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Fisheries enhancements in inland waters in Sri Lanka with special reference to culture based fisheries: current status and impacts

Jayantha Chandrasoma[1] and K.B. Chandrani Pushpalatha[2]*

[1]*No. 153, Horana Road, Panadura, Sri Lanka*
[2]*National Aquaculture Development Authority of Sri Lanka, No. 41/1, New Parliament Road, Pelawatte, Battaramulla, Sri Lanka*

*Correspondance (pushpakbc@gmail.com)
https://orcid.org/0000-0002-7840-991X

Abstract Sri Lanka is endowed with more than 12,000 reservoirs. Depending on their hydrological regimes, they are broadly categorized into perennial and seasonal reservoirs and are secondarily used for the development of inland fisheries. This paper discusses the importance and status of culture-based fisheries (CBF) in reservoirs of Sri Lanka and assess the impacts of introduction of CBF. The CBF in seasonal reservoirs was initiated in the 1980s and it is well documented. There are around 200,000 ha of perennial reservoirs in Sri Lanka and CBF in perennial reservoirs is a recent development. Introduction of CBF into perennial reservoirs has resulted in significant increases in fish production, increased availability of fresh fish to rural communities, enhanced livelihood opportunities and income for fishers and strengthening the rural economy. Progress achieved so far in respect of seasonal reservoirs has not reached the envisaged levels.

Nile tilapia, catla, rohu and mrigal are the main contributory species for fish production through CBF in perennial reservoirs. Although the contribution to fish catches is low, stocking of freshwater prawn (*Macrobrachium rosenbergii*) is financially feasible. Adequate stocking with suitable species, the existence of active Community Based Organizations (CBOs) and their involvement in planning and implementation of CBF, and the existence of a legal framework which facilitate implementation of activities pertaining to CBF are the key factors for successful implementation and sustainability of CBF in perennial reservoirs.

Keywords: exotic carps; giant freshwater prawn; inland fisheries; irrigation reservoirs; stocking-and-recapture fisheries

INTRODUCTION

Sri Lanka is reputed to have a large number (>12,000) of irrigation reservoirs. In Sri Lanka, reservoir construction and use have always been an integral part of human activity, with some major reservoirs more than 2,000 years old. Most of these reservoirs are concentrated in the dry zone (1,250 – 1,900 mm annual rainfall) of the country (Thayaparan 1982). The total reservoir extent of the country is about 260,000 ha (MFAR, fisheries statistics). On average, size of these reservoirs ranges from few ha to 8000 ha. Depending on their hydrological regimes these reservoirs are broadly categorized into seasonal and perennial reservoirs. These reservoirs, with a few exceptions are irrigation reservoirs and are very diverse in age, size, hydrology and catchment features (Amarasinghe et al. 2002).

These irrigation reservoirs have been secondarily used for inland fisheries. Historical evidence indicates that inland fish were exploited from reservoirs even during the time immemorial (Siriweera 1986, 1994). Perimiankulam rock inscription made during the latter part of the first century refers to revenue from fish caught in the channels of two reservoirs (Paranavithana 1958) indicating that inland fishing was an important economic activity during this period. However, prior to 1950s, fish yields in Sri Lankan reservoirs were reported to be very low (Fernando 1984, 2000). Development of inland fisheries in Sri Lanka commenced with the introduction of the exotic tilapia, *Oreochromis mossambicus*, in 1952. Introduction of exotic species has resulted in significant changes in fish production and fisheries in reservoirs and yielded 70,600 tonnes in 2014, contributing around 93% to the total inland fisheries and aquaculture production of the country (MFAR, fisheries statistics).

Stock enhancement practices are aimed at increasing fish production through human intervention in the life cycles of fish (Lorenzen et al. 2001; De Silva and Funge-Smith 2005; Miao et al. 2010). Ingram and De Silva (2015) summarized the purposes of stocking in inland waters. The most commonly used stock enhancement practice is stocking seed, where the primary purpose is often to increase the yield. Stocking typically involves the release of large numbers of early-life stage animals that are mass-produced in hatcheries. Culture-based fisheries (CBF) is a form of stock enhancement widely practiced in Asia. The stock enhancement practice of CBF falls within the realm of aquaculture as the stocked seed are cared for by a community group or group of individuals that will own the resource at harvest. In CBF natural productivity of the water body is utilized by the stocked seed. De Silva et al. (2003, 2006, 2015) gave detailed accounts of CBF practices. The CBF is less resource intensive; utilize existing water resources and technically far less complicated than conventional aquaculture, and as such is relatively easy to transfer to farming communities (De Silva et al. 2006). Moreover, CBF is a good strategy for a country like Sri Lanka, where there is no tradition of aquaculture, to convert from hunting in waters to farming. The government of Sri Lanka has recognized CBF as an effective means of increasing fish supplies in rural areas at affordable prices. Further, CBF provides employment opportunities, additional income to rural communities and strengthen rural economy and thereby contributing towards alleviating poverty.

This paper discusses the importance and status of CBF development in respect to both seasonal and perennial reservoirs in Sri Lanka and assesses the impacts with respect to increase of fish production, provision of employment opportunities, and enhancement of income of rural communities for strengthening the rural economy. Further, constraints to the development and sustainability of CBF are also discussed.

CBF IN SEASONAL RESERVOIRS

The CBF in seasonal reservoirs of Sri Lanka initiated in the early 1980s and its potential and development were well documented (Thayaparan 1982; Chakrabarthy and Samaranayake 1983; Chandrasoma 1986a; Chandrasoma and Kumarasiri 1986; Amarasinghe 2006; De Silva et al. 2006). Chandrasoma (1986), De Silva et al. (2004), Jayasinghe et al. (2005a, 2005b 2006) and Wijeyanayake et al. (2014) reported on limnological and morphometrical aspects related to seasonal reservoirs. Socio-economic aspects related to development of CBF in seasonal reservoirs have been dealt by Jarchau (2008), Jayasekara (2008) Kularatne et al. (2008, 2009) and Lidzba et al. (2008). Chandrasoma (1988) and Murray (2006) discussed the marketing aspects related to fish produced in seasonal reservoirs.

PRIORITY GIVEN FOR CBF IN SEASONAL RESERVOIRS

Potential of seasonal reservoirs for increasing freshwater fish production in the country has been identified decades ago (Mendis 1965; Thayaparan 1982). The planning mission of the FAO/UNDP (1980) estimated fish production of 25000 tons/annum from a programme of judicious stocking and management of seasonal reservoirs. Chandrasoma and Kumarasiri (1986) and Athula et al. (2008) demonstrated high productivity of seasonal reservoirs with reported high yields with an average of 891.5 kg ha^{-1} $cycle^{-1}$ in 1980s and 449.8 kg ha^{-1} $cycle^{-1}$ in 2003-2004.

CBF in seasonal reservoirs is a priority area in inland fisheries and aquaculture development programme of the country, since the early 1980s except for 1990 –1994 period, during when state patronage for inland fisheries had been withdrawn. Country’s programme to develop CBF in seasonal reservoirs received the support not only of the Central Government but also of Provincial Councils, donor funded projects, Non-Government Organizations etc. A summary of activities related to the development of CBF in seasonal reservoirs undertaken under various projects/programmes and relevant outputs are given in Table 1. The number of seasonal reservoirs utilized annually for CBF during 1983-

1990 and 2009-2015 periods is shown in Figure 1. Annual fish production from CBF in seasonal reservoirs from 2009 to 2015 and its contribution to total inland fisheries and aquaculture production of the country are given in Table 2.

The Department of Agrarian Services (Anon. 2000) estimated that there are more than 13,000 small reservoirs in Sri Lanka and most of them are non-perennial or seasonal. Mendis (1977) estimated the total extent of small village reservoirs of Sri Lanka about 39,300 ha. Thayaparan (1983) estimated the extent of seasonal reservoirs as around 100,000 ha. Athula et al. (2008) reported that the actual reservoir area estimated by the Global Positioning System (GPS) was found to be 2.09 ± 0.21 times greater than the reservoir area reported in the records of the Department of Agrarian Development (Anon. 2000). Above information indicates that estimates made on the extent of seasonal reservoirs need further reviewing.

Sri Lanka has vast extent of seasonal reservoirs. Productivity of these reservoirs is very high. Development of CBF in seasonal reservoirs received high priority in the fisheries development programs of the government during the last four decades. Furthermore, concerted efforts have been made for the development of CBF in seasonal reservoirs with the support provided by the central government, provincial councils and other development partners. In addition, considerable Research & Development efforts have been made in respect of CBF in seasonal reservoirs. Fish fingerling (which is the only material input required for the development of CBF in seasonal reservoirs) availability, too has increased significantly in recent years. In spite of existence of favourable conditions discussed above, average number of seasonal reservoirs utilized for CBF during 2009 – 2015 period is around 500 (around 4% of the seasonal reservoirs available in the country) with a contribution of around 7.6% to the total inland fisheries and aquaculture production in Sri Lanka.

Table 1. Summary of activities related to development of CBF in seasonal reservoirs under various projects /programmes

Project/ Programme	Main thrust	Achievements/ outputs related to CBF in seasonal reservoirs
Aquaculture Dev. & Training Project (SRL/023/79), (1981-1984)	Development of CBF in seasonal reservoirs	Suitable species combinations for polyculture introduced; demonstrated CBF methodologies and fish production potential to rural communities; trained village communities, govt. officers including officers of the Dept. of Agrarian Development (DAD); Established institutional arrangements for cooperation between MFAR and DAD for implementation of seasonal tank programme (DAD circular no.225 of 1984); 172 seasonal reservoirs utilized for CBF during 1983/84 culture cycle (Source: Anon. 1985)
Aquaculture Dev. Project (ADB loan no. 684-SRI (SF) (1985-1990)	Development of freshwater and brackish water aquaculture. Included in the freshwater component were upgrading carp hatcheries/ rearing stations and seasonal tank programme.	204 seasonal reservoirs utilized for CBF; improved & repaired 141 seasonal reservoirs; trained 402 govt. officers (mainly DAD officers) and 1466 farmers on CBF in seasonal reservoirs. (Source: Aquaculture Development Project 1992)
GTZ sponsored Fisheries Community Development and Management Project (FCDRMP) (1999-2004)	Promotion of community-based fisheries approaches in southern dry zone reservoirs	Supported introduction of community-based approaches for CBF in seasonal reservoirs; developed a comprehensive procedure for a feasibility assessment of fish farming in seasonal reservoirs including technical, social and financial feasibility assessment; developed a detailed training curriculum for CBF in seasonal reservoirs. (Sources: NAQDA/FCDRMP 2002; Jarchau et al. 2008)
R & D project supported by Australian Centre for International Agricultural Research (2001-2006)	Research and Development related to CBF in seasonal reservoirs	Better practice approaches including selection of village reservoirs suitable for CBF development, based on biological productivity related parameters such as reservoir morphometry, allochthonous input of nutrients through livestock farming and socio-economic characteristics of rural communities developed; produced a documentary film on CBF in seasonal reservoirs. (Sources: De Silva et al. 2006; Amarasinghe & Wijenayake 2015).

FAO supported special programme for food security (SPFS) (2002-2008)	Improve food security through a community-based programme for development of agriculture, water management, aquaculture and livestock farming.	Promoted community-based fish farming integrated with water management, livestock and agriculture in four seasonal reservoirs with the participation of farmer organizations. (Source: Jayasekara 2008)
Aquatic Resource Dev. & Quality Improvement Project (ARDQIP). (2003-2009)	Promoting market driven and sustainable inland fisheries & aquaculture.	Supported utilization of 283 seasonal reservoirs (3129 ha); seed production capacity of three aquaculture development centers through expansion of facilities; established 25 community-based fish nurseries; trained 664 DAD officers on CBF in seasonal reservoirs; out of 4756 CBO members trained on CBF, considerable number of people are from farmer organizations of seasonal reservoirs; produced a documentary film on CBF in seasonal reservoirs to be used as an extension tool. (Source: ARDQIP 2010)

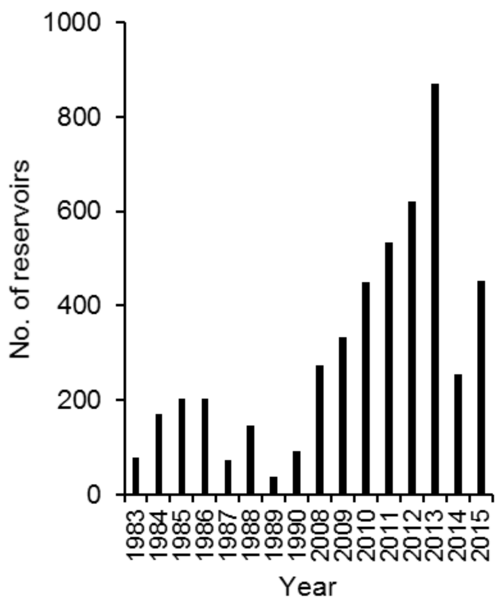

Figure 1 Number of seasonal reservoirs utilized annually for CBF (Sources: Aquaculture Development Project 1992; MFAR, Fisheries Statistics)

Table 2. Annual fish production from CBF in seasonal reservoirs (2009–2015) and its contribution to total Inland Fisheries and Aquaculture (IF & A) production.

Year	Fish Production* (tonnes)		% Contribution of CBF to total IF & A production
	CBF (seasonal res.)	Total IF & A	
2009	3980	46560	8.5
2010	4550	52410	8.7
2011	5360	59560	9.0
2012	6960	68950	10.1
2013	7460	66910	11.1
2014	1780	75750	2.3
2015	3150	67300	4.6

*Source – MFAR, Fisheries Statistics.

FACTORS HINDERING THE DEVELOPMENT OF CBF IN SEASONAL RESERVOIRS

Factors that contribute to hinder the development of CBF in seasonal reservoirs are discussed below.

(i). Vulnerability to climate changes: Seasonal reservoir fish culture programme is highly vulnerable to climate change including an irregularity in rainfall patterns and prevalence of frequent droughts. Delays in onset of monsoonal rains shorten the culture period and this very often discourages farmers as shortened culture period results in low fish production. In addition, changing weather patterns impact the onset of maturity of broodstocks of carp species (Tennakoon et al. 1988; Das et al. 2012) and in turn affecting supply of fish fingerlings at the correct time for stocking in seasonal reservoirs.

(ii). Inadequate availability of fish fingerlings of desired species: Success of the CBF in seasonal reservoirs to a great extent depends on the availability of fish fingerlings of suitable species at the correct time. Stocking needs to be completed within a short period of 2-3 months with the filling of water (Amarasinghe 2006). In order to obtain the optimum fish production, stocking has to be carried out at the correct time, with the correct species combination. Although there had been a significant increase in production of fish fingerlings in the country in recent years, a mismatch between the availability of fish fingerlings of desired species and the stocking period of the seasonal reservoirs was observed as attempts were increased to utilize more seasonal reservoirs in different regions of the country. Difficulties in obtaining fish fingerlings of required species at the correct time has discouraged many farmer groups to abandon undertaking fish farming in seasonal reservoirs. In many instances, non-availability of fish fingerlings of desired species compelled farmers to deviate from adapting suitable species combinations (Chandrasoma 1986; Wijenayake et al. 2005), which resulted in low fish production.

(iii). Un-coordinated release of water from reservoirs: Seasonal reservoirs have been built for irrigating the downstream paddy cultivation, and utilization for CBF development is a secondary activity. Although institutional arrangements exist for undertaking fish farming in seasonal reservoirs with the participation of farmer organizations, which are responsible for management of water in these reservoirs, release of water for paddy cultivation at the early stages of the fish culture cycle, to a level that fish cannot survive, have disrupted CBF programmes in many reservoirs.

(iv). Low income generation: Unlike in perennial reservoirs, where fish harvesting is a daily activity, in seasonal reservoirs, fish harvesting season is limited to few days to few weeks in a year. Hence, the ability of the CBF in seasonal reservoirs to supply fresh fish for village communities living around is limited to a shorter period. The CBF in seasonal reservoirs offer part-time opportunities to a group of people to be involved in fish farming. These community groups receive financial benefits once a year only. Amarasinghe and Nguyen (2009) provided details of incomes from CBF in 15 seasonal reservoirs in 2003/2004 culture period. Total commercial net income ranged between Rs. 37,259 and Rs. 312,764 (average of Rs. 106,757 reservoir^{-1} annum^{-1}). Based on the assumption that community groups involved in CBF in each reservoir consist of an average of 10 members, net income received is around Rs. 10,676 per member per year (Rs. 890 per month). Although there had been very few instances of high incomes obtained through CBF in these reservoirs, in most cases income received by community group members are not attractive enough to keep their interests unchanged. Low fish production and low incomes can be attributed to the various reasons discussed under this section. Lidzba et al. (2008) reported that community group members lost interest in the programme as labor and financial inputs were higher than the expected individual gains after the harvest, while Jarchau et al. (2008) reported that many fish farming communities in seasonal reservoirs gave up their activities after one or two years of operation due to a number of problems that they encountered.

(v). Problems related to marketing of produce: Marketing and price fluctuations can be a disincentive in seasonal water bodies using CBF (De Silva 2015). In a given geographical location/region the harvesting in CBF will usually be in compliance with the prevalent hydrological cycle and also in most instances harvesting is confined to a very short duration. According to De Silva (1988, 2015) there could be a glut of food fish and the respective communities may not get the best returns for the produce. Chandrasoma (1988) observed that as fish harvesting was seasonal, there was no established fish marketing structure as found in perennial reservoirs, and reported that due to glut situations few fish vendors were able to create a buyer's market at the expense of fish farmers. According to Chandrasoma (1988), in some seasonal reservoirs, farmers have adopted a staggered harvesting procedure to prolong the harvesting period to prevent creation of glut situations. De Silva (2015) is of the view that it is appropriate that adjacent communities work out suitable time frames to harvest, so that possibilities of glut of fish in the market within a narrow time frame in a small geographical area is minimized, thereby ensuring fair farm gate prices.

(vi). Other factors: Among other factors which have resulted in hindering the development of CBF are poaching or catching of fish by force by other groups of people; lack of coordination among relevant officers at the grass-root level (Lidzba et al. 2008), and lack of collective action by farmer communities (Kularatne et al. 2008) for CBF activities.

All these factors show that further development of CBF in seasonal reservoirs will be a great challenge for relevant government authorities.

PERENNIAL RESERVOIRS

Inland fisheries in perennial reservoirs

Perennial reservoirs of Sri Lanka (around 200,000 ha in cumulative 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. A considerable number of perennial reservoirs (e.g., Deduru-oya reservoir (1945 ha) in Kurunegala district, Rambaken-oya (1400 ha) in Ampara district, Mau-ara (1551 ha) and Weheragala (1416 ha) reservoirs in Monaragala district, Moragahakanda (2950 ha) in Matale district) have been built in recent years. Further, with the implementation of new irrigation schemes such as Weli-oya scheme in Monaragala district, some seasonal reservoirs became perennial in nature. All these new developments including other reservoirs under Moragahakanda scheme, which has been completed very recently, have resulted in significant increase in the extent of perennial reservoirs. Hence information available on the extent of perennial reservoirs under different categories needs updating.

Development of inland fisheries in these perennial reservoirs commenced with the introduction of exotic cichlid, *Oreochromis mossambicus* in 1952 and inland fisheries in perennial reservoirs are well documented (De Silva 1983, 1988; Indrasena 1965; Fernando and Indrasena 1969; Mendis 1977; Fernando 1993; Amarasinghe and Weerakoon 2009).

Stock enhancements with cichlids

Since the first introduction of *Salmo trutta* from Europe in 1882, 19 exotic species belong to four families of which Cichlidae and Cyprinidae are best represented, have been introduced into freshwater of Sri Lanka (De Silva 1988). Prior to 1950s fish yields in Sri Lankan reservoirs were 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 and Holčik 1991). Stock enhancements in perennial reservoirs were carried out, for the first time in the 1950s, when exotics *Oreochromis mossambicus*, *Cyprinus carpio* and *Osphronemus gorami* were stocked and the productive fishery was established after the introduction of *O. mossambicus* in 1952 (De Silva 1988). According to De Silva (1988), *O. mossambicus* became the most dominant species in the fishery contributing over 70% to the total landings. Various reasons have been attributed to the success of this species in Sri Lanka. Among them are breeding success (Fernando and Indrasena 1969), lack of lacustrine species in the indigenous fauna capable of colonizing the lake habitat (Fernando and Holčik 1991) and ability of *O. mossambicus* to change its dietary habits from season to season depending on the availability (De Silva 1985). By 1990, another cichlid species, Nile tilapia (*Oreochromis niloticus*) became the dominant species of the inland fisheries in perennial reservoirs following heavy stocking. Chandrasoma (1986b) observed the replacement of *O. mossambicus* by Nile tilapia in Sorabora wewa and discussed possible reasons for the success of *O. niloticus*.

Stock enhancements with carp species

Exotic carps have been stocked in perennial reservoirs since the 1960s. Of the cyprinids, major carps, namely common carp, grass carp, bighead carp, silver carp, rohu, catla and mrigal have been used for stocking of perennial reservoirs (De Silva 1988; Illukkumbura, 1986; Chandrasoma 1992, 1996; Chandrasoma and Wijeyaratne 1994; Jayasekara 1989). Various workers have dealt with the use of exotic carps in the fisheries management in Sri Lankan reservoirs and have expressed conflicting views on the stocking of carps in perennial reservoirs during the 1980s and 1990s. There were two schools of thought: one advocating stocking of carps in perennial reservoirs (Sreenivasan and Thayaparan 1983; Chandrasoma 1992; Chandrasoma and Wijeyaratne 1994) and the other not in favour of it (De Silva 1983, 1987, 1988, 1989; Amarasinghe 1992, 1998; Amarasinghe and De Silva 1992; Fernando 2000: Fernando and Halwert 2001). Views expressed by various workers on the stocking of exotic carp species in perennial reservoirs of Sri Lanka are summarized in Table 3.

Table 3. Summary of views expressed by various workers on the stocking of exotic carp species in perennial reservoirs of Sri Lanka

Views expressed	Reference
For the multitude of perennial reservoirs, which are relatively large (>250ha) extensive culture operations are unlikely to succeed and their fishery potential lies in developing a capture fishery, a fishery which does not depend on continuous stocking and harvesting but relies on sustaining natural or quasi-natural populations; A fishery based on periodical stocking is likely to be unprofitable and almost meaningless in the context of the Sri Lankan conditions; Stocking is usually not economical in larger bodies of water, where natural reproduction of an adequate variety of species occur.	De Silva (1983, 1988)
Establishment of CBF based on non-tropical major carps is irrational, because such a strategy has to be established at the expense of the existing productive cichlid fishery. This strategy will lead to over exploitation of the cichlid fishery as a result of the efficient fishing gear; Optimum yield of non-tropical major carps that can be achieved is 30kg/ha/annum; Cichlids have established natural breeding populations in perennial reservoirs and already support profitable fisheries. By contrast stocking of Chinese and Indian major carps require considerable investment and development of efficient fishing methods to ensure sufficient returns in terms of fisheries yield.	Amarasinghe (1998)
Stocking-recapture fisheries are illogical if the returns are low.	Amarasinghe & De Silva (1992)
Stocking of African cichlids were the most successful and that the other species have had little impact on the fisheries of perennial reservoirs; Using Chinese and Indian carps for stocking small/large reservoirs has not been a success and was an unmitigated failure. Carp culture is a failure and few that are caught not marketable.	Fernando (2000); Fernando & Halwart (2001)
Stocking of *L. rohita* is economically feasible in all three reservoirs studied; From the available data on planned stocking of perennial reservoirs, it appears that exotic carp species can play a significant role in enhancing freshwater fish production in Sri Lanka; In some reservoirs, where intensive stocking of carp fingerlings has been carried out fish yields have considerably enhanced.	Chandrasoma (1992, 1996; Chandrasoma & Wijeyaratne (1994)
Indian and Chinese carps would be the candidates for stocking the Mahaweli reservoirs.	Sreenivasan & Thayaparan (1983)

CBF in perennial reservoirs

The CBF in perennial reservoirs is a recent development. Introduction of CBF in minor reservoirs commenced in 2004 under the Aquatic Resource Development and Quality Improvement Project (ARDQIP) of the Ministry of Fisheries and Aquatic Resources (MFAR) gradually expanded to cover the other two size categories, medium and major perennial reservoirs (ARDQIP 2010). Pushpalatha and Chandrasoma (2009), Pushpalatha et al. (2015a), Pushpalatha et al. (2015b) and Chandrasoma et al. (2015) described the methodology adopted in introducing CBF in perennial reservoirs. According to them formation/ reorganization and strengthening of fisher Community Based Organizations (CBOs); regular stocking with a fish seed of suitable species; implementation of fisheries management measures; sustainable harvesting and collection of fish catch statistics are the key steps in developing and ensuring sustainability of CBF in perennial reservoirs.

Stocking of fish seed

Stocking has been a continuous activity with the introduction of CBF. Unlike in seasonal reservoirs, where stocking is limited to a narrow period of 2 – 3 months in a year, in perennial reservoirs stocking is carried out throughout the year. Hatchery produced, fish fingerlings of Nile tilapia (Genetically Improved Farmed Tilapia - GIFT strain of *O. niloticus*), Indian major carps catla (*Catla catla*), rohu, (*Labeo rohita)*, mrigal, (*Cirrhinus mrigala)* and post-larvae (PL) of freshwater prawn (FWP), (*Macrobrachium rosenbergii*) are being used for stocking. Chandrasoma et al. (2015) reported that average stocking rates were 1,037 individuals ha^{-1} $annum^{-1}$ (range 251-1,940) and 1,023 individuals ha^{-1} $annum^{-1}$ (range 533-2,315) in eight minor and seven medium perennials respectively covered under the study. Stocking rates reported for two major reservoirs, Senanayake Samudra and Jayanthiwewa were 192 and 804 individuals ha^{-1} $annum^{-1}$ respectively.

Statistics available with Ministry of Fisheries and Aquatic Resources (MFAR) shows that during 2011-2014 period, an average of 14,144 ha of minor perennials have been stocked with 14.87 million fish fingerlings (excluding FWP) annually at a stocking rate of 1051 individuals ha^{-1} $annum^{-1}$. During the same period, an average of 21,706 ha of medium perennials have been stocked with 10.74 million fish fingerlings annually at a stocking rate of 495 individuals ha^{-1} $annum^{-1}$. Similarly, 59,588 ha of major perennials have been stocked with an average of 8.07 million fingerlings annually at a stocking rate of 135 individuals ha^{-1} $annum^{-1}$.

According to Chandrasoma et al. (2015) fish species to be stocked; stocked numbers; time of stocking; source of fish seed etc. were determined by the fisher CBOs: in taking decisions on the species to be stocked, CBOs gave due consideration to consumer preference and availability of fish seed; the species for stocking and stocking numbers were revised if necessary in subsequent years, depending on the stocking outcome.

Freshwater prawn is considered as an important species in stock enhancement practices in all three categories of perennial reservoirs in the recent past. During 2009-2015 period an average of 61,314 ha of major perennials received an average of 5.41 million post-larvae (PL) of FWP at a stocking rate of 88 individuals ha^{-1} $annum^{-1}$ while 21,634 ha of medium perennials received 2.94 million PL at a stocking rate of 136 individuals ha^{-1} $annum^{-1}$ (MFAR, fisheries statistics). Similarly, 4,263 ha of minor perennials received 3.66 million PL (859 individuals ha^{-1} $annum^{-1}$) during the same period.

Fish seed production in respect of cultivable freshwater species increased significantly in recent years (Figure 2) due to the efforts made by the government such as increasing production capacities in government aquaculture development centers/hatcheries; supporting the establishment of community-based fish nurseries; supporting the individuals to undertake fish fingerling production in ponds as small enterprises; supporting and encouraging the establishment of water-based community managed nurseries etc. Increased availability of fish seed facilitated the enhanced stocking of water bodies.

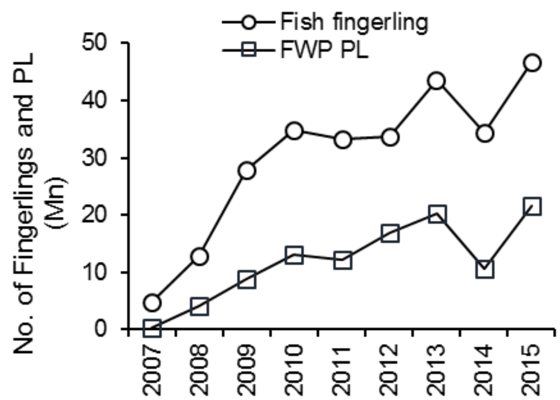

Figure 2 Details of seed production of culturable freshwater fish species from 2007 – 2015.

LEGAL FRAMEWORK AND IMPLEMENTATION OF FISHERIES MANAGEMENT MEASURES

Adequate legal provisions exist under the Fisheries and Aquatic Resources Act (FAR Act, 1996) for the management of CBF. These provisions include registration of fishing crafts; the need for a license to engage in fishing operations; prevention of the fishing gear specified as illegal and use of gillnets above 8.5 cm etc. In addition, there are provisions to limit the number of licenses issued to each reservoir and also to limit the number of units of fishing gear (gillnets) that can be used by a fisher in a reservoir. Use of dragnets; seine nets; mono-filament gillnets and trammel nets are prohibited to catch fish in inland waters. The use of explosives; sedatives; poisonous substances etc. to kill fish is also prohibited under these regulations. The requirement for obtaining a license for fishing operations prevents open access to fishing and ensures ownership of the fish catch to a group of fishers, who has organized into a CBO.

Accordingly, the above provisions ensure that CBF as practiced in Sri Lankan reservoirs, irrespective of the size of the water body, fall within the realm of aquaculture as per the definition of the FAO (FAO 1994).

The legal foundation for co-management arrangements is also provided under section VI of the FAR Act and the amended Act (FAR (amendment) Act 2013). These provisions include the declaration of certain areas as special areas of management and facilitation of involvement of fishing communities in fisheries management and decision making. Provisions are also available under this Act to institutionalize the CBO working committee as the management authority for a particular reservoir, frame regulations specific to the declared area of management if decided by the CBO and acceptable to the minister of fisheries and aquatic resources development. Accordingly, based on requests made by fisher CBOs, some reservoirs have been declared as special management areas by the minister under the provisions available in the FAR Act. Further, the minister has published, through gazette notifications, certain regulations which are required to facilitate management of reservoirs. The minimum mesh size of 102 mm for gillnets and minimum landing size of 250 g and 1,500 g for tilapia and carps respectively have been stipulated under regulations specific to identified reservoirs including Senanayake Samudra, the largest reservoir in the country.

Chandrasoma et al. (2015) reported that fisher CBOs were actively involved in the implementation of fisheries management measures. Regulations of FAR Act were strictly adhered to and only gillnets were used for fishing. Although minimum mesh size of gillnets allowed is 8.5 cm (in some cases 10. 2 cm as discussed above), CBO members in most reservoirs collectively agreed and used gillnets with a mesh size of 11.5 cm and above. A fixed time period for fishing operations and the use of one landing site for fishing crafts for each reservoir are two other important fisheries management measures adopted by fisher CBOs, which facilitated close monitoring of fisheries activities. Further, these measures facilitated more accurate data collection at landings. Funds required for stocking was generated by levying a fee for every kilogram of fish landed.

FISH PRODUCTION

Introducing CBF in perennial reservoirs resulted in significant increases in fish production. Chandrasoma et al. (2015) reported that annual fish production increased by 206.5% (range 144.8% - 510%) in eight minor perennials and by 318.5% (range 49.0% - 668.5%) in seven medium perennial reservoirs considered under their study. In Senanayake Samudra and Jayanthiwewa, two reservoirs of major category, fish production increased by 594.9% and 769.5% respectively in the 6th year after the introduction of CBF (Figure 3). The annual fish production from perennial reservoirs and total annual inland fisheries and aquaculture fish production in Sri Lanka from 2009-2014 is shown in Figure 4. The average annual contribution of fish production from perennial reservoirs to the total inland fisheries and aquaculture production in the country was 85.4% during this period. Fish production from perennial reservoirs increased by 76.3% in 2014, when compared to that in 2009.This significant increase in fish production from perennial reservoirs can be attributed to enhanced stocking coupled with the introduction of fisheries management measures.

Statistical unit of the Ministry of Fisheries and Aquatic Resources (MFAR) in association with Department of Census and Statistics provide fish production statistics related to different sub-sectors. Although considerable progress has been made with regard to the development of CBF in perennial reservoirs in the recent years, it is not reflected in fisheries statistics separately as fish productions in perennial reservoirs are categorized under "Capture (perennial water bodies)" in the fish production statistics of the MFAR. As CBF falls under the realm of aquaculture (FAO 1994), it is suggested to separate the fish production statistics in respect of perennial reservoirs into two categories, namely "fisheries" and "CBF".

Fish Production per unit area

Chandrasoma et al. (2015) observed significant increases in unit area fish production in all three categories of perennial reservoirs after the introduction of CBF. Average annual fish production per unit area increased to 353.3 kg ha^{-1} annum^{-1} during post-CBF period from pre-CBF production of 131.5 kg ha^{-1} annum^{-1} in minor perennials. Similarly, fish production in medium perennials covered under their study increased to 310.1 kg ha^{-1} annum^{-1} from 71.1 kg ha^{-1} annum^{-1}. Fish production data for Senanayake Samudra and Jayanthi wewa (major perennial reservoirs) indicate that by 2014, fish production in these two reservoirs reached 100.4 kg ha^{-1} from 14.3 kg ha^{-1} and 274.8 kg ha^{-1} from 31.6 kg ha^{-1} respectively.

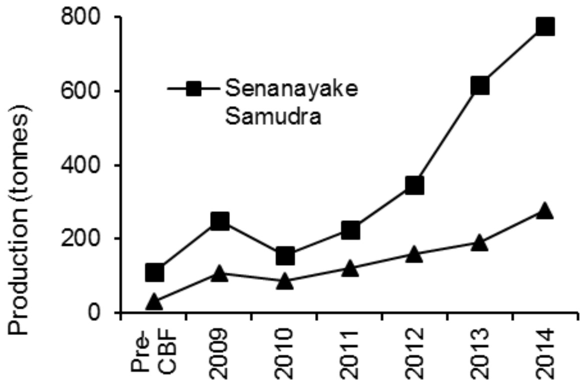

Figure 3 Annual fish production in Senanayake Samudra and Jayanthi wewa after introduction of CBF

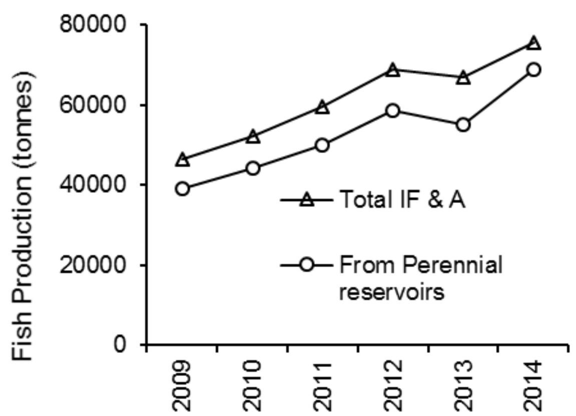

Figure 4 Total annual Inland Fisheries and Aquaculture (IF & A) production and fish production from perennial reservoirs in Sri Lanka

Species composition of fish catches

Introduction of CBF has not only resulted in significant enhancement of fish production, but also in changing the species composition of fish catches. De Silva (1985a, 1988) reported that *O. mossambicus* dominate in almost all the major reservoirs and was 70% of the total fish catch. Chandrasoma et al. (2015) reported that Nile tilapia was the dominant fish species, contributing 80-90% to the total fish catch in all three categories of perennial reservoirs prior to the introduction of CBF. Species composition of fish catches after the introduction of CBF in eight minor perennials and seven medium perennials as reported by Chandrasoma et al. (2015) is given in Figures 5(a) and 5(b). Species composition of fish catches of Senanayake Samudra and Jayanthi wewa in 2014, six years after the introduction of CBF is given in Figures 5(c) and 5(d).

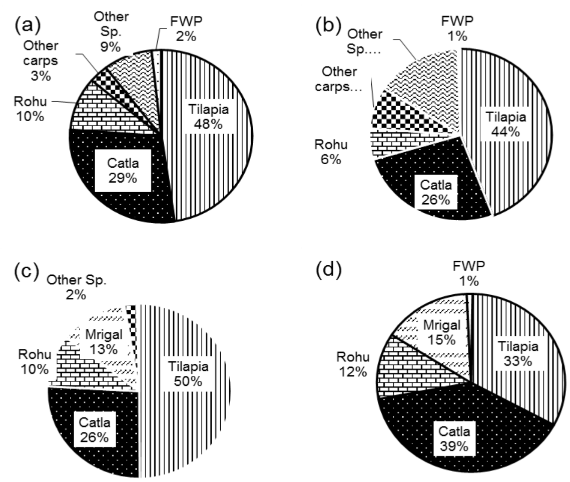

Figure 5 Species composition of fish catches of perennial reservoirs, (a) Minor perennial reservoirs, (b) Medium perennial reservoirs, (c) Senanayake Samudra and (d) Jayanthi wewa

Observations related to the changes in species composition of fish catches in perennial reservoirs resulted due to the introduction of CBF is summarized as follows: (a) The percent contribution of Nile tilapia to fish catches of all three categories of reservoirs decreased during post-CBF period (minor perennial reservoirs – 57.6%; medium perennial reservoirs – 59.3%; major perennial reservoirs, Senanayake Samudra – 49.9 % and Jayanthi wewa –32.6 %). Although there had been a decrease in percent contribution of Nile tilapia to the total catch, tilapia harvest increased significantly in all three categories of perennials mainly due to enhanced stocking and implementation of fisheries management measures. (b) Stocked exotic carps (mainly catla, rohu and mrigal) contributed 41.9% and 39.5% to the total landings of minor and medium perennials. In 2014, stocked exotic carps contributed 47.7% and 66.4% to the total catch of Senanayake Samudra and Jayanthi wewa respectively. It is important to note that unit area production of exotic carps in these two major perennials were 47.8 and 182.5 kg ha^{-1} $annum^{-1}$ respectively. Percent annual contribution of exotic carps to country's freshwater fish production from 2010 – 2014 varied from 19.9% to 27.6%, with an annual average contribution of 23.7%. Chandrasoma (1992), Pushpalatha and Chandrasoma (2009) and Pushpalatha et al. (2015a, 2015b) observed that monetary gains from stocking exotic carp species are attractive. (c) The average annual contribution of stocked FWP to the freshwater fish production of the country during 2010 – 2014 was around 0.6% ranging from 0.44% to 0.86%. Percent return of stocked FWP in perennial reservoirs calculated based on stocking numbers and FWP production during the 2009-2015 period (assuming average size at landing as 250g) was around 9.4%. This recapture rate can be considered as satisfactory when compared with the recapture rates reported for reservoirs in Thailand. Jutagate and Rattanchai (2010) observed that recapture rates of FWP were less than 5% in reservoirs of Thailand and the highest recapture reported was around 10% from a freshwater wetland in Nakhon Sawan province (Rithcharung and Srichareondham 1998).

SOCIO-ECONOMIC IMPACTS IN FISHING COMMUNITIES

Chandrasoma et al. (2015), Pushpalatha et al. (2015a) and Pushpalatha et al. (2017) discussed the impact of the introduction of CBF in perennial reservoirs of Sri Lanka. In addition to increase of fish supplies in rural areas, other impacts include enhanced income for fishers, increase in livelihood opportunities and strengthening of the rural economy. Details of the provision of livelihood opportunities in five medium perennial reservoirs, where CBF was introduced are given in Table 4. Introduction of CBF has resulted in significant increases (ranging from 50% to 323%) in livelihood opportunities provided in all five reservoirs.

Table 4 Details of provision of livelihood opportunities in five medium perennial reservoirs during pre-CBF and post- CBF periods

Reservoir	Pre-CBF period		Post- CBF period (2013)		% increase
	Full-time	Part-time	Full-time	Part-time	
Ampara wewa*(240ha)	13	-	33	21	323
Hambegamuwa*(480ha)	16	16	57	20	140
Aluthdivulwewa*(239ha)	-	15	37	-	147
Morawewa**(789ha)	22	10	37	20	78
Mahadivulwewa**(543ha)	25	15	40	20	50

*after Pushpalatha et al. (2017), **Pushpalatha (in preparation)

Significant increases were resulted in fish production due to the introduction of CBF in perennial reservoirs, and in turn resulted in higher income for fishers. Table 5 compares average monthly incomes of full-time fishers in three medium perennials during pre-CBF and post-CBF periods. It is interesting to note that introduction of CBF in these reservoirs has facilitated elevating incomes of full-time fishers to middle-income levels.

Table 5 Comparison of average monthly incomes of full-time fishers in three medium perennial reservoirs during pre-CBF and post-CBF periods

Reservoir	Avg. monthly income of a fisher (Rs.)	
	Pre-CBF	Post-CBF
Morawewa*(789ha)	7900.00	55615.00
Mahadivulwewa*(543ha)	8360.00	58619.00
Amparawewa**(240ha)	8862.00	40366.00

*Pushpalatha et al. (in preparation), **Pushpalatha et al. (2015a)

Almost all irrigation reservoirs, both seasonal and perennial reservoirs, are situated in rural areas of the country, where the main economic activity in rural areas is downstream paddy cultivation in the command areas of reservoirs. Pushpalatha et al. (2017) compared the income generated from downstream paddy cultivation and CBF in three medium perennial reservoirs (Table 6). Gross incomes and profits generated from CBF, which is a non-consumptive secondary user of water, indicate that CBF has developed into an important rural activity. It is important to note that profits obtained from CBF have surpassed the profits generated from downstream paddy cultivation in respect of two reservoirs covered under their study. These observations illustrate the important contribution made by CBF towards strengthening the rural economy.

Table 6 Comparison of gross income (GI) and profits per annum from downstream paddy cultivation and culture-based fisheries (CBF) in Ampara wewa, Hambegamuwa and Aluthdiulwewa during 2012–2014 (after Pushpalatha et al. 2017)

Name of Reservoir	GI from downstream paddy cultivation (Rs. Mn)	GI from CBF (Rs. Mn)	GI from CBF as % of GI from paddy cultivation	Profit from downstream paddy cultivation (Rs. Mn)	Profit from CBF (Rs. Mn)	Profit from CBF as % of profit from paddy cultivation
Ampara wewa	23.938	21.290	88.9	13.900	18.517	133.2
Hambegamuwa	69.448	47.287	68.1	34.214	44.269	129.4
Aluthdiulwewa	38.376	19.446	50.6	19.406	16.756	86.3

CONCLUSION

Although the CBF in perennial reservoirs in Sri Lanka is a recent development after 1980s, its introduction has resulted in significant increases in fish production, and in turn ubiquitous availability of fresh fish for rural communities, enhancing the livelihood opportunities and income of fishers. Further, its role in strengthening the rural economy is significant. On the other hand, in spite of all the inputs provided and efforts made, progress achieved so far in respect of CBF in seasonal reservoirs has not reached the envisaged expectations.

Exotic carps in particular, catla, rohu and mrigal and exotic cichlid Nile tilapia are the main contributory species for CBF in perennial reservoirs. Although some community groups and individuals are involved in the rearing of fish fry of cultivable species to fingerling stage, all fish breeding activities including maintenance of broodstocks of fish, induced breeding and rearing of post larvae to fry stage are carried out in government Aquaculture Development Centres. It is essential that fish breeding activities are planned and coordinated properly to meet the increasing requirements of above species, while maintaining the balance between the species based on the demand. FWP contributed around 0.6% to the total annual freshwater fish production of the country during 2010-2014 and percent return of post larvae of FWP stocked is around 9.4%. Although the contribution to fish catches is low, stocking of FWP is financially feasible and has become attractive to fishers as this fetches a high price (Chandrasoma et al. 2015). Government strategy in respect of FWP, at present, is focused on enhancing production capacities of existing hatcheries, the establishment of new hatcheries and increasing stocking in perennial reservoirs. These new investments need to be carried out with caution, as information based on scientific studies are not available on optimum production capacities of FWP in perennial reservoirs, where the bulk of FWP is produced.

Adequate stocking of reservoirs with suitable fish species; the existence of active CBOs and their involvement in decision making; existence of a legal framework for ensuring ownership of the harvested fish and the regulation of CBF and implementation of fisheries management measures are the key factors for the successful introduction and implementation of CBF in perennial reservoirs. Presence of an active extension service is also vital for the implementation and to ensure the sustainability. Considering the vast potential for further increase of fish production and its benefits to rural communities the government should continue to extend priority for development of CBF in its policies and programs. It is important to provide production statistics related to CBF in perennial reservoirs separately as CBF is falling under the realm of aquaculture.

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