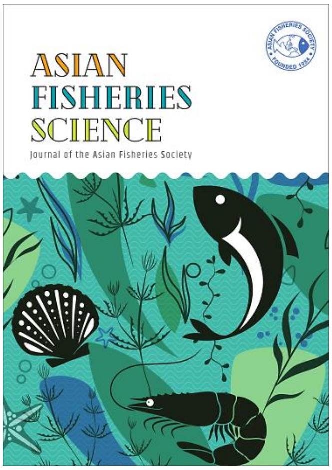

Institutional Robustness of Culture-based Fisheries in Perennial Reservoirs of Sri Lanka

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Abstract

The utilisation of irrigation reservoirs for culture-based fisheries (CBF) development is a recent development in Sri Lanka. The trends in CBF development in five reservoirs were investigated, to identify the robustness of institutional arrangements in the rural fisheries organisations (RFOs) for the sustainability of CBF. Basic socio-economic characteristics of five fisher communities showed enabling features for implementing CBF through community participation. After the 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 % in Urusita and Ampara reservoirs respectively. The CBF management options of RFOs in two reservoirs, viz. Ampara and Jayanthi were at high compliance levels of Ostrom's modified design principles, where fishers enjoyed increased mean annual income registering 2187 % in Ampara and 409 % in Jayanthi reservoirs after introduction of CBF. In Senanayake Samudra, where there was moderate compliance, there was 249 % increase in CBF income. However, the lowest increase of income (194 %) in Urusita reservoir was due to high annual fisheries income even during pre-CBF period. In Hambegamuwa reservoir, where levels of compliance of RFOs with design principles were relatively poor compared to other four fisher communities, increase of fishers' CBF income, compared to that of pre-CBF period, was marginal (202 %). Economic gains of RFOs due to increased levels of compliance with design principles through improving leadership qualities and empowering fishers for management decision-making would, therefore, ensure sustainability of CBF.

Keywords: Cichlidae, Cyprinidae, inland fisheries, Ostrom's design principles, tropical reservoir fisheries

Introduction

The global consumptive demand for food fish is expected to originate from aquaculture production (OECD/FAO, 2019). Nevertheless, the influences of major drivers such as decentralisation, climate change, demographic transition and resource use rights on the contribution of aquaculture for poverty alleviation, are still insufficiently documented, and therefore poorly understood (Béné et al., 2016). As such, environmentally friendly approaches of increasing fish production such as fisheries enhancement (Lorenzen et al., 2001; De Silva, 2003; Taylor et al., 2017) have received increasing attention. De Silva (2003), through a comprehensive review, has shown that culture-based fisheries (CBF) in inland waters are environmentally friendly strategies.

In Sri Lanka, being a country endowed with the multitude of reservoirs, CBF development in village reservoirs has made a progressive impact on the inland fisheries enhancement (Amarasinghe and Nguyen, 2009). The strategies for CBF development in inland reservoirs of Sri Lanka are essentially rural development activities involving artisanal fisher communities and agricultural farming communities (Kularatne et al., 2009), and as such community participation is an indispensable component for its success and sustainability. This situation is not unique to Sri Lanka, and many efforts for CBF development in small reservoirs in Cambodia (Song et al., 2013) Lao

PDR (Saphakdy et al., 2009; Phomsouvanh et al., 2015) and Vietnam (Nguyen et al., 2001) also involve the participation of rural communities.

CBF falls within the realm of aquaculture since there is ownership of the stocked fish by an identifiable group of people so that resource users can manage the resource through self-governing institutions (Dietz et al., 2003). Such institutional arrangements are found in many traditional fisheries around the world (Feeny et al., 1990; Basurto, 2005; Deepananda et al., 2016).

Ostrom (1990) defined a set of eight design principles that local communities could use to develop more robust institutions for managing common pool resources (CPR) such as fisheries. This is to ensure the sustainability of resources by self-organising resource-use mechanisms rather than through regulations imposed by the external organisations. These eight design principles were expanded to 11 principles (Cox et al., 2010), to investigate the robustness of institutional arrangements in community-based management of natural resources. Although not completely analogous to institutional arrangements in community-based capture fisheries, institutional approach in CBF systems is somewhat similar to those in traditional capture fisheries because CBF systems are mostly managed by the rural communities (Kularatne et al., 2009; Amarasinghe and Nguyen, 2009). As such, it is hypothesised that Ostrom's 11 modified design principles (Ostrom, 1990; Cox et al., 2010) can be used to investigate the institutional robustness of CBF. Hence, in the present study, an attempt was made to evaluate community-based CBF management in five Sri Lankan reservoirs through the framework of modified design principles (Ostrom, 1990; Cox et al., 2010). This study has important implications for elucidating the strengths and weaknesses of institutional arrangements in CBF, for identifying aspects which require further intervention for their sustainability.

Materials and Methods

The present study was carried out in five irrigation reservoirs of Sri Lanka. Geographic locations of the five reservoirs viz. Ampara, Hambegamuwa, Jayanthi, Senanayake Samudra and Urusita, are shown in Figure 1, and some of their morphometric characteristics and number of registered fishers per ha of the reservoir are given in Table 1. In these five reservoirs, stocking of fish fingerlings commences in 2004 for the development of culture-based fisheries (CBF) and as such, the period prior to 2004 was termed as 'pre-CBF period'.

The CBF development in small village reservoirs of Sri Lanka in mid-1980s was severely interrupted due to many reasons including technical and political constraints as described elsewhere (De Silva, 1988; Amarasinghe, 1998). Lack of effective methods to select suitable reservoirs for CBF, inadequate involvement of fisher communities in management decision making and politically inspired withdrawal of state patronage for the development of the inland fisheries sector from 1990 to 1994 (Amarasinghe and Nguyen, 2009) were major setbacks for sustainability of CBF. Amarasinghe and Nguyen (2009) further mentioned that the general collapse of CBF development activities in village reservoirs after discontinuation of government support in 1990 was a clear indication that high dependence on state subsidies for fingerling supply made CBF unsustainable. This strategy was, however, revived around 2003-2004 and CBF development in small village reservoirs has been carried out adopting scientific approaches (Wijenayake et al., 2005; Amarasinghe and Nguyen, 2009). More recently, Pushpalatha et al. (2015) have shown that CBF development in medium and large reservoirs would also be feasible. Accordingly, fisher communities in the five reservoirs selected for the present study were strengthened establishing a legal basis for them under the provisions of "Registration of Aquaculture Societies Regulations, 2009" of the country (Anon., 2009). With the active participation of members of fisher communities, entrepreneurship plans for CBF development were prepared in all five reservoirs. This included plans for stocking, managing stocked fish, harvesting strategies, marketing, record keeping, income saving and sharing of dividends (Chandrasoma et al., 2009). This strategy was effective for social mobilisation of fisher communities for CBF development.

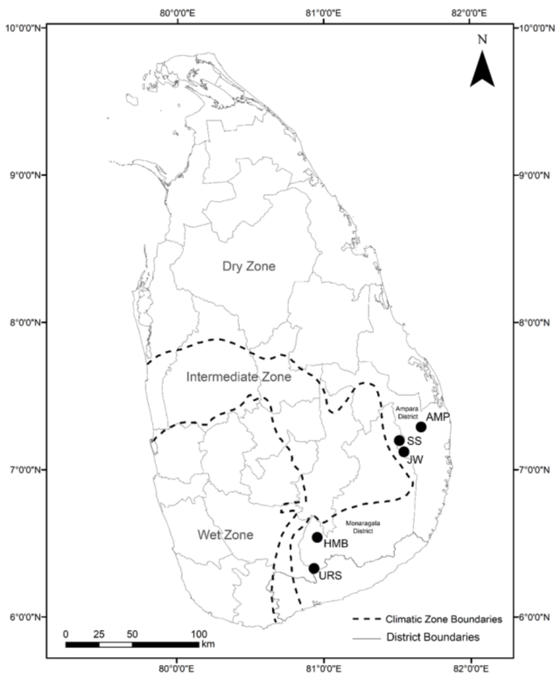

Fig. 1. Map of Sri Lanka showing geographic locations of the five irrigation reservoirs where trends in culture-based fisheries were investigated. AMP – Ampara reservoir; HMB – Hambegamuwa reservoir; JW – Jayanthi reservoir; SS – Senanayake Samudra; URS – Urusita reservoir.

Table 1. Some morphometric characteristics of the five irrigation reservoirs where trends in culture-based fisheries were investigated. Number of registered fishers per ha of each reservoir is also given here.

Name of reservoir	Ampara reservoir	Hambegamuwa	Jayanthi reservoir	Senanayake Samudra	Urusita reservoir
Location	7°17′32.47″N; 81°39′44.52″E	6°32′33.90″N; 80°57′18.90″ E	7°7′24.71″N; 81°32′43.08″ E	7°12′0.98″N; 81°30′49.78″ E	6°19′56.18″N; 80°55′59.58″ E
Area at FSL (ha)	240	210	1012	7793	260
Catchment area (km^2)	6.6	53.0	36.4	384.0	ND
Mean depth (m)	1.6	3.1	5.6	10.2	3.6
Maximum depth (m)	29.2	6.3	12.5	33.54	6.7
Number of registered fishers per ha	0.2000	0.3048	0.0533	0.0535	0.1462

ND – No data.

The five reservoirs were stocked annually with hatchery produced Nile tilapia (*Oreochromis niloticus* (Linnaeus, 1758)), catla (*Catla* (=*Gibelion*) *catla* (Hamilton, 1822)), rohu (*Labeo rohita* (Hamilton, 1822)), mrigal (*Cirrhinus mrigala* (Hamilton, 1822)) and freshwater prawn (*Macrobachium rosenbergii* (de Man, 1879)). The approximate species combinations were; carps 30 %, tilapia 40 % and freshwater prawn 30 %, while stocking densities used were 200-4500 per ha. The stocking composition was adopted by fisheries authorities in Sri Lanka depending on experience of CBF (Chandrasoma and Kumarasiri, 1986; Pushpalatha and Chandrasoma, 2010). There are several factors determining stocking densities in reservoirs including scarcity of fingerlings to support all CBF activities in the country, and impossibility to achieve high stocking densities in large-sized reservoirs such as Senanayake Samudra (7793 ha). Fishing commenced one year after stocking, and non-mechanised fibreglass outrigger canoes were used for harvesting of fish in these perennial reservoirs, which was a year-round activity. Gillnets of stretched mesh size ranging from 10.2 cm to 25.4 cm were used as fishing gear.

Data on fish production in the five reservoirs were based on log-book records of fisheries societies and subsequently from their computerised databases. Accordingly, fish production data for the present analysis were obtained from 'pre-CBF period' (from 2000 to 2003) and from 2007 to 2018 (i.e., 'post-CBF period'). During the intermediate period (2004-2006), the introduction of CBF in the five reservoirs through social mobilisation was performed by National Aquaculture Development Authority of Sri Lanka (NAQDA) so that fisheries production data during this period were not used in the analysis. Species-wise fish production data were grouped as (i) exotic carps, (ii) tilapia, (iii) giant freshwater prawn and (iv) others. The category of exotic carps mainly consisted of Chinese and Indian carps that were stocked, and tilapias were exclusively *O. niloticus*, which were formed by both stocked ones and naturally breeding counterparts. The category of 'others' were mainly formed by *Labeo dussumieri* (Valenciennes, 1842), *Channa striata* (Bloch, 1793). Giant freshwater prawn, *M. rosenbergii* was treated as a separate category because this species fetched at higher prices at the landing site providing substantial financial benefits to producers. In each reservoir, annual fish production (FP) of the four categories was estimated in tonnes, and catch per unit effort (CPUE) of four categories was determined as kg per fisher per year. Mean FP and CPUE and corresponding standard error were determined for 'pre-CBF period' and for 'post-CBF period' separately in the five reservoirs. Mean annual fish yield (FY), expressed as $kg.ha^{-1}$ yr^{-1} of each reservoir was also determined for the four categories of landings separately. Based on the mean unit price of fish of the four categories, monetary values of FP, CPUE and FY were computed for 'pre-CBF period' and for 'post-CBF period' separately for each reservoir.

Furthermore, field data collection was carried out in the five reservoirs from January to December 2018. For data collection on socio-demographic profiles (i.e., age structure, education level, period of experience in fishing and distance from residence to the landing site) of the household heads (fishers) in five fisher communities, all registered fishers in Ampara (48), Hambegamuwa (64), Jayanthi (54) and Urusita (38) reservoirs were interviewed. However, in Senanayake Samudra, where there were 417 registered fishers, only 254 fishers were interviewed. To evaluate the strategies developed by fisher communities for institutional robustness and resource management Ostrom's modified design principles (Ostrom, 1990; Cox et al., 2010) were used as benchmarks. Semi-structured questionnaires, which have been recognised as standard ethnographic methods for gathering information in an open-ended format (Briggs, 1986), were used to collect data. All the interviews and discussions with respondents were carried out in their mother language, Sinhalese. The data collection process for this questionnaire survey was characterised by series of interviews carried out using the saturation method, an adaptive approach to determine sample sizes in qualitative research (Glaser and Strauss, 1967; Francis et al., 2010; Hennink et al., 2019). The samples grew gradually until the researchers felt comfortable that the desired level of saturation had been achieved. The selection of respondents for data collection was based on their willingness to participate voluntarily. However, the resultant samples comprised of 15 fishers each in Ampara, Hambegamuwa and Urusita reservoirs, 20 fishers in Jayanthi reservoir and 30 fishers in Senanayake Samudra (Table 2). The data collection was focused on evaluating the compliance of elements of institutions with the modified design principles (Cox et al., 2010). For this purpose, a semi-structured questionnaire was designed to address various components, which were pre-tested prior to final evaluation, under each design principle as given in Table 3.

Final evaluation was based on five-point Likert scale, a psychometric approach (Likert, 1932) in which values ranged from 5 (very prominently exist) to 1 (non-exist). Whereas the values 4, 3 and 2 were assigned to indicate 'prominently'; 'moderately' and 'slightly' exist, respectively. Based on the responses of fishers interviewed in each of the five reservoirs, each component of the 11 design principles (Table 3) was assigned the corresponding value (from 1 to 5 of Likert scale). For some components (e.g., design principles 7 and 8 given in Table 3), assigning the values was based on authors' observations and experience. In this analysis, nine design principles, except 7th and 8th principles (i.e., externalities) related to governance, were treated as the ones pertinent to community-based resource management (i.e., internalities). Fishers' mean annual income levels derived from the fisheries of five reservoirs were then compared in relation to the compliance levels of fisher communities with the components of 11 design principles.

Table 2. The number of registered active fishers and number of fishers interviewed for gathering information on compliance with Ostrom's modified design principles (Ostrom, 1990; Cox et al., 2010) in the five reservoirs studied.

Reservoir	Number of registered fishers	Number of fishers interviewed
Ampara reservoir	48	15
Hambegamuwa reservoir	64	15
Jayanthi reservoir	54	20
Senanayake Samudra	417	30
Urusita reservoir	38	15

Results

Socio-demographic profiles of fisher communities in the five reservoirs indicate that age composition (Fig. 2A) and levels of education (Fig. 2B) of household heads were more or less similar in all five reservoirs studied. Majority of fishers interviewed had more than 5 years of experience in fishing (Fig. 2C). Most fishers interviewed were residing close to the fish landing site of the reservoir (<5 km) so that they had easy access to fishing equipment in the landing site.

In all five reservoirs studied, total fish production, especially exotic carp and Nile tilapia production had considerably increased after the introduction of CBF (Fig. 3A). In all five reservoirs, CPUE of exotic carp and Nile tilapia landings also showed a remarkable increase after the introduction of CBF (Fig. 3B) providing a clear indication of the increase in stock abundance. Mean annual fish yield of exotic carp and Nile tilapia in each reservoir had also increased after the introduction of CBF, particularly in Ampara, Hambegamuwa, Jayanthi and Urusita reservoirs (Fig. 3C). In Senanayaka Samudra, total annual fish production had appreciably increased after the introduction of CBF (Fig. 3A). However, when the annual fish yield was expressed as kg ha^{-1}, the magnitude of increase was not prominent (Fig. 3C) due to the large size of the reservoir.

The average farm-gate prices of one kg of fish in the four categories in five reservoirs (Table 4) indicate that *M. rosenbergii* fetched the highest price followed by Nile tilapia, exotic carps and others. The mean annual income derived from the fisheries of five reservoirs has significantly increased during 'post CBF' compared to that of 'pre CBF' (Figs 4A-4C). It must be noted however, that increase in income of fishers during 'post CBF' was partly due to increase in price of fish (as compared to that of 'pre CBF'). Nevertheless, the occurrence of exotic carps and freshwater prawn in the landings was attributed to CBF, and as such, harvesting of stocked fish during 'post CBF' could be treated as a factor responsible for the increased income. One striking feature was that during 'post CBF', giant freshwater prawn contributed significantly to total annual fisheries income in the reservoir (Fig. 4A), mean annual income per ha per fisher (Fig. 4B) and mean annual income per ha (Fig. 4C). Apparently, Nile tilapia accounted for the highest fisheries income during 'post-CBF' in all five reservoirs, while exotic carps ranked second (Figs. 4A-4C).

Table 3. Components of different design principles that were used for information gathering using a semi-structured questionnaire.

Design principle	Component
1A. Clearly defined user boundaries	i. Clearly defined user boundaries are present for resource users ii. User boundaries are accepted by non-appropriators iii. User boundaries are accepted by government authority/ legitimacy iv. User boundaries are used for resource management purpose v. User boundaries exist for the resource (water) availability vi. User boundaries are used from generation to generation vii. User boundaries exist at proximity to the home
1B. Clearly defined resource boundaries	i. Clearly defined resource boundaries exist ii. Resource boundaries are accepted by non-appropriators iii. Resource boundaries are accepted by the government authority iv. Resource boundaries are used for resource management purpose
2A. Congruence with local conditions	i. A similarity is existing between resource environment and its governance structure (rules) *Excludability rules:* ii. Eligibility rules exist iii. Intercommunity access rules exist *Subtractability rules:* iv. Temporal allocation rules exist v. Fishing time/place/gear is restricted vi. Technology rules exist vii. Fishing behaviour rules exist viii. Conservation rules exist
2B. Appropriation and provisions	i. An analogy between cost and benefits exists ii. A mechanism to proportionally share the cost exists iii. A mechanism to proportionally distribute the benefits exists iv. A mechanism to distribute the benefits to appropriators during non-temporal allocations exists
3. Collective-choice arrangements	Operational and collective-choice rules are existing (raids, fish selling methods) Resource users have the right to make, enforce and change existing rules These rules are effective External authorities accept these rules (legitimacy)
4A. Monitoring users	There is an effective mechanism to monitor the enforced rules (fishing activities, violations, violators) They regularly monitor appropriators'/non-appropriators' activities/behaviour This monitoring of appropriators' behaviour is effective
4B. Monitoring the resources	An effective mechanism to monitoring resources (water and fishes) and fishing territory exists They regularly monitor the resource/commons This monitoring of the resource/commons is effective
5. Graduated sanctions	A mechanism for graduated sanctioning exists This mechanism is effective Government bureaucratic authorities accept the mechanism/ legitimacy There is an official appointed accountable for appropriators
6. Conflict resolution mechanisms	Low-cost mechanism exists to resolve conflicts between resource users The existing mechanism is effective Users support effective monitoring and rule enforcement
7. Minimal recognition of the right to organise	There is a possibility to compromise and device their own decisions within the community Higher-level state authorities recognise the right of the community institution/resource users to self-govern Collaborative decision-making process in the community with government authorities is effective
8. Multi-level institutional structure	A multiple layer of institutional structure is established A horizontal integration exists A vertical integration exists A frequent procedure exists for measuring each linkage This multi-level institutional structure is effective

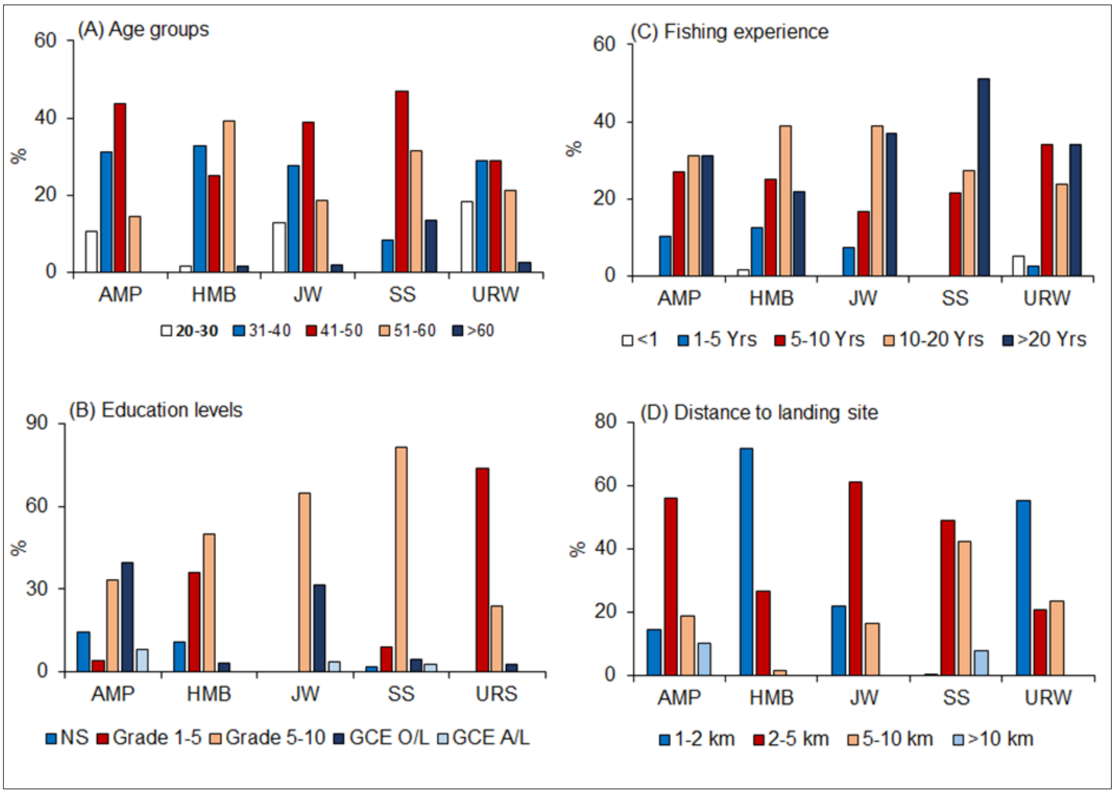

Fig. 2. Socio-demographic profiles of fisher communities in the five reservoirs. AMP – Ampara reservoir; HMB – Hambegamuwa reservoir; JW – Jayanthi reservoir; SS – Senanayake Samudra; URS – Urusita reservoir.

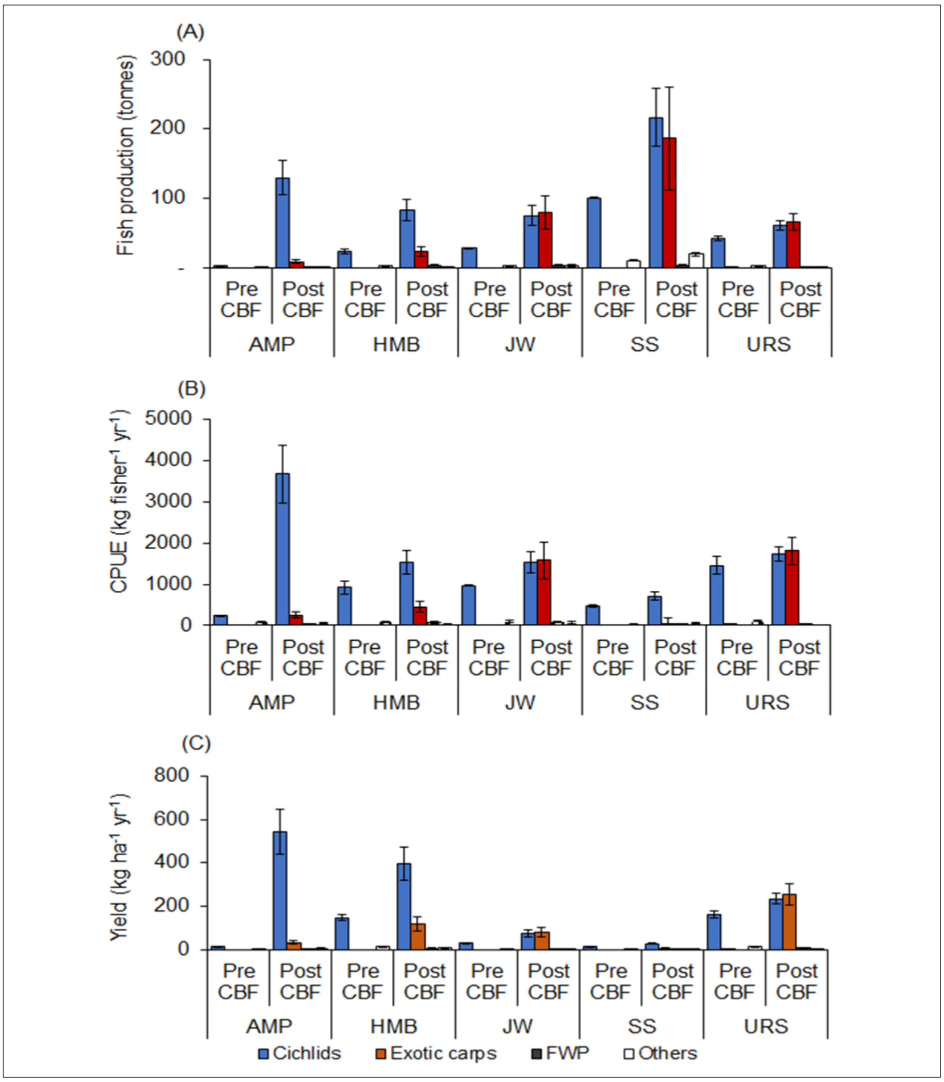

Fig. 3. (A) Total fish production; (B) catch per unit effort (CPUE); (C) fish yield in five reservoirs during 'pre CBF' and 'Post CBF'. AMP – Ampara reservoir; HMB – Hambegamuwa reservoir; JW – Jayanthi reservoir; SS – Senanayake Samudra; URS – Urusita reservoir.

Table 4. The average farm-gate prices (LKR) of one kg of fish in the four categories in five reservoirs.

Fish category	AMP		HMB		JW		SS		URS	
	Pre-CBF	Post-CBF	Pre-CBF	Post-CBF	Pre-CBF	Post-CBF	Pre-CBF	Post-CBF	Pre-CBF	Post-CBF
Nile tilapia	80	100-220	80	100-240	80	100-200	80	100-300	100	120-320
Exotic carps	-	50-100	-	60-140	-	60-100	-	50-150	50	60-200
Freshwater prawn	-	200-1200	-	300-1200	-	200-1000	-	200-1200	-	300-1300
Other	80	80-100	60	70-100	60	60-100	60	70-150	70	100-120

AMP – Ampara reservoir; HMB – Hambegamuwa reservoir; JW – Jayanthi reservoir; SS – Senanayake Samudra; URS – Urusita reservoir. LKR – Sri Lanka Rupees. In October 2019, USD 1 ≈ LKR180.70.

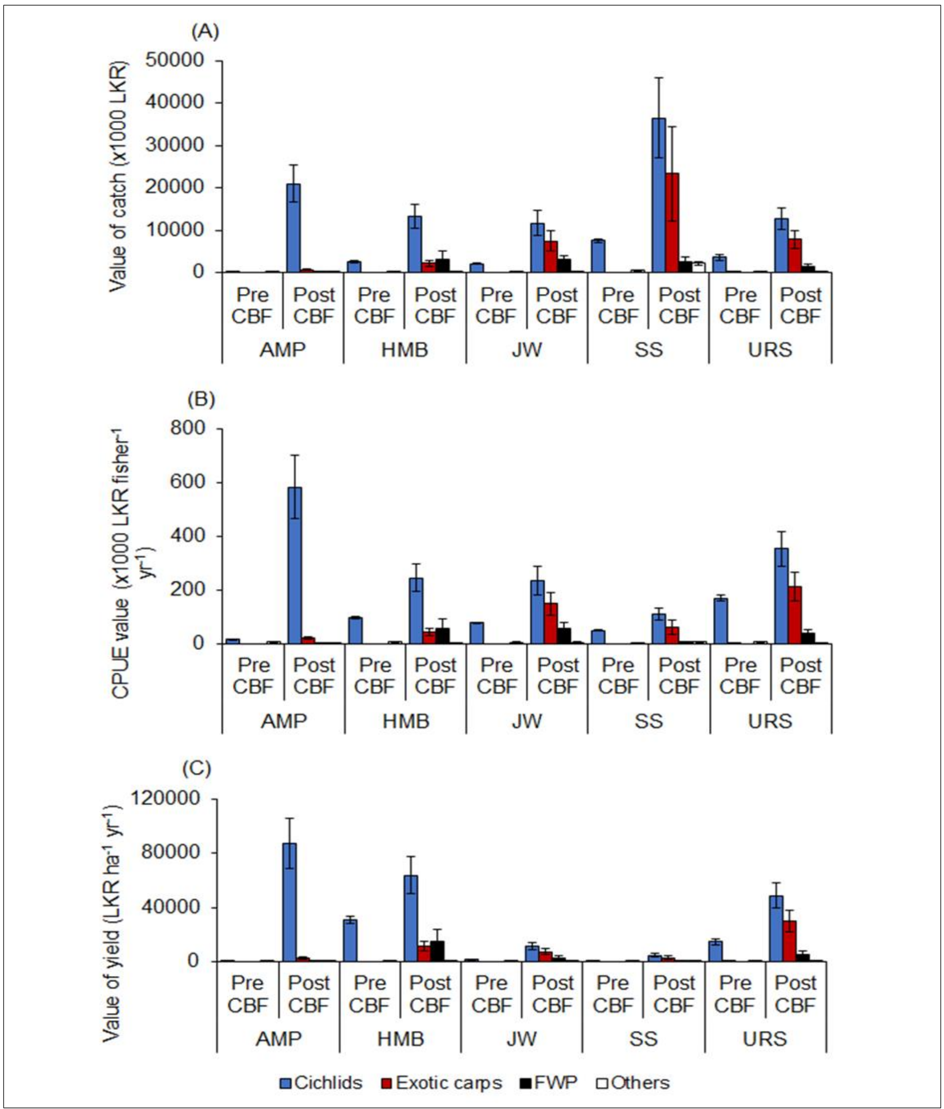

Fig. 4. (A) Value of total fish production; (B) value of catch per unit effort (CPUE); (C) value of fish yield (LKR per ha per year) in five reservoirs during 'pre CBF' and 'Post CBF'. AMP – Ampara reservoir; HMB – Hambegamuwa reservoir; JW – Jayanthi reservoir; SS – Senanayake Samudra; URS – Urusita reservoir.

Summary of compliance of five fisher communities with Ostrom's modified design principles (Table 5; Ostrom, 1990; Cox et al., 2010) indicated that fisher communities of Ampara and Jayanthi reservoirs had high levels of compliance with the benchmarks set by design principles. In contrast, the RFOs in Senanayake Samudra and Urusita reservoirs had moderate levels of compliance. However, fisher community of Hambegamuwa reservoir exhibited low levels of compliance (Table 5) with the design principles of community-based fisheries management (i.e., design principles from 1A to 6 or internalities).

Table 5. Summary of the compliance of elements of institutions with the modified design principles in the fisher communities of five reservoirs.

ID	Compliance of elements of institutions	Reservoir RFOs
1A	Water spread area of reservoir is radially divided into 13 fishing zones No clearly defined user boundaries	AMP HMB, JW, SS, URS
1B	User rights are Accepted by irrigation authorities	AMP, HMB, JW, SS, URS
2A	User rights are restricted to members of RFOs	AMP, HMB, JW, SS, URS
2B	From every kg of fish landed, a levy is charged for the revolving fund of RFO	AMP, HMB, JW, SS, URS
3	RFO imposes fishery regulations on mesh restriction etc. and mechanism for monitoring exists. RFO imposes fishery regulations on mesh restriction etc. but mechanism for monitoring does not exist.	AMP, JW, SS, URS HMB
4A	RFO assigned a committee to monitor fishing activities RFO has not assigned a committee to monitor fishing activities	AMP, JW, SS, URS HMB
4B	RFOs regularly monitor resource base, level of exploitation Barrier nets were installed at the sluice and spillway to prevent fish escape. No mechanism for monitoring status of fishery resource	AMP, JW, SS, URS JW HMB
5	RFO formulates and implements fishing rules through collective agreement RFO formulates fishing rules, but implementation process is weak, especially due to poor leadership	AMP, JW, SS, URS HMB
6	RFO members are empowered to apprehend fishing rule violators RFO members do not take the responsibility of controlling fishing rule violators, but seek support of AEO	AMP, JW, SS, URS HMB
7	RFO is mainly responsible for decision making RFO depends on AEO for making CBF management decisions	AMP, JW, SS, URS HMB
8	A multi-layer institutional structure (Fig. 4) exists, which links RFOs between reservoirs (horizontal integration) and with fisheries organisations at district level, provincial level and at national level (vertical integration)	AMP, HMB, JW, SS, URS

Identification codes (ID) of the design principles are as given in Table 3. AMP – Ampara reservoir; HMB – Hambegamuwa reservoir; JW – Jayanthi reservoir; SS – Senanayake Samudra reservoir; URS – Urusita reservoir; RFO – Rural Fisheries Organisation; AEO – Aquaculture Extension Officer.

In all five fisher communities, multi-level institutional structure, which links RFOs between reservoirs (horizontal integration) and with fisheries organisations at the district level, provincial level and at the national level (vertical integration), is identical (Fig. 5). The multi-level institutional structure in the fisher communities is in line with the administrative hierarchy in NAQDA so that institutional structure in the fisher communities is strongly supported by the institutional structure in the government (Fig. 5).

Institutional arrangements of RFOs in five reservoirs indicated different levels of compliance of institutional structure (Fig. 6) to benchmarks of Ostrom's modified design principles (Ostrom, 1990; Cox et al., 2010). The RFOs in Ampara reservoir (Fig. 6A) and Jayanthi reservoir (Fig. 6C) showed 'very high compliance' and 'high compliance" with modified design principles so that these two RFOs can be treated as those with strong institutional arrangements for sustaining CBF. The weakest institutional arrangements in terms of compliance with design principles were in the RFO of Hambegamuwa reservoir (Fig. 6B). In RFO of this reservoir, design principle 1B (i.e., clearly defined resource boundaries) having 'high compliance' and 7th and 8th design principles with 'very high compliance', institutional arrangements pertaining to rest of the design principles were either 'moderately exist' or 'slightly exist' exist (Fig. 6B). The RFOs of Jayanthi reservoir (Fig. 6B) and Urusita reservoir (Fig. 6E) showed moderate compliance with the design principle 1A (clearly defined user boundaries), while having high or very high compliance with other 10 design principles. In Senanayake Samudra, the largest reservoir in the present study, the RFO had moderate compliance with the design principles 1A and 1B (clearly defined resource boundaries) while showing high or very high compliance with rest of the design principles (Fig. 6D).

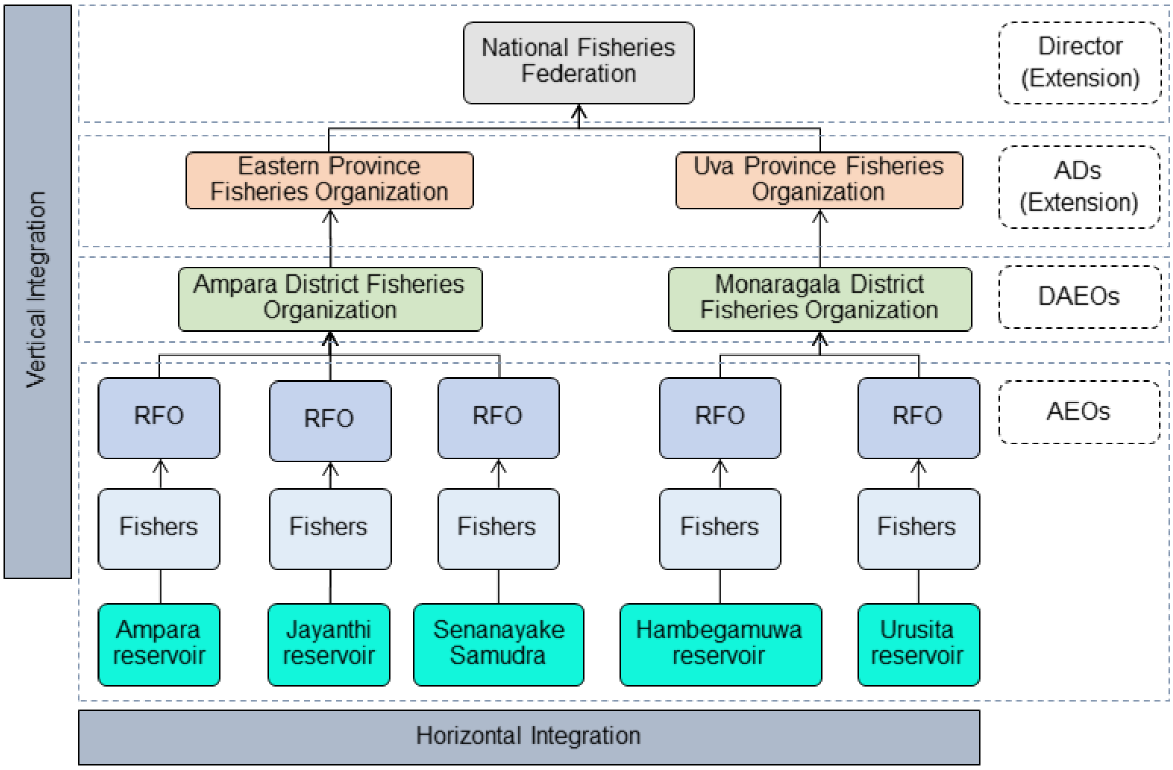

Fig. 5. Multi-layer institutional structure, which links rural fisheries organisations (RFOs) between reservoirs (horizontal integration) and with fisheries organisations at the district level, provincial level and at the national level (vertical integration). The multi-layer institutional structure 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.

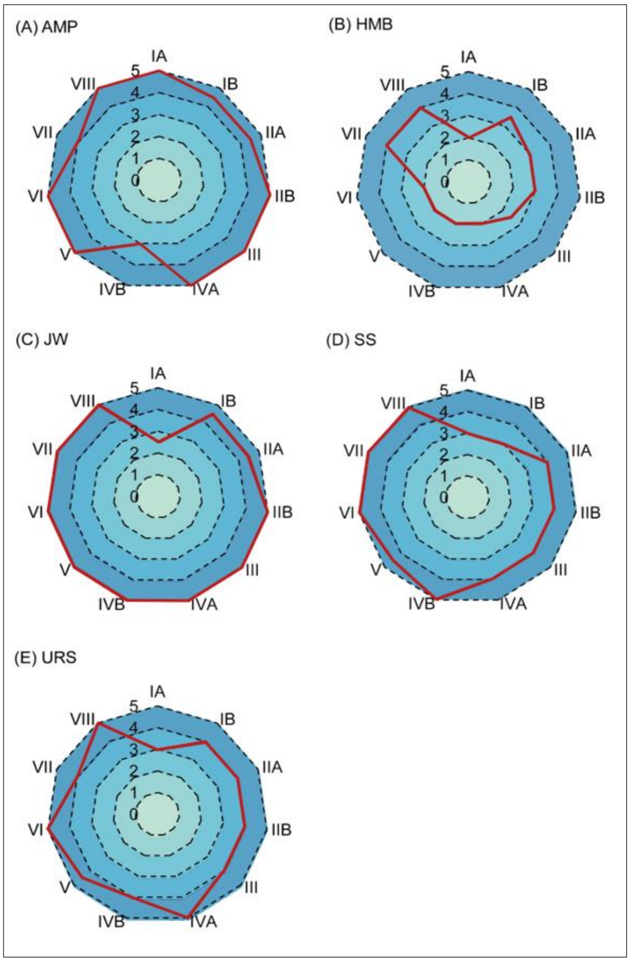

Fig. 6. Radar diagram (red solid line) for levels of compliance of institutional arrangements of RFOs in five reservoirs with eleven modified design principles (1A, 1B, 2A, 2B, 3, ...8; see Table 3 for definitions). AMP – Ampara reservoir; HMB – Hambegamuwa reservoir; JW – Jayanthi reservoir; SS – Senanayake Samudra; URS – Urusita reservoir. The axis labels are indicated in five levels (median values; broken lines) of compliance as 5- very high compliance; 4-high compliance; 3- moderate compliance; 2- slight compliance; 1- no-compliance.

The reservoir fisher communities having high compliance with components of Ostrom's design principles (Table 3), benefitted from the elevated mean annual income levels after introduction of CBF (e.g., Ampara reservoir, Jayanthi reservoir and Urusita reservoir; Fig. 7). In Hambegamuwa reservoir, where levels of compliance with design principles were considerably low (Fig. 7), mean annual income of fishers was also low. In Senanayake Samudra, although fishers had high compliance with design principles, fishers' mean annual income was comparatively low (Fig. 7), which might be due to low catch efficiency in the vast extent of reservoir and/or low fishing intensity (i.e., number of fishers per ha; Table 1). As the cost of fingerling was LKR2.00, cost of stocking varied from LKR400 per ha in Senanayake Samudra (7,793 ha), where low stocking density was adopted, to LKR9,000 per ha in Ampara reservoir (240 ha), which was intensively stocked. When compared to the value of yield, which ranged from LKR8,166 ha^{-1} yr^{-1} in Senanayake Samudra to LKR90,742 ha^{-1} yr^{-1} in Ampara reservoir (Pushpalatha, 2020), there had been an obvious profit for RFOs through CBF strategies.

Discussion

In the recent years, there has been a paradigm shift in research, management and policies of fisheries in developing countries around the world from a primary concern of fish stocks to include broader issues relating to poverty alleviation and the livelihoods, wellbeing and capabilities of small-scale fishing communities (Neiland and Bènè, 2004). Hence, socio-economic characteristics of resource users remain unprecedented to understand their strengths for contributing to management decision making. For example, there is a widely held view that low literacy rates and widespread educational disadvantage in small-scale fishing communities are a barrier to many aspects of development, as they limit people's ability to diversify and improve their business activities, and to receive benefit from extension advice (Maddox, 2007). In the South Asian context, the literacy rates within fishing communities are reported to be low compared with other occupational groups (George and Domi, 2002). From the present study, however, it was revealed that the majority of the members of RFAs of five reservoirs had received at least primary education. The dominant age group of all five fisher communities was 31-50 years, and many of them had over 5 years of experience in fishing. All these socio-demographic characteristics of five fisher communities have positive impacts on the effective implementation of CBF in reservoirs. Because most fishers were residing close to the fish landing site of the reservoir (<5 km), easy access to landing sites in five reservoirs is facilitated, where fishing crafts are kept under lock and key during non-fishing time of the day.

CBF development in perennial reservoirs is remarkably different from such strategies in non-perennial reservoirs in that almost entire biomass is harvested during low water levels of the reservoir (Amarasinghe, 1998). In perennial reservoirs, various biological factor such as growth, reproduction and mortality and fisheries factors such as catch efficiencies of fishing gear are responsible for CBF yields that are essentially formed by part of the biomass exploited through fishing (Gulland, 1983; Amarasinghe, 1998). Recent attempts to develop CBF in perennial reservoirs of Sri Lanka have given promising results in terms of increased fisheries production (Pushpalatha and Chandrasoma, 2010), enhanced income for fishers and their improved standards of living (Pushpalatha et al., 2017). From the present analysis, it was evident that the introduction of CBF in the five reservoirs studied has resulted in an apparent increase in fish production and fishers' income derived from the fishery. Of the species groups stocked, however, Nile tilapia (*O. niloticus*) remained the dominant species in the landings. This might be due to its self-propagation ability in reservoir habitats, in contrast to exotic carps and freshwater prawn (*M. rosenbergii*), which do not establish breeding populations in Sri Lankan reservoirs. Some unconfirmed evidence suggests, however, that breeding populations of Indian major carps have established in some reservoirs such as Udawalawe reservoir (6°25′55″N; 80°51′02″E) in the Walawe river basin of Sri Lanka (Deepananda et al., 2014). Nevertheless, such trends were not evident in the five reservoirs selected for the present study.

Despite the dominance of *O. niloticus* in the landings, there has been a striking diversification of species composition after the introduction of CBF because stocked fish species and freshwater prawn, which have not established breeding populations also contributed to the landings. This was due to the reason that RFOs regularly stocked fingerlings/post-larvae of these species groups. Although stocking is not the sole mechanism for improvement of a fishery, this strategy is often adopted as a means of increasing fish production per unit area in inland waters perhaps because of its perceived simplicity (Welcomme and Bartley, 1998a, 1998b; Cowx et al., 2015). In small village reservoirs of Sri Lanka, the introduction of culture enhanced capture fisheries or culture-based fisheries has made a significant positive impact in the country's inland fish production (Amarasinghe and Nguyen, 2009).

The present study indicated an increased fish production in the five perennial reservoirs due to introduction of CBF, substantiating the findings of Pushpalatha and Chandrasoma (2010). They showed that fisheries enhancement would be prospective through CBF in perennial reservoirs of Sri Lanka.

Many management strategies of resource-oriented approaches have, however, failed in the past as they

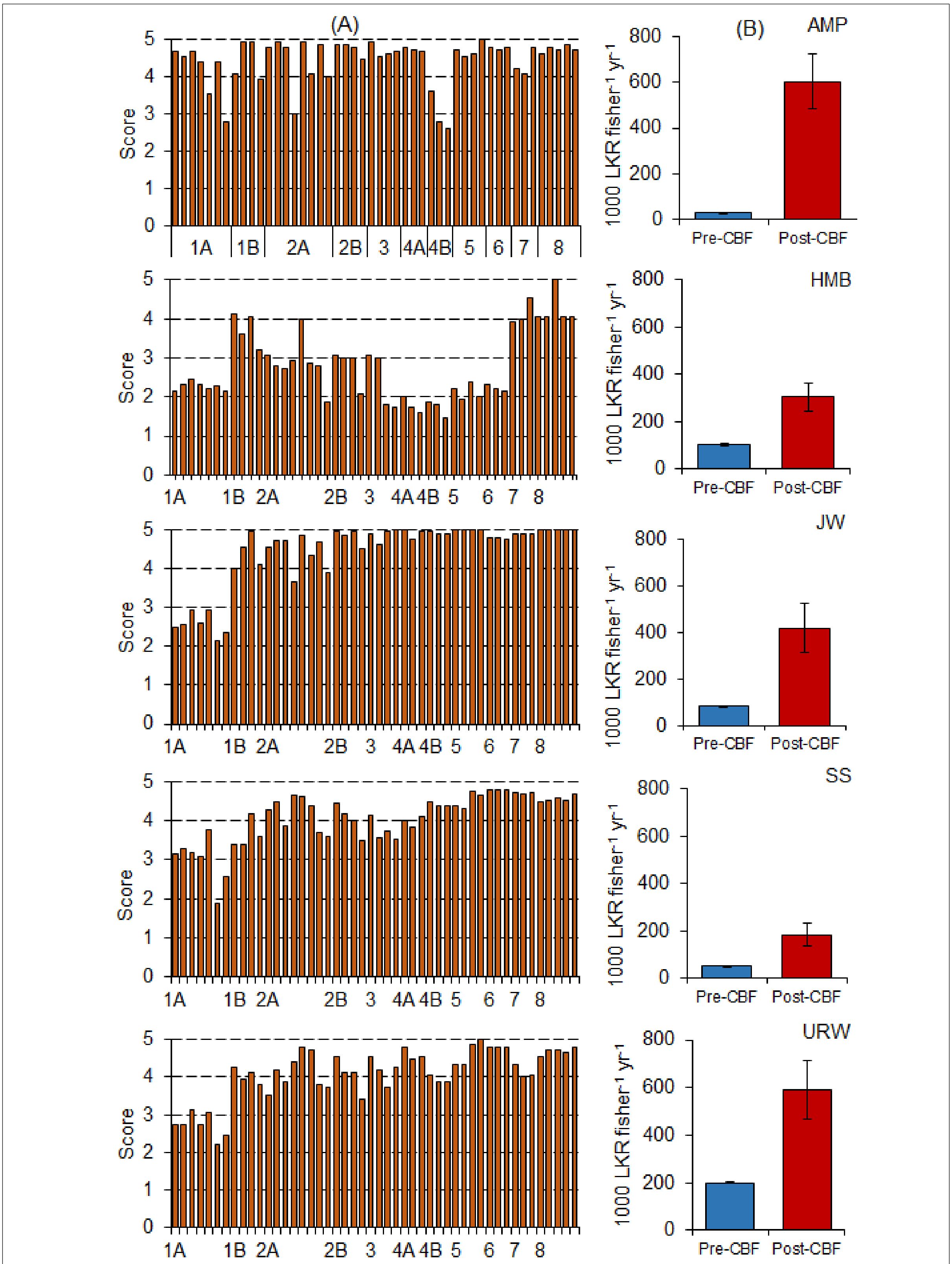

Fig. 7. (A) Levels of compliance (five levels based on Likert scale) with the components of Ostrom's design principles (as given in Table 3); and (B) mean annual income per fisher derived from the fisheries during pre-CBF and post-CBF periods in five reservoir fishing communities. AMP – Ampara reservoir; HMB – Hambegamuwa reservoir; JW – Jayanthi reservoir; SS – Senanayake Samudra; URS – Urusita reservoir.

were essentially top-down management and their command-and-control approaches have marginalised fishers in decision-making processes (Andrew et al., 2007). Also, in terms of sustainability, conventional approaches of resource management are shown to be in crisis, possibly due to the consequences of the predominant view of science, which are often isolated from society (Bocking, 2004). It is unblemished that CBF strategies in Sri Lankan reservoirs, as elsewhere in tropical Asia, can essentially be treated as socioecological systems due to the reason that community participation is an obligatory requirement for effective implementation of CBF (De Silva, 2003; Amarasinghe and Nguyen, 2009).

CBF development in reservoirs has become popular among fisher communities due to the obvious financial benefits that they gained after the introduction of CBF. In all five reservoirs studied, there have been remarkable increases of fishers' income due to introduction of CBF (Fig. 7B). Market forces associated with CBF strategies, therefore, appear to play a significant role to motivate fishers to adopt CBF as an instrument of their livelihood support. Importance of market forces for motivating fishers to adopt CBF is further evident from their action during CBF planning phases to incorporate stocking of post-larvae of freshwater prawn, *M. rosenbergii* in reservoirs. In terms of recovery rates, *M. rosenbergii* ranked the lowest in the reservoirs, but due to its prominent market value, RFOs of the five reservoirs have decided to regularly stock *M. rosenbergii*.

Fishing is essentially an economic activity having interaction between the dynamics of the economy and the dynamics of the aquatic ecosystem. The value of CBF harvest should surpass the cost of stocking and the cost of other allied activities of CBF. The exotic cichlid species, *O. niloticus* continued to be the dominant species in the landings of all five reservoirs, whose natural recruitment was supplemented by regular stocking. Net profit of CBF strategies in the five reservoirs was enriched by high yields, despite relatively low market prices of exotic carps in the harvest. The fish biomass and its supplementation through regular stocking can be considered as the natural capital, which in the time perspective, would add resource value through the dynamic aspects of fish stock related to availability, markets and biological growth (Aide, 2009).

For sustainability of CBF in reservoirs as in any other renewable resource exploitation, it is imperative that the stock should be maintained at an exploitable level. Apart from the biological perspective of fish stocks, economic aspects are also crucial for the purpose. In small-scale fisheries, management failures are mainly driven by market forces (Rhodes et al., 2011; Frawley et al., 2019), and as such, economic aspects associated with CBF should be given due consideration in the management options.

In the present study, the organisation of RFOs for resource management across the reservoirs varied considerably. When Ostrom's modified design principles were used as benchmarks for evaluating institutional robustness of RFOs for making decisions on resource management, the poorest internal arrangements for rational exploitation and management of fishery resources were evident from Hambegamuwa reservoir (Figs 5A and 6). The robust institutional arrangements in terms of design principles were in Ampara reservoir (Figs 6 and 7A) and other three reservoirs were of intermediate character. However, the 7th and 8th design principles, which were essentially related to extension mechanisms of the fisheries and aquaculture authorities were at the 'very prominently existing' compliance level. As mentioned above, these two design principles are related to 'externalities' because they did not arise from the communities. This study, therefore, indicates that the two design principles that are treated as 'externalities' are not sufficient to ensure sustainability of CBF. The remaining design principles, which can essentially be treated as 'internalities' for CBF management, are therefore crucial for strengthening institutional arrangements in RFOs for the sustainability of CBF.

The Ostrom's design principles (Ostrom, 1990; Cox et al., 2010) are generally applied to evaluate general institutional regularities that can be observed among common pool resource systems. Such systems were sustained over a long period of time such as small-scale fisheries (Ostrom, 2009; Arias Schreiber and Halliday, 2013). The present study, however, showed that these design principles could be adopted to evaluate institutional robustness of the five RFOs, which were successful in the implementation of CBF in reservoirs to alleviate individual income derived from the fisheries.

The five RFOs exhibited different levels of compliance with design principles related to 'internalities' for CBF management, which require stronger extension mechanisms to empower fisher communities for decision making in management planning. The diverse levels of compliance with design principles across the RFOs are due to differences of the contribution of community leaders in the decision-making process. Local leadership is vital for the effective functioning of local organisations in the rural sector. But individuals who are willing to take up leadership roles are often mired by poverty, low educational levels, or poor social cohesion among community members (Sutton and Rudd, 2016). It is also a fact that motivation to take up leadership in a community group can either be altruistic or oriented toward self-enhancement. In the RFO of Hambegamuwa reservoir, poor social cohesion coupled with inadequate leadership, appears to be the reason for low levels of involvement of its members in the decision-making process of CBF management. It is, therefore, possible to improve leadership qualities of members of RFOs through effective extension services. Empowering resource users is known to be one of the crucial factors for meaningful co-management of small-scale fisheries (Brown et al., 2005).

Apart from Sri Lanka, there are several countries in Asia where small water bodies are present, some of which are already utilised for CBF development. For example, in Bangladesh (Hasan and Middendrop, 1998), Cambodia (Song et al., 2013; De Silva and Song, 2015), India (Sugunan and Katiha, 2004), Lao PDR (Phomsouvanh et al., 2015) and Vietnam (Nguyen et al., 2001), successful attempts have been made to develop CBF in ubiquitous small water bodies. In all these countries and elsewhere, CBF development is essentially a rural economic activity, and as such, institutional robustness of rural social groups is needed to be identified and respected to ensure the sustainability of CBF strategies. The importance of social aspects in CBF management in Sri Lanka was highlighted by Kularatne et al. (2009), Amarasinghe and Nguyen (2009) and Amarasinghe and Wijenayake (2015).

Conclusion

In the five reservoirs investigated, fish production has considerably increased after the introduction of CBF. There were encouraging socio-economic characteristics of fisher communities, which supported the adoption of community-based fisheries management options. They include age structure dominated by plebeian members having a preference for self-employment, high literacy rate supporting better participation in the decision-making process of resource management and worthy experience in fishing. The major driving force for members of RFOs in the five reservoirs to adopt CBF was due to the success of enhancing fishers' income. Members of RFOs have therefore made several institutional arrangements for managing CBF.

There was a striking change of species composition of the landings from virtually mono-specific fisheries dominating by *O. niloticus* to diverse species with significant portions of exotic carps. This has resulted in increased income for fishers, and made CBF popular among their communities. When the robustness of institutional arrangements in the five RFOs was evaluated using Ostrom's modified design principles (Cox et al., 2010) as a benchmark, it was evident that mean annual income of fishers derived from CBF was remarkably higher in Ampara reservoir, Jayanthi reservoir, Senanayake Samudra and Urusita reservoir. In these reservoirs, fisher communities had high compliance with design principles. In Hambegamuwa reservoir however, where the levels of compliance with design principles were rather poor, increase of fishers' CBF income was marginal. Effective fisheries extension mechanisms to empower fisher communities in the decision-making process of CBF management and to improve leadership qualities of fishers are therefore desired for ensuring the sustainability of CBF in reservoirs.

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