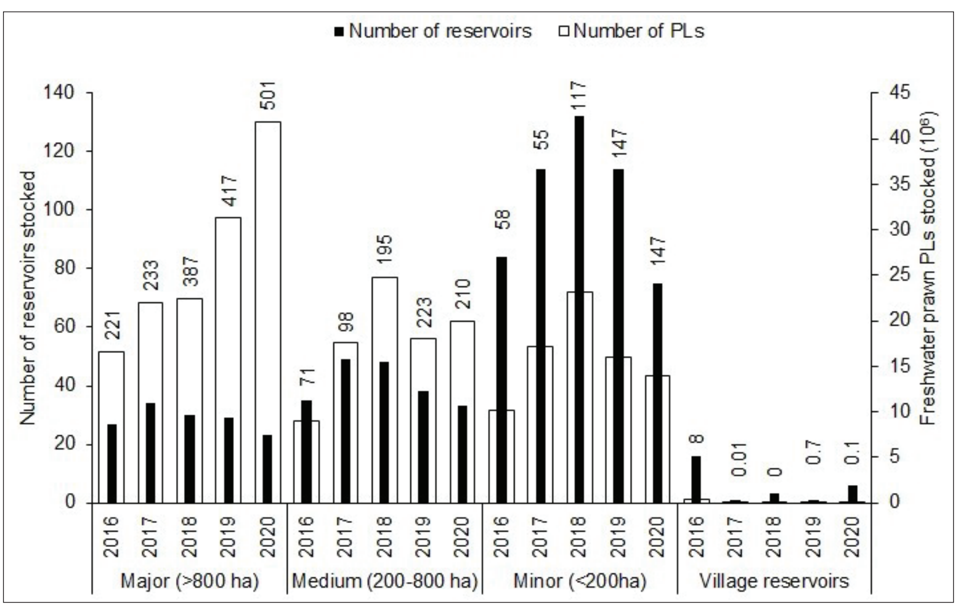

Figure 7: Number of reservoirs of different categories and number of freshwater prawn post larvae (PLs) stocked during 2016–2020. White bars: number of PLs stocked; dark bars: number of reservoirs stocked; numbers above columns indicate cumulative freshwater prawn yield per annum in tonnes (source of data: NAQDA)

Figure 8: Umbrella-shaped traps that are used in Thai reservoirs to catch freshwater prawn (Curtesy: T. Jutagate, Ubon Ratchathani University, Thailand)

The stocking data and reported yields of *M. rosenbergii* in different types of reservoirs in Sri Lanka during 2016-2020 (Figure 7) indicate that there is potential for incorporating freshwater prawn into CBF development in the country. Jutagate & Rattanachai (2010) reported that in Pak Mun reservoir (a run-of-river type reservoir of about 185 km^2 surface area) in Thailand, stocking of 2 million post larvae of *M. rosenbergii* resulted in an annual yield of 3 kg ha^{-1} and by stocking 40 million post larvae in 2003, a yield of 11.5 kg ha^{-1} yr^{-1} was achieved. Jutagate & Kwangkhang (2015) also reported that in Thailand, 30-day old post larvae of *M. rosenbergii* have been released into inland waters nationwide since 1980s for stock enhancement purposes. With the stocking density of about 2,500 prawn larvae/ha, harvests with an average individual weights ranging from 100 to 200 g after a year of release could be achieved. Common fishing gear used were gillnet, and traps that were designed exclusively for *M. rosenbergii*. However, the recapture rate was generally less than 5 %. Nevertheless, the economic return was high, which was about 3 times more than the average price of marketed freshwater fish (Jutagate & Kwangkhang, 2015).

In Sri Lankan reservoirs, fishers do not use special fishing methods to catch freshwater prawns but they are caught as by-catch in gillnets targeting finfish species. It would therefore be possible to introduce horizontal cylindrical traps (Deap *et al*., 2003) for catching *M. rosenbergii* in reservoirs where they have been stocked, which might increase freshwater prawn yields in reservoirs. Also, in Thai reservoirs, fishermen devised an umbrella shaped trap for catching *M. rosenbergii* in reservoirs (Figure 8) the efficiency of which was apparently high (T. Jutagate, pers. comm.). Although the freshwater prawn yield was much lower than finfish yields in CBF activities in Sri Lankan reservoirs, there were obvious financial benefits to the fishers because of high farm-gate price of freshwater prawn (LKR 570 – 705) compared farm-gate price of LKR 150-200 for freshwater finfish species.

Co-management

Co-management is essentially the sharing of responsibilities of decision-making and responsibility for the management of resources between the community (local fishers) and government centralised management (Pomeroy & Berkes, 1997). According to Brown *et al.* (2005), four pillars of successful co-management are as follows:

1) An enabling policy and legal framework
2) Participation and empowerment of communities (and other users).
3) Effective linkages and institutions.
4) Resources – a resource worth managing and the people and money to do it.

The CBF development strategies in Sri Lanka consist of these characteristics. As shown by Amarasinghe & Nguyen (2010), there are legal provisions to develop CBF in inland water bodies of the country under the Agrarian Development Act of 2000. Also, CBF development is a high priority area of fisheries development agenda of the country (Anon., 2007). CBF in village reservoirs are conducted by FOs (agrarian communities) rather than fishers. In medium and major reservoirs, CBF is practiced by fishers, who are also organised into rural fisheries organizations (RFOs). Community-based aquaculture (for fingerling rearing in mini-nurseries) is also within the organisational mandate of RFOs, whenever a farmer community decides to adopt it. The FOs are established under the Agrarian Development Act of 2000. The legal provisions in this Act facilitate empowering communities. The residents of a village involved in agriculture are essentially members of FOs. The small village reservoirs, whose command areas are less than 80 ha, come under the jurisdiction of Department of Agrarian Development and those which have irrigable area greater than 80 ha are under the control of Irrigation Department. Divisional Agriculture Committees (DvACs) are the major district-level institutions, which are responsible for facilitating agricultural development. There are monthly meetings of DvACs and the Divisional Secretary presides the meeting. Regional Officer (RO) of the Department of Agrarian Development, irrigation engineer, Samurdhi officer (government officer responsible for implementing state-sponsored poverty alleviation programmes), 'Grama Niladhari' (village-level administrative officer), aquaculture extension officer are the middle level government officers in this committee. Agrarian Research and Production Assistants (ARPAs), who work under the supervision of District Officer (DO), are the major contact persons of FOs. The officer bearers of FOs and ARPAs are also participants of monthly meetings of DvAC (Amarasinghe, 2010; Amarasinghe & Nguyen, 2010). These institutional linkages provide a positive environment for introduction of co-management strategies for CBF.

Extensive availability of village reservoirs, which are not used for fisheries development, willingness of agricultural communities to take up CBF, and well-established CBOs for operating mini-nurseries for fingerling rearing are the resources prevailing for CBF development in the country. In some reservoirs, CBF committees have invested money to establish computer-assisted data bases for stocking, harvesting, marketing and welfare fund mobilisation, due to promising financial benefits from CBF. Members of CBF committees become partners of community-based enterprises and they invest in the community owned venture. Also, members share the financial benefits of CBF activities on an agreed basis, which ensures sustainability of the strategy. These features in CBF strategies in Sri Lankan reservoirs indicate potential for establishing co-management effectively. In fact, such co-management strategies exist in several reservoirs of the country (Chandrasoma *et al*., 2015).

Pushpalatha *et al.* (2020) used Ostrom's modified design principles (Ostrom, 1990; Cox *et al*., 2010) as benchmarks to evaluate the strategies developed by fisher communities in five irrigation reservoirs for institutional robustness and resource management. Results indicated that increased levels of compliance with design principles through improving leadership qualities and empowering fishers for management decision-making would ensure sustainability of CBF due to high economic gains of CBF communities in reservoirs (Pushpalatha *et al*., 2020). Also, Pushpalatha *et al.* (2020) have shown that in five irrigation reservoirs of Sri Lanka, there was a multi-layer institutional structure, which links fisher communities between reservoirs (horizontal integration) and with fisheries organisations at the district level, provincial level and at the national level (vertical integration). Such kind of a multi-layer institutional structure as depicted in Figure 9, is recommended to be established for effective co-management of CBF in Sri Lankan reservoirs.

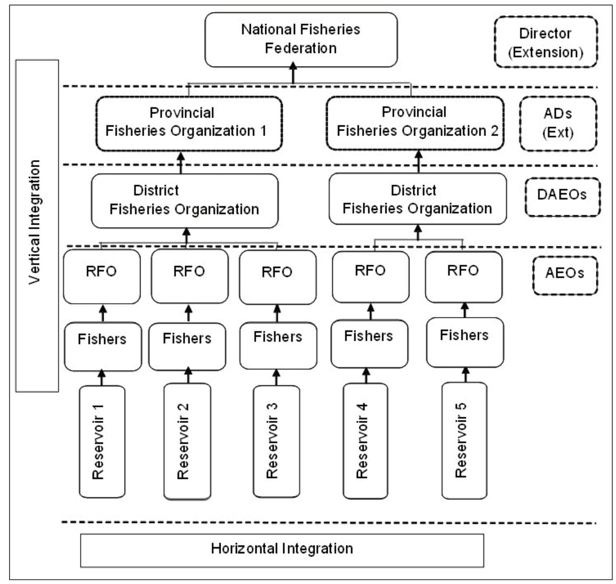

Figure 9: Multi-layer institutional structure, which links rural fisheries organisations (RFOs) between reservoirs (horizontal integration) and with fisheries organisations at the district level, provincial level and at the national level (vertical integration). The multi-layer institutional structure in NAQDA includes aquaculture extension officers (AEOs) in the RFO level, district aquaculture extension officers (DAEOs) in district level, assistant directors of extension [ADs (Extension)] in provincial level, and Director (Extension) at the national level.

Constraints to CBF development

Most of small village reservoirs dry up almost entirely during the dry season in August-October. Utilization of them for CBF development should therefore be planned essentially depending on the inter-monsoonal rains, generally during December-January period. It is therefore necessary to make fingerlings available for stocking reservoirs at the correct time. Consequently, the strategy should involve correct timing of fry-to-fingerling rearing, and induced breeding of Chinese and Indian major carps in the hatcheries (Wijenayake *et al*., 2021). The highest number of non-perennial reservoirs stocked in a year over the period of 2016 – 2020 was 819 (Figure 6), which was approximately 7% of total number of small village reservoirs in the country. As such, opportunities exist for further development of CBF in small village reservoirs of Sri Lanka. However, the full potential of utilization of these water bodies for CBF development is not achieved mainly due to the inadequacy of stocking material at the correct time under the present strategy of fish fingerling production for stocking reservoirs. It is therefore imperative that effective intervention be in place for the establishment of backyard hatcheries using simple technologies to the self-help community groups in the rural areas. Mohapatra *et al.* (2015) reported a case study of introduction of a portable fibreglass reinforced plastic (FRP) hatcheries along with technical support to a remote and inaccessible village in Odisha, India targeting women self-help groups. In this case, a poor group of women with no ownership of such assets was able to produce fish seed in a remote area. Through the government extension mechanism, an enabling environment was provided which contributed to the group having sufficient confidence for successful operation of the hatchery. It would be possible that through 'technology transfer research', small-scale carp hatcheries can be established in rural areas of Sri Lanka, as practiced in rural villages in Odisha, India.

Pushpalatha (2020) reported that in some irrigation reservoirs, semi-circular barrier nets were installed in front of the sluice gates to prevent escape of stocked fish fingerlings when water is released for irrigation for downstream paddy cultivation. According to Pushpalatha (2020), substantial increase in the CBF yield was evident in several perennial reservoirs where such barrier nets were installed. However, economic feasibility of this strategy is yet to be evaluated. In Chinese reservoirs, where CBF are practiced, fish escape prevention devices such as barrier nets and electrical barriers have been reported to be established (Xu, 1983; 1985).

Wijenayake *et al.* (2021) have shown that due to anomalies in monsoonal rainfall patterns under climate change scenario, water availability in non-perennial reservoirs in the dry zone of Sri Lanka for CBF development is rather unpredictable. As such, there is an uncertainty that rural groups engaged in fry-to-fingerling production face the difficulty of selling fish fingerlings to CBF farming groups when the non-perennial reservoirs are not filled due to insufficient monsoonal rains. An alternative strategy to link fingerling-producing community groups with the agricultural farming communities in minor perennial reservoirs should be in place to prevent such potential financial losses of fingerling producers (Wijenayake *et al*., 2021).

Opportunities for further development

The gradual success of CBF based on the application of science and improved community organisation sparked off an ancillary sector of fry to fingerling rearing bringing about employment opportunities and economic gains to rural households. When the feasible solutions are adopted to address constraints such as fingerling scarcity and those associated with climate change anomalies, there are promising future prospects of achieving full-scale CBF production. It is a reality that consumer preference in Sri Lanka for freshwater fish is generally low compared to marine fish. This is particularly so for exotic carp species, which significantly contribute to CBF yields in reservoirs. As such, at full-scale CBF development in Sri Lanka reservoirs, there is a potential to create a glut in the local market. Through the initiative by NAQDA, a fish canning company started producing three products of canned fish from catla flesh. As a new demand has arisen due to these fishery products, farmgate price of Indian carps in many reservoirs has elevated. Also, there are more popular postharvest fishery products available in the market (James, 1998). These include, surimi, fish mince-based products, fish cutlets, fish burgers, fish fingers, fish protein extract, etc. For this purpose, research on postharvest product development using freshwater fish including market research is needed to be carried out.

The primary uses of reservoir resources in Sri Lanka are irrigation of agricultural lands and hydroelectricity generation. Inland fisheries development is essentially a secondary use of reservoirs. As a result, there are many constraints to inland fisheries development due to the multiple uses. Hence, potential conflicts of interest in the inland fishing industry due to different multiple uses should be minimized. A synergy between water management related to downstream activities and fisheries enhancement should therefore be ensured for sustainability of CBF. A new act named as 'Aquaculture and Culture-based Fisheries Act' is proposed. There are several provisions under this proposed Act for multi-sectoral coordination, under which there shall be a culture-based fisheries management coordinating committee. This committee is proposed to consist of officials of various government institutions having responsibilities for the management of reservoirs and their catchments.

De Silva (2003) mentioned that CBF is an environmentally friendly form of aquaculture. It would therefore be possible to acquire global recognition for

CBF through implementation of the FAO code of conduct for responsible fisheries through an ecosystem approach to fisheries and aquaculture (Staples & Funge-Smith, 2009). This will also help achieving balance between conservation and fishery resources enhancement.

CONCLUSIONS

Sri Lanka is endowed with a multitude of freshwater reservoirs most of which are very small (< 50 ha) village irrigation reservoirs. These small village reservoirs are not capable of supporting any commercial scale fisheries through natural recruitment, although biologically very productive. As such, there is a high potential for the development of culture-based fisheries (CBF) in Sri Lankan reservoirs. The efforts made in 1980s to develop CBF in these water bodies were disrupted due to lack of proper scientific approaches for selection of suitable reservoirs. Under a comprehensive research project, a best practice approach was developed to select suitable reservoirs for CBF development using multi-criteria decision-making procedure. Social mobilisation and development of entrepreneurship plan among rural communities ensured sustainability of CBF in many reservoirs. Also, there were positive initiatives of fisheries authorities such as establishing mini nurseries for rearing of fingerlings of Chinese and Indian major carps, pilot scale CBF development in minor perennial reservoirs and establishing effective data recording systems. As detailed out by Chandrasoma *et al.* (2015) CBF has been successfully extended to medium and major perennial reservoirs that have resulted in significant increases in fish yield, and consequent gains in the socio-economic status of fishers and related communities. Increased fish yields through CBF activities also have expanded the associated value and market chains benefiting rural communities through added employment opportunities. Recent attempts at stocking *Macrobrachium rosenbergii* post larvae in inland reservoirs as part of CBF contributed to significant elevation of rural income. In many rural communities, there had been remarkable trends that part of the profit earned by CBF had been mobilised for various welfare activities in the village. Opportunities exist for establishment of effective co-management strategies for CBF in irrigation reservoirs of Sri Lanka. Being a rural development strategy, CBF development in Sri Lankan reservoirs should essentially be a transdisciplinary approach. Such an approach should take into consideration of the biological productivity favouring growth of stocked fish, institutional linkages for supporting different stages of the strategy, social attitudes for adopting CBF within the realm of participatory development, and market forces driving the entire process.

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