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Local Ecological Knowledge in Community-Based Management as Smart Management Options for Coastal Fisheries: A Review of the Sri Lanka Context

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Even though small-scale fisheries throughout the globe are based on local ecological knowledge (LEK), it is often not involved in the decision-making process. An attempt is made to review the potential of using LEK of traditional coastal fisher communities in Sri Lanka and self-governing institutions in managing fisheries commons sustainably. Fisheries management in Sri Lanka is mainly a top-down system through the state legislation, while many fishing communities still maintain some level of informal or traditional management systems. The traditional community-based fisheries management (CBFM) systems in coastal fisheries of Sri Lanka, which are essentially based on LEK of fisher communities, hold long history from several decades to centuries. In active fisheries, *i.e.*, beach seining and stilt fishing, traditional fishers accurately use LEK for day-to-day fishing activities for predicting harvests before operating the fishing gear. Long-term viability of beach seining, stilt fishing, brush park fishing, kraal fishing and stake net fishing systems in coastal fisheries of Sri Lanka confirms that CBFM systems in coastal fisheries provide better economic and livelihood standards for fisher communities. Empirical studies confirm that the coastal fisher communities manage fisheries commons through self-governing institutions through which the property rights are vested to fisher communities averting the common pool dilemma. This synthesis confirms that fishers' LEK is an integral part of CBFM systems of coastal fisheries, which strengthen the collective action of the fishers, and is invaluable for sustaining the CBFM systems for the long run. It is clear that CBFM systems governed through robust customary institutions and evoked by traditional authority and LEK of fishers are vital for the sustainability of the coastal fisheries. In conclusion, CBFM systems and LEK can be hailed as smart management options, which can be an alternative to centralized fisheries management in Sri Lanka.

(***Key words:*** *Commons, Property rights, Self-governing institutions, Small-scale fisheries, Sustainability, Traditional fishing methods*)

Modern human has been exploiting marine resources since they emerged as fishable species. Since then, they have thrived and strongly affected particularly marine coastal species and ecosystems (Watson and Pauly, 2013), especially in the last 150 years through the industrialization of fisheries. World fisheries, either large-scale industrial fisheries or small-scale fisheries are complex social-ecological systems (Pittman *et al*., 2019). Small-scale fisheries characterized by relatively low levels of capitalization and carried out by a small group of fishers with small-scale vessels in coastal waters, impose lesser impact on ecological systems when managed sustainably and thus have a crucial role in averting overexploitation in the marine environment over the globe (Lowitt *et al*., 2020). Conspicuously, the small-scale fisheries sector, found mostly in developing countries (Pittman *et al*., 2019) accounts for around half of global fish catches, provides food and livelihoods for hundreds of millions of people, and employs more than 90% of the 39 million capture fishers and fish workers around the world (Westlund and Zelasney, 2019; Kalikoski and Franz, 2014). In the marine fisheries sector, there is a rapid adoption of new technologies in a context of finite resource availability, and consequently, resource management has become key to fisheries management that is often assumed as a government responsibility (Gordon, 1954). Nevertheless, the capacity of government agencies to regulate the fishery resources in widely scattered fishing grounds is distinctly limited. Considering continuous degradation of marine and coastal fisheries, states/governments have adopted some directives for fisheries management,

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but with limited success. The common notion is that the failure of this form of management is very much due to the centralized top-down approach that focuses on objectives relating to fishery resources and based exclusively on formal biological science (Viswanathan *et al*., 2003) and mostly disregards the experiences and knowledge of fishers (Degnbol, 2003).

Even though small-scale fisheries throughout the globe are based on local ecological knowledge (LEK) of fishers (Grant and Berkes, 2007), LEK is often not involved in the decision-making process (Westlund and Zelasney, 2019). Analytical fisheries science tends to consider LEK as "anecdotal", and in most parts of the world and is not included in the development of management plans (Mackinson, 2001; Haggan *et al*., 2007) or harvest strategies (Dowling *et al*., 2015). Local ecological knowledge, also referred to as indigenous knowledge, traditional knowledge/traditional ecological knowledge or fisher knowledge, is essentially a system of experiential knowledge gained by fishers through continuous observation and trial and error, a kind of pre-scientific adaptive management (Berkes *et al*., 2000). Being a way of acquiring knowledge, it can be treated as similar to modern science because it is based on the accumulation of observations (Berkes *et al*., 2000). LEK may be based on the experience of many generations and is transmitted culturally among members of a community (Huntington, 1998; Johannes *et al*., 2000). It is inseparable from cultural values, spiritual beliefs and customary legal systems of local communities. Thus, it is viewed as the intellectual property of the entire community and does not belong to any single individual within the community (Pauly *et al*., 2002). Nevertheless, fishers' LEK has been increasingly recognized as an appropriate source of information that can complement fishery data collected through conventional approaches (Saenz-Arroyo *et al*., 2005) to improve the management of artisanal fisheries (Zukowski *et al*., 2011; Leite and Gasalla, 2013) especially in tropical areas (Silvano and Valbo-Jorgensen, 2008; Butler *et al*., 2012; Espinoza-Tenorio *et al*., 2013). Several studies have confirmed the existence of an "expertise knowledge base" in traditional fishers, especially in tropical developing countries where scientific data are deficient (Begossi, 2008).

Fisheries systems involve an inherent interplay between people and the natural world, which has made the challenges of maintaining a healthy resource base fundamental to fisheries (Charles, 1994). Modern laws and regulations that have been put in place to manage fisheries are not well received by resource users and lead to violation of imposed regulations by fishers whether they are industrial, medium-scale or individuals fishing for their daily income and consumption (Kuperan and Sutinen, 1998). Therefore, devolution of fishery management and allocation decisions to the local level may be more effective than top-down management, which distant and understaffed government agencies can provide. One of the promising alternative approaches to manage small-scale fisheries is community-based fisheries management (CBFM), since it increases the commitment of fishers to the system and allows the resource to flourish (Berkes *et al*., 2000; McConney *et al*., 2000). CBFM has been widely promoted as a strategy to conserve biodiversity and enhance the rural livelihood, and thereby improve the resource base, benefitting local fishers (Ostrom, 1990). Advantages of local management of fishery resources have been well documented in many parts of the world and scattered and fragmented literature reveals that traditional community-based marine resource management systems exist widely in the Asia-Pacific region extending from Japan to Sri Lanka in managing the fisheries (Ruddle, 1994). CBFM systems offer opportunities to allocate resource rights and benefits to the appropriators in a more sustainable manner.

Historically, fisheries management at the local level are well established and the best means to achieve sustainability is seen to be through small-scale CBFM systems (Charles, 1994). Studies that closely worked with coastal communities unfolded the existence of robust CBFM systems in coastal fisheries in Sri Lanka. The objective of the present study is to introduce LEK of fishers and CBFM therein as a smart management option for coastal fisheries in Sri Lanka. Considering theoretical perspectives, the present paper describes the commons, property rights and commons dilemma and elaborate characteristics of CBFM systems. More importantly, this paper includes the comprehensive review of Alexander(1977); Atapattu (1987); Amarasinghe *et al*. (1997); Deepananda *et al*. (2015, 2016a, 2016b) and Gammanpila *et al*. (2019) that have empirically ascertained the CBFM systems in coastal fisheries of Sri Lanka, to elaborate how fishers use LEK and how CBFM systems support to sustain the small-

scale coastal fisheries of Sri Lanka. In this context, an attempt has been made to synthesize how traditional coastal fisher communities in Sri Lanka employ LEK and self-governing institutions in managing fisheries commons sustainably. Moreover, a systematic search strategy, aiming at identifying use of local ecological knowledge and self-governing institutions in coastal fisheries was employed to retrieve the supportive literature.

Commons

Commons is a general term that refers to shared resources in which each stakeholder has an equal interest. The commons can be: (1) small serving a tiny group; (2) at the community level; and (3) extended to the international and global level. Further, the commons can be either well-bounded; transboundary or without clear boundaries. Ostrom and Hess (2008) defined those commons refers to a system in which it is difficult to limit access, but one person's use does not subtract a finite quantity from another's use. Ostrom's (2008) definition is close to the concept of public goods in economics. Ostrom *et al*. (1999) used the term common pool resources (CPR) to refer to resource systems regardless of the property right involved (see the next section). CPRs include the natural and human-constructed resources in which (1) exclusion of beneficiaries through physical and institutional means is especially costly, and (2) exploitation by one user reduces resource availability for others (Ostrom *et al*., 1994). CPRs have traditionally included terrestrial and marine ecosystems that are simultaneously viewed as depletable as well as renewable (Ostrom *et al*., 1999). However, as of the paramount importance in humans and their livelihood, scholars tended to explore and classify CPR. Consequently, for the first time in 1995, the International Association for Study of Common Property (IASCP) expanded its focus to non-traditional CPR with its conference theme "Reinventing the Commons." (Hess, 2008). It is important to understand the distinctions between "Open access" and "common property" and that the two terms should not be used synonymously (Stevenson, 1991; Agrawal, 2001). Stevenson (1991) described the following characteristics that define the form of resource ownership in common property.

1. The resource unit has bounds that are well defined by physical, biological, and social parameters.
2. There is a well-delineated group of users, who are distinct from persons excluded from resource use.
3. Multiple included users participate in resource extraction.
4. Explicit or implicit well-understood rules exist among users regarding their rights and their duties to one another about resource extraction.
5. Users share joint, non-exclusive entitlement to the *in situ* or fugitive resource prior to its capture or use.
6. Users compete for the resource, and thereby impose negative externalities on one another.
7. A well-delineated group of rights holders exists, which may or may not coincide with the group of users.

New CPRs, that can evolve from institutional changes within traditional CPRs, in contrast to traditional CPRs, are often uncharted territories. Also, the new CPR does not necessarily mean that they are newly evolved or created through new technologies. These may be the resources that have been newly conceptualized as CPR. With the board interest in the topic, CPR has been broadly classified into seven categories, and CPR included earth system components (such as groundwater basins and atmosphere) as well as products of civilization (such as irrigation systems or the worldwide web) (Ostrom *et al*., 1999). Traditional CPR includes natural resources such as forests, irrigation systems, grazing lands, and fisheries resources as major components (Fig. 1). Fish is a resource that has frequently, but not exclusively been viewed as CPR by both small- and large-scale users in both traditional and modern societies (Berkes, 1985).

Property rights

Concepts related to resource systems and those concerning property right must be separated to understand commons problems clearly. A property right is an enforceable authority to undertake particular actions in a specific domain (Commons, 1968). Within the property regime, different kinds of rights define actions that individuals can take in relation to other individuals regarding "something". If one individual

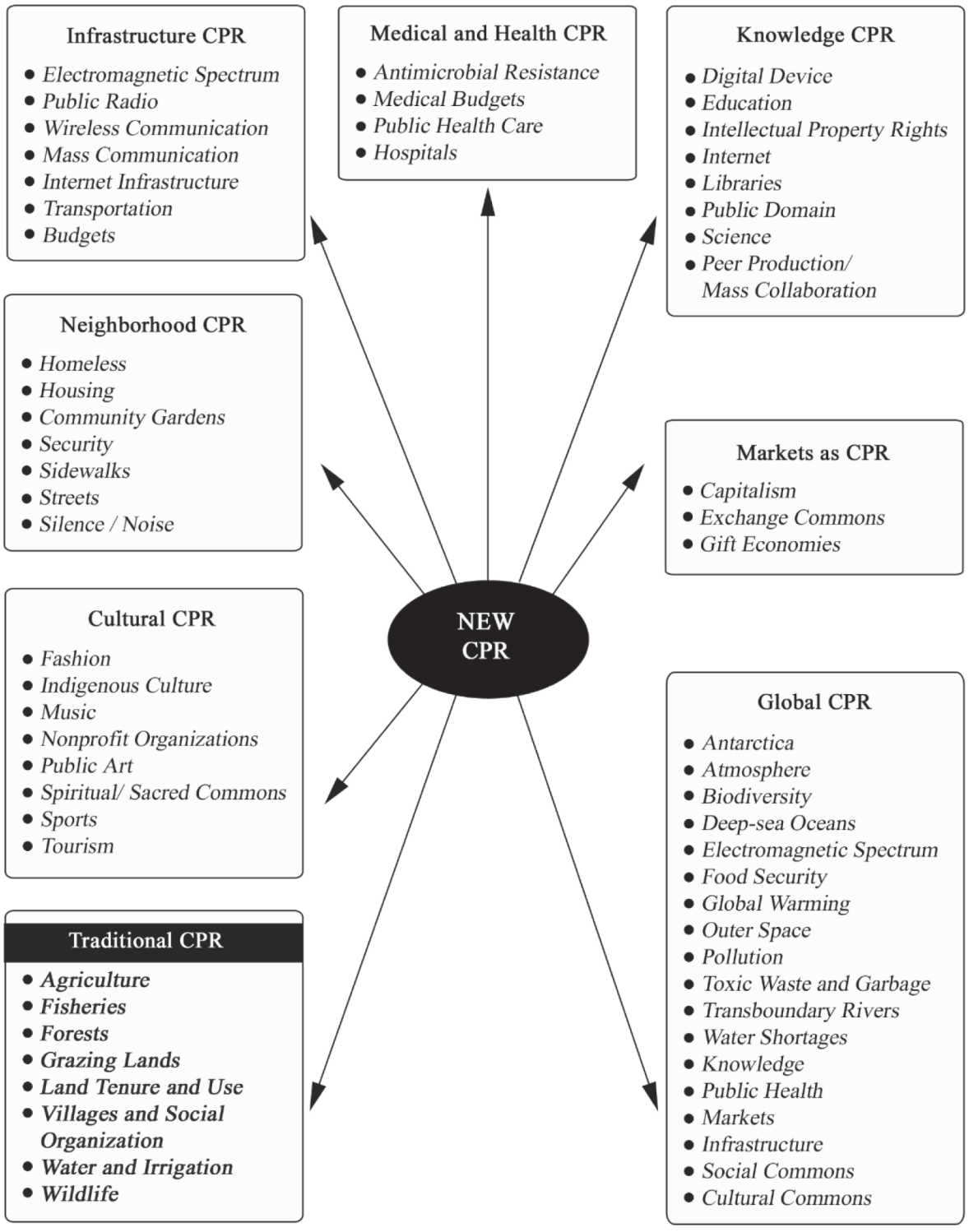

Fig. 1. *Classification of common-pool resources (after Hess, 2008). Traditional CPRs are highlighted*

has a right, someone else has a commensurate duty to observe that right. Schlager and Ostrom (1992) have identified five major bundles of rights (Table 1) that are most relevant for the use of commons (Ostrom and Hess, 2008). These bundles of rights are independent but with respect to fisheries, are frequently held in an accumulative manner (Schlager and Ostrom, 1992).

Four broad types of property rights; (i) open access, (ii) state property, (iii) private property and (iv) common property (communal property) have been evolved or are designed in relation to CPR (Table 2), all of which but open access may, under various circumstances lead to sustainable resource use (Berkes, 2009). Common (group) property and private (individual) property regimes are used to manage the resources that grant individuals varying rights to access and use of the resource. The primary difference between these two regimes is the ease with which individual owners can buy or sell a share of a resource. State (government) property involves ownership by a national, regional or local public agency that can forbid or allow to be used by individuals. Open access resources can be exploited on a first-come, first-serve basis, as there are no personnel (individual) or groups having the capacity or legal power to restrict access, promoting a "use it or lose it" situation (Tietenberg and Lewis, 2009). When valuable CPR is left to open access, they are subjected to degradation and potential destruction (Ostrom *et al*., 1999). Empirical studies have shown that no single type of property regime works efficiently, fairly and sustainably to all CPR. A long-lasting solution to CPR problems involves two distinct elements: (1) restricting access and (2) creating incentives (usually by assigning individual rights to, or share of, the resources) for users to invest in the resource instead of overexploiting it (Ostrom *et al*., 1999).

Table 1. *Bundles of rights most relevant in using the commons (Hess and Ostrom, 2003)*

Rights	Definition
Access	The right to enter a defined physical area and enjoy non-subtractive benefits
Extraction	The right to obtain resource units or products of a resource system
Management	The right to regulate internal use patterns and transform the resource by making improvements
Exclusion	The right to determine who will have access rights and withdrawal rights, and how those rights may be transferred
Alienation	The right to sell or lease management and exclusion rights

Table 2. *Types of property rights systems used to regulate CPR (Feeny et al., 1990; Ostrom et al., 1999)*

Property rights systems	Characteristics
Open access	Absence of enforced property rights
Private (individual) property	Resource rights held by individuals (or firms) who can exclude others
State (government) property	Resource rights held by a government that can regulate or subsidize use
Common (group) property	Resource rights held by a group of users who can exclude others

Commons dilemma

Understanding what causes depletion of commons under today's complex institutional, political, scientific and economic institutions is not easy. At its core, however, is a simple explanation, one that has been known literally for ages. Aristotle (*politics ii*) noted, "those things which are owned by the greatest number of people are the least well cared for". Two economists (H. Scott Gordon and Anthony Scott) in the 1950s who modelled the choices faced in fisheries, pointed out the fundamental importance of property rights to resource stewardship and conservation. Gordon (1954) wrote, "The fish in the sea are valueless to the fishermen because there is no assurance that they will be there for him tomorrow if they are left behind today." With no incentive to leave fish in the sea, depletion naturally follows. Scott (1955) expanded upon the notion that no one will maintain a resource unless they have a residual claim to its production (*i.e*., property right in the yield of a fishery) and extended the analysis to reflect the idea that the ideal standard of comparison for fisheries management should be a sole owner who "has complete control of the asset" (the fishery) thereby eliminating the risk that anything left in the water could simply be caught by someone else.

Some millennia after Aristotle (*politics ii*), drawing primarily on the work of Gordon (1954) and Scott (1955), the same idea was neatly encapsulated by Ecologist, Garrett Hardin (1968) when he coined the phrase "the tragedy of the commons." The concept was developed by Hardin (1968) to describe the conditions that shape the degradation of resources held in "common." Despite making a semantic mistake in his use of the word "commons" (he meant open access), Hardin's basic point was that valuable resources free for taking will inevitably be depleted. Since Hardin's challenging article in Science (1968), the expression "the tragedy of the commons" has come to symbolize the degradation of the environment to be expected whenever many individuals use the scarce resources in common (open to all). Hardin's model is based on the notion that 'common property' will be degraded due to the competing interests of the individual users. Noteworthy, Hardin (1968) drew attention to two human factors that drive environmental change, *i.e.*, (1) increasing demand for natural resources and environments services, stemming from human population growth and per capita consumption of resources and (2) way in which humans organize themselves to extract the resources from the environment and eject effluents into it (Dietz *et al*., 2003). Hardin argued that rational users of commons make demands on a resource until the expected benefit of their action equals to expected cost. Because each user ignores costs imposed on others, individual decisions cumulate to a tragic overuse and potential destruction of the open access resources. The solution proposed by Hardin was either socialism or the privatisation of free enterprise (Hardin, 1968).

The starkness of Hardin's original statement has been used by many policymakers and scholars to rationalize top-down control of all commons and to paint a disempowering, pessimistic version of the human prospects (Ludwig *et al*., 1993). Thus, it is argued that solutions must be imposed on appropriators by external authorities. The tragedy of the commons theorists also acknowledges the potential for state action and management as alternative arrangements for promoting conservation of the resource (Dietz *et al*., 2003). In general, the tragedy of the commons was built on the premise that only private control or state management can avert ecological devastation and the tragedy (Hardin, 1968). Overexploitation in modern fisheries is often referred to as a manifestation of the "tragedy of the commons" which is unfortunately institutionalized by the authorities responsible for managing many fisheries worldwide.

Hardin's (1968) famous essay, the expression "the tragedy of the commons" inspired a generation of scientists as the only way in which commons were conceptualized until the 1980s (Dietz *et al*., 2003; Berkes, 2009). Many people agreed with Hardin's metaphor that the users of commons are caught in an inevitable process that paves the way to destruct the very resource on which they depend. Nevertheless, a scientist who studied in Cree Indian village of Chisasibi, James Bay in eastern Sub-Arctic Canada in the 1970s, had identified that Hardin's model did not fit for communities self-governing their commons, contradicting the predictions of the "tragedy" (Platt, 1973; Berkes, 2009). Since then, Hardin's theory was aptly criticized as an oversimplification of the context (Feeny *et al*., 1990), which was twofold: (1) he claimed that only two state-established institutional arrangements (private property and state property) could sustain commons over the long run; and (2) he presumed that resource users were trapped in a commons' dilemma, and unable to create solutions (Platt, 1973; Costanza, 1987). The article entitled, "Revisiting the commons: Local lessons, Global challenges" authored by Ostrom *et al*. (1999) emphasized that more solutions exist than Hardin proposed. In par with the negative prognosis, commons theory underwent major transformations in the concept that many communities were successful against threats of resource degradation by maintaining self-governing institutions (Dietz *et al*., 2003).

Characteristics of CBFM systems

CBFM refers to a management system within which fishers responsibly exercise primarily for stewardship and management, taking part in decision making on all aspects of management such as access, compliance, harvesting, marketing and research. Sustainable resource use is the key objective of the CBFM systems (Ruddle, 1994). Self-governing CBFM systems are very rich in Asia-Pacific region and also occur in the Caribbean, South America, Africa and the Middle East. They are not restricted to developing countries, and first nations in North America, Australia and New Zealand, as well as Japan and several countries in Europe (Ruddle, 1994).

In CBFM systems, resource territories, as well as rights and duties of appropriators and non-appropriators are well defined. Rules that reflect the local governing structure can be visible. Ruddle (1994) has documented five principal organizational characteristics (1) authority, (2) rights, (3) rules, (4) monitoring, accountability and enforcement and (5) sanctions for traditional CBFM systems in marine resource management, each of which consists of several types/categories that may overlap in some systems (Fig. 2). Traditional authority implements sanctions and punishments for infringement of regulations controls the system. Resource control and management are vested to the traditional authority, which varies in type in different CBFM systems. Use rights to the property are protected as well as regulated by customary laws and practices to resist resource exploitation. Rights that may be exclusive, primary or secondary define the resource users' legitimately and impose sanctions against violating rights. Rules in CBFM systems give substrate and structure to property rights by defining how rights are to be exercised. Even though fishers have the rights, their activities are governed by basic rules and operational rules in CBFM system. Basic rules define the geographical areas in which rights apply, while operational rules govern fishing behaviour, gear externalities, conservation practices, and distribution of cost and benefits within the community. Rights are meaningful when monitoring comply with rules and sanctions. The community itself does monitoring, accountability and enforcements in CBFM systems. Sanctions are invoked for the infringements of rights and breaking/ignoring locally formulated rules, governing the fisheries commons (Ruddle, 1994).

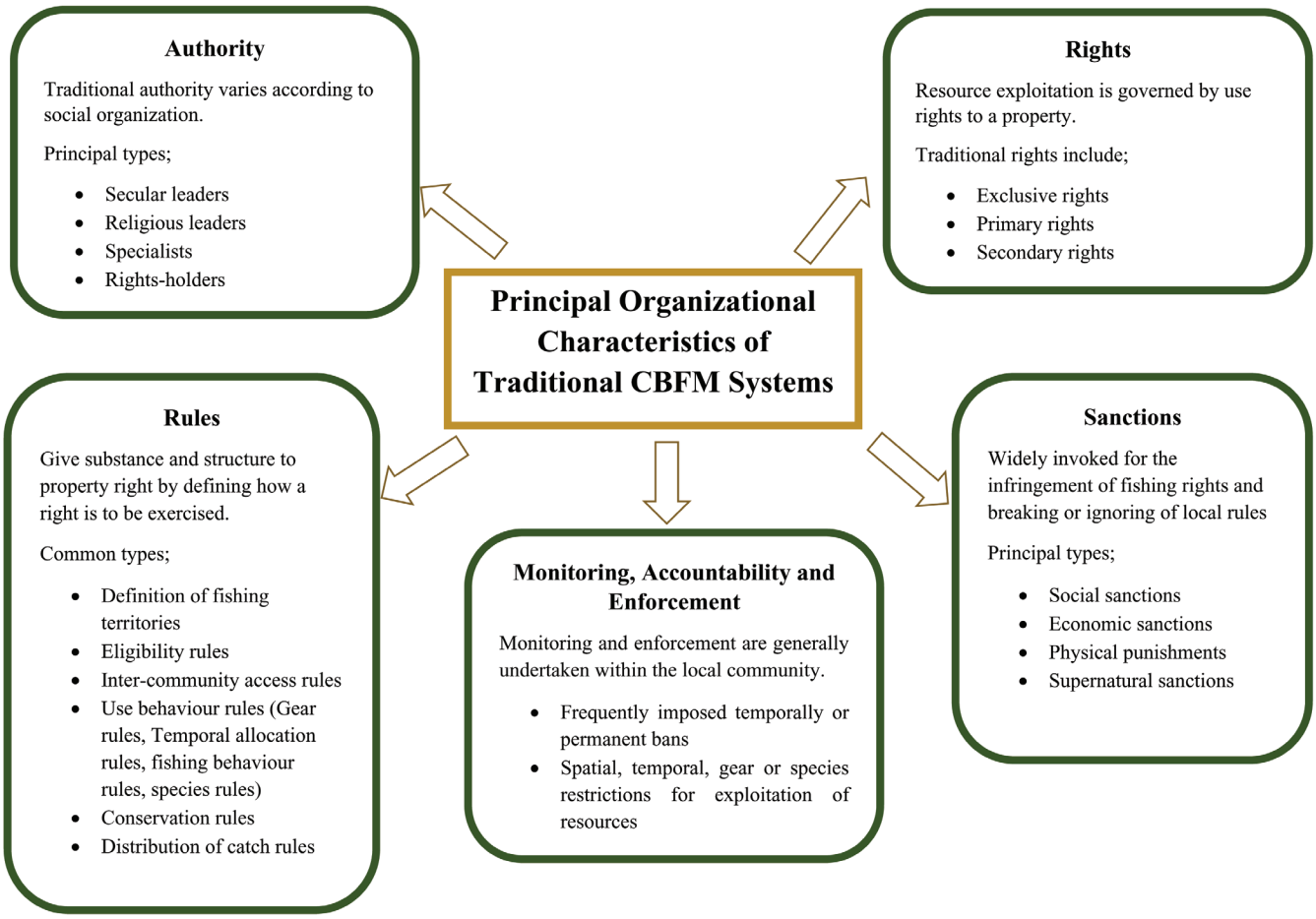

Fig. 2. *The types/categories in the five principal organizational characteristics of traditional CBFM systems in marine resource management*

Asian scenario

Small-scale fisheries in Asia that are characterized by diversity of gears, targeting diversity of species and ecosystems are well suited for CBFM systems (Pomeroy, 2012). Coastal communities in Asia depend on diverse ecosystems for their livelihood through fisheries, which are characterized by an assortment of self-governing institutions. Initiatives in CBFM systems in coastal fisheries in Asia have a long history. The existence of traditional CBFM systems in Bangladesh is reported by Ruddle (1994) and scattered literature confirmed that CBFM systems are widely spread in India (Lobe and Berkes, 2004). Studying three small fishing communities, Suryanarayana (1977) has provided the outline of the CBFM systems in India. In south India and Sri Lanka, CBFM systems have survived and evolved for at least three centuries (Lobe and Berkes, 2004), and several studies have documented customary fishing rights in coastal fisheries of Sri Lanka (Alexander, 1977; Amarasinghe *et al*., 1997; Deepananda *et al*., 2015, 2016a, 2016b; Gammanpila *et al*., 2019). Studies have confirmed that CBFM systems in Indonesia have long and effective history. Being an archipelagic state, the Philippines is rich in traditional fishery systems. Fijians are traditional inshore fishers in Asia, and women do routine fishing activities, while traditional owners retain their exclusive fishing rights (Ruddle, 1994).

Sri Lanka context

Fisheries management in Sri Lanka is mainly top-down management through the state legislation, while many fishing communities still maintain some level of informal or traditional management systems. Centralized fisheries management is characterized by having a national policy that all marine waters are state property, to be managed centrally, through the provincial, regional, and village offices of the central government, for the benefit of the entire nation (Ruddle, 1993). Traditional fisher communities successfully manage the fisheries commons through self-governing institutions, and several customary fishing rights have been unfolded in small-scale coastal fisheries. Resource depletion due to overexploitation is not evident in CBFM systems in which exclusion and subtractability problems are addressed by devising collective action (Berkes, 1985; Kurien, 1995; Johnson, 2001). The ability of the traditional community to limit the access of outsiders and self-regulate its harvest is the key in this context. Beach seine fisheries in southern and north-western coasts (Alexander, 1977; Deepananda *et al*., 2015, 2016a), stilt fisheries in southern coast (Deepananda *et al*., 2016b), brush park fisheries in Negombo lagoon (Gammanpila *et al*., 2019), kraal fisheries in Madu Ganga (Atapattu, 1987), and stake net fisheries in Negombo lagoon (Atapattu, 1987; Amarasinghe *et al*., 1997) are the examples for CBFM systems in coastal fisheries of Sri Lanka.

Beach seining in Sri Lanka has a long history and fishers were using small beach seines at least a century earlier. The earliest record of beach seining in Sri Lanka dates back to the 19th century (Pearson, 1922). Modern large beach seine locally known as "madela" has been introduced by migrant fishers from the Madras coast around 1860 (Alexander, 1977). Beach seining was considered as the backbone of the marine fishery industry in Sri Lanka and was the single most important contributor to coastal fisheries in the early days (Samaranayake, 2003). Harvest of beach seine fisheries consists of almost all fish species recorded from the coastal waters of Sri Lanka. Stilt fishing is a unique method confined to southern Sri Lanka from Galle to Matara. Stilt fishers sitting on a crossbar called petta tied to a vertical pole of 3-4 m long, carrying out rod and line fishing is a Sri Lankan icon. Stilt fishery exists for more than 60 years and is considered an important part of the southern coastal economy. Stilt fishers use fisher made, non-baited, specific hooks made of lead, and the catch composition consists of only two species: bluestripe herring (*Herklotischthys quadrimaculatus*) and bigeye scad (*Selar crumenophthalmus*). Brush parks, piles of branches of mangrove leaves placed in shallow waters are found in Negombo lagoon. Fish attracted to brush parks are harvested after surrounding the brush park by a net held in place by wooden poles and removing mangrove branches completely. Harvest of brush park fishery mainly consists of finfish species. Fish kraals (Jakotu) constructed by a vertical rattan or bamboo strip barrier leading into several traps are operated in lagoons and estuaries in the western and southern coastal area of the country. The history of fish kraals goes back to the 1910 (Atapattu, 1987). The catch mainly consists of shrimps and fish. Stakenet (kattu del), a special fyke net having cod end, body and two wings are operated by traditional fisher communities in Negombo and Chilaw

lagoons. The history of the stakenet fishery is extended at least back to the 18th century (Atapattu, 1987). Target species of stake net fishery are sub-adults of penaeid shrimp, other crustaceans like crabs, and finfish species.

These traditional CBFM systems in coastal fisheries of Sri Lanka hold traditional management practices through customary institutions that are not clearly visible unless the mode of the fishery is closely investigated. Long-term viability of beach seining, stilt fishing, brush park fishing, kraal fishing and stake net fishing systems in coastal fisheries of Sri Lanka confirms that CBFM systems in coastal fisheries provide better economic and livelihood standards for fisher communities. Institutional architecture in each CBFM systems is comparatively summarized in Table 3. This was performed through the lenses of principal organizational characteristics of the traditional CBFM system proposed by the Ruddle (1994), reviewing studied carried out by Atapattu (1987), Amarasinghe *et al*. (1997), Deepananda *et al*. (2015, 2016a, 2016b) and Gammanpila *et al*. (2019). This comparison confirms that CBFM systems in Sri Lanka have ensured greater security of access and cooperation leading to enhanced sustainability of the resource, more equitable distribution of benefits, improved conflict resolution among fishers, enhancing the status of fishers in relation to other stakeholders, sharing of information between appropriators, and higher levels of voluntary compliance, as stated by Pinkerton (1989). Economic benefits gained from the resource base is relatively high and sustainable in five traditional CBFM systems comparatively reviewed, and livelihood standards of fishers are better than other fishers, engaged in fishing activities in centralized coastal fisheries management systems (Atapattu, 1987; Deepananda *et al*., 2015). For this reason, there were disputes in stilt fishery, kraal fishery and stake net fishery in the early days, and for conflict resolution, fisheries authorities imposed and implemented regulations on the kraal fishery in 1951 and for the stake net fishery in 1958. Also, the demarcation of beach seine sites (*madel padu*) was made through a government gazette in 1985. Also, Gammanpila *et al*., (2019) have proposed to implement regulations for brush park fisheries to avoid any future disputes between appropriators and non-appropriators. For higher economic benefits and better livelihood standards of fishers, CBFM systems need to be strengthened to ensure collective actions and more adherence to the institutions, which govern the fisheries commons. The present synthesis empirically confirmed that CBFM systems in coastal fisheries are smart management options for the sustainability of small-scale fisheries in Sri Lanka.

Table3. *Characteristics of five CBFM systems in coastal fisheries of Sri Lanka through the lenses of principal organizational characteristics (Ruddle, 1994)*

Principal Organizational Characteristics	Beach Seine fishery (Deepananda *et al*., 2015; Gunawardena and Amarasinghe, 2016)	Stilt fishery (Deepananda *et al*., 2016)	Brush park fishery (Gammanpila *et al*., 2019)	Kraals (Jakottu) fishery (Atapattu, 1987)	Stake net (Kattudel) fishery (Amarasinghe *et al*., 1997; Atapattu, 1987)
Authority	Beach seine fisher society (madel samithi), a unity formed by owners and shareholders of beach seines	Stiltfisher society (ritipanna deevara samithi), a unity formed by owners and shareholders of stiltfisher community	Brush park fisher organization, which is weak and inseparable from fisher society of the estuary	Kraal fishers belongs to 10 villages. Since 1935, licencing authorities were also added, including Ambalangoda V.C., Kosgoda V.C., Ministry of Fisheries.	Stake net fisher association, formed by members of Rural Fishing Societies (RFS), supervised by Roman Catholic Church.

Rights	Residential proximity rights to fishing territory (madel padu). Fishing rights exist as: (i) exclusive right; (ii) primary right, and (iii) secondary rights.	Residential proximity rights to fishing territory (renda pola). Fishing rights exist as: (i) exclusive right; (ii) primary right, and (iii) secondary right	Close vicinity to homesteads of fishers hold user rights. Fishing rights exist asprimary rights (passed down from father to son)	Use rights to erect and operate Kraals vested to fishers from 10 villages, who are in close proximity to Madu Ganga and Kudakalapu Ganga estuaries. Fishing rights exist as primary rights (passed down Patrilineally and Matrilineally).	Non-transferable use rights in Kattudel padu is vested to the members of four Rural Fishing Societies (RFS). Negombo (Kattudel) Fishing regulations were gazetted in 1958, and use rights vested the members of RFS now in demarcated areas. Fishing rights exist as; (i) exclusive rights, and (ii) primary rights (passed down Patrilineally, and descendants of members hold right to become new members).
Rules	Institutions governing commons includes; ● Eligibility rules (annual registration at FI office is prerequisite, showing beach seine and *madel vallum*) ● Intercommunity access rules(All right holders must agree for newcomers, but FI do only the renew the registration, limiting new comers) ● Gear rules (gear must be the traditional beach seine with *madel vallum*) ● Temporal allocation rules (enforced both	Institutions governing commons includes; ● Eligibility rules (right holders,annual registration at FI office as fishers without fishing vessels is prerequisite) ● Intercommunity access rules(any community member who acquired the necessary skills for fishing and owned the fishing pole) ● Gear rules (gear must be a rod and line with specific traditionally made non-baited hook) ● Temporal allocation	Institutions governing commons are embedded as fishing traditions includes; ● Minimum distance rule (minimum distance between two brush parks are to be 50 m) ● Location rule (install brush park in appropriate locality) ● Brush park construction rule (materials for brush park are mangrove branches) ● Spatial allocation rule (when a site is ear-marked by a fisher, others refrain from	Institutions governing commons are embedded as fishing traditions that includes; ● Kraal structure and operational rules (use traditional knowledge and materials) ● Minimum distance rule (minimum distance between two Kraals is to be 50 m) ● Atoli nets operation rule (nets are to be operated in space between two Kraals)	Institutions governing commons, implemented by RFS includes; ● Eligibility rules (Only the household headfrom each family are eligible to become a member of RFS) ● Gear rules (only traditional boat and stake nets are to be used) ● Rules for new entrants (maximum 2 persons per annum) ● Spatial allocation rules (enforce to share the *Padusamong* appropriators, and use lottery system followed

	orderly and equitable exploitation of fish resourcesup to four fishing turns per day) ● First-comer rule(applied only at the beginning of the season to start rotational sequence from that particular beach seine number) ● Fishing behaviour rules (enforced to perform customary traditions and rituals; employ six traditional fishers as crew members; usespecific division of labour; get manpower from helpers; make all shareholdersto participate in loading beach seine back to the *madel vallum*; cease beach seining on full-moon day) ● Conservation rules (by-catch such as turtles (threatened species), flat fishes and box fishes (fishes of low Commercial value) etc. immediately	rules (three fishing turns within which fishers are allowed to fish in *renda pola*) ● Fishing behaviour rules (enforcedfishers to hoist their own fishing poles in the fishing territory; followset rules; ensure that fishing pole is hoisted at night before starting fishing season or after migrating back the fish schools from fishing territories during the season; ensure that fishers are essentially required to go their own fishing poles without disturbing to the fish schools) ● Conservation rules (enforced to avoid fishing non-target species; avoids tilt fishing on full-moon day)	installing brush park in said site) ● By-catch reducing rule (release young fish back)	Regulations introduced by Government Gazette No. 10332 of 1951 includes; ● Length of the Jakottu (should not exceed 70 yards/ 64 m) ● Extreme end of Jakottu (lamps are to be lit at the extreme ends of Jakottu).	by bidding system or similar kind of method) ● Temporal allocation rules (define the date of fishing) ● Harvest distribution rules (auctioning and distribution rules are well established) ● Participation to society meetings (all must participate to AGM of the Society held March every year to win/bid/get fishing site) ● Length of the wing (wingspan length of stake net is to be 15 m)

	release back to sea) ● Cost-benefit distribution rules (distribution of cost and benefit among appropriators)	● Cost-benefit distribution rules (imposed to distribute costs and benefits among appropriators)			
Monitoring, accountability and enforcement	Appropriators themselves do monitoring, accountability and enforcement voluntarily (violation of customary rules among appropriators was negligible, and observed violations are mainly from non-appropriators through poaching with other type of gears, such as cast net, long lines etc.)	Appropriators themselves do monitoring, accountability and enforcement voluntarily (violation of customary rules among appropriators was negligible, and observed violations are mainly from non-appropriators through setting gill nets across the migratory path of fish schools).	Appropriators themselves do monitoring, accountability and enforcement voluntarily (concerns from other fishers are on obstructing navigation of fishing crafts, interfering migratory fish, increasing siltation in the estuary)	Appropriators themselves do monitoring and accountability voluntarily	Appropriators themselves do monitoring, accountability and enforcement voluntarily. After implementing regulations in 1958, FI also has monitory powers, and no one tends to breach customary rules/ regulations
Sanctions	Sanctions were widely invoked for those who infringe fishing right and break or ignore rules. Both social and economic sanctions are not rare.	Sanctions were widely invoked for those who infringe fishing right and break or ignore rules. Both social and economic sanctions are not rare.	No prominent sanctions are visible. Any minor violations are resolved through discussions within the community.	Violations are resolved within the community. Major dispute between appropriators and non-appropriators have been resolved through the regulations	Sanctions are rare after implementing the regulations. Recorded violations were punished by cash fine. Disputes are due to non-appropriators

Use of local ecological knowledge

The rich Sri Lankans legacy of LEK in natural resource management passed down verbally from generation to generation, has been well documented in ancient classical literature (De Silva, 2013). Aligned with other sectors, the fisheries sector in Sri Lanka uses LEK that has not been properly investigated and documented. Nevertheless, it is well known that LEK of fishers is useful in formulating a new biological hypothesis and informing fisheries management (Johannes *et al*., 2000; Silvano and Valbo-Jorgensen, 2008). Traditional knowledge of fishers about target fish species is the key factor to make/construct their fishing gear/method, for which fishers use traditional materials and skills immensely. Fishers in beach seining, stilt fishing, brush park, kraal fishing and stake net fishing use fascinating gears, some of which are constructed using natural materials with the aid of LEK of fishers on target species and their behaviour. The stilt fishers use a specific fishing hook (silver or black colour) made of lead (Pb), based on LEK. Fishers' knowledge base on making/ constructing fishing gears are apparent especially in fisheries of passive gear type; *viz.,* brush park, kraal and stake net fisheries, as they are designed to attract and/or

trap target species. In inactive type fisheries, fishers use LEK immensely in day-to-day fishing, which has been empirically confirmed through comprehensive studies (Deepananda *et al*., 2015, 2016a).

Traditional beach seine and stilt fishers use LEK; firstly, before the commencement of the fishing season, and then for day-to-day fishing activities throughout the fishing season. Beach seining is a seasonal fishery and fishers observe changes in physical characteristics of seawater to set the fishing date and season. Traditional fishers use several methods to confirm the arrival of fish schools and predict catch composition and potential yield arrived at the fishing territory, *madel padu*. These traditional techniques include observation of change of colour of seawater, specific current pattern in sea surface water, emergence of muddy water from the bottom, behaviour of big sea terns, behaviour of little sea terns, arrival of artificial floating objects, sniffing smell that comes from fish schools, and presence of oil layer patches over surface water. Furthermore, Deepananda *et al*. (2015) confirmed that all the traditional fishers and 4% of non-traditional fishers are specialists in predicting the species to arrive at the fishing territory. Division of labour amongst fishers in beach seining is evidence for efficient use of LEK. Deepananda *et al*. (2015) empirically confirmed that traditional fishers accurately use one or a combination of several methods to predict the catch composition and potential harvest. Authors have empirically tested the fishers' predictions before fishing operation (*ex-ante*) and confirmed the accuracy of the predictions after completion of the fishing operation (*ex-post*). Accurate predictions benefit fishers to minimize the gear damages and maximize the harvest, leading to a sustainable beach seine fishery. Stilt fishing in southern Sri Lanka is also a seasonal fishing activity, and traditional stilt fishers use LEK to accurately decide the commencement date of the fishing season. In this regard, fishers use both physical and biological factors. The former includes the changes of wave height and wave frequency in the sea and the latter includes indicator species, *i.e*., the arrival of non-target fish species, Samoan silverside (*Hypoatherina temminckii*) to fishing territory, renda pola. Throughout the fishing season which lasts over 8 months, stilt fishers use the colour changes on sea surface water (*folk oceanography*) to predict the species/species composition arrived at the fishing territory. Stilt fishers know very well the migratory behaviour and route of the target species as well as their feeding behaviour, all of which are empirically confirmed by Deepananda *et al*. (2016a). Consequently, LEK is used for averting disturbances to the migratory route of the target species and adopting appropriate measures to facilitate the continuous daily migration of target fish schools throughout the fishing season. Furthermore, fishers use their traditionally accumulated knowledge and skills to catch the high valued, big eye scad (*Selar crumenophthalmus*) to maximize the profit, by changing the fishing hook and fishing strategy, when two target fish species have arrived at the same time at the fishing territory. An experimental study (Deepananda *et al*., 2016a) carried out to ascertain the knowledge base of stilt fishers through the lenses of an expert system further confirmed that LEK of stilt fishers was accurate and precise. Customary rules are solely based on the fisher knowledge of target species and from the study of Deepananda *et al*. (2016a), it was evident that LEK of fishers was used for livelihood and sustainably managing the fishery resources. Further, a study has empirically confirmed the use of traditional fisher knowledge based on fishing activities and subsequent decision-making processes as an expert system.

Fishers' knowledge of the behaviour of target species and season/time of occurrence is used in constructing and deciding appropriate/profitable sites for deploying the passive type fishing methods, brush park, kraal and stake net fishery. In a study on brush park fishery Gammanpila *et al*. (2019), demonstrated that accumulated fisher knowledge on the behaviour of target species is used as the basis for installing brush park. The fishers are well aware of their optimized harvest using appropriate mangrove species. The way of cutting mangrove branches for establishing brush park is solely based on LEK of fishers about the regeneration of mangroves. Traditional fishers decide the suitable site for brush parks using their expert knowledge to maximize the harvest and keep the distance between two brush parks that trigger target fish to settle in brush parks. Fishers know the effect of twig density in brush parks on fish yield and, they maximize the harvest by installing brush park with low twig density ($\leq$22 kg m^{-3}) because the attraction of high valued crustaceans is higher in brush parks with low twig density. Also, brush park fishers can predict the degree of attraction

of Mugillid species to brush park by observing their swimming and schooling behaviour. Targeting high valued species, such as *Caranx* sp*., Epinephelus* sp*., Lutijanus* sp*., Lates calcarifer* and crustaceans, fishers tend to harvest the brush park within or around 35 days after installation of brush park. The period that brings high catch; *viz*., inter-monsoonal period is decided by fishers and occasional windy days, which are unfavourable for fishing are well known to fishers. Also, fishers refrain from fishing during the rainy season, during when low yield could be harvested. At par with the other passive type fishing methods, kraal fishers use LEK in constructing and operating kraals to trap the target fish species, which is based on the behaviour and temporal abundance of target species. The way of establishing kraals in estuaries is solely based on LEK aiming at maximizing the yield and profit. According to Atapattu (1987), the fishing activities of kraal fishery completely rely on LEK of traditional fishers. Similarly, fishing operations and setting stake net in the estuary is based on fisher knowledge, and fishers perform fishing activities in line with the tidal patterns and tidal flow that bring the shrimps and fish to the stake net. Stake net fishers are well aware of the migratory behaviour of the target species, and how they are caught by the net at night. Fishers use their expert knowledge to maximize the catch based on tidal flow and are aware of strong current and floods result in a low catch. Also, fishers know the best fishing site (*Padu*) that brings the highest yield. In the stake net fishery in Negombo lagoon, new entrants to the fishery are qualified to exhibit their skills to construct and fix a net using nine mangrove poles from the board of canoe, which need careful manoeuvring essentially based on the LEK (Amarasinghe *et al*., 1997).

This synthesis confirms that traditional fishers of CBFM systems in coastal fisheries of Sri Lanka use LEK for every aspect of fishing activity especially for maximizing the yield by changing harvest strategy. In CBFM systems reviewed, fishing rights exist as primary rights, which pass down patrilineally and/ or matrilineally so that CBFM systems based on LEK appear to sustain. Also, the present review supports the notion that traditional fishers have a wealth of LEK and experience about the ecology of fish, including feeding behaviour, fish migration, reproduction and temporal changes of abundance as reported elsewhere (Lavides *et al*., 2009; Silvano and Begossi, 2012; Fisher *et al*., 2015; Ramires *et al*., 2015).

Institutional sustainability

Self-governing CBFM systems are excellent examples of the complexity when social systems interact with natural systems (Cox *et al*., 2010; Fischer *et al*., 2015). Although some common attributes are shared by long-enduring CBFM systems, these are not in the form of specific institutional rules such as those propounded in literature (Cox *et al*., 2010). Nobel laureate, Elinor Ostrom (1990) drew on this work to posit a set of eight design principles that characterize the efficiency of multiple types and sets of rules managing CPR, and explained under what condition, trust and reciprocity collective action can be built and maintained for managing CPR. A substantial volume of literature has amassed con the usefulness and validity of these design principles, and Cox *et al*. (2010) re-evaluated Ostrom's design principles directly or indirectly in the context of communities that use common property arrangements to manage commons and proposed 11 modified sets of design principles. Since then, modified design principles (Cox *et al*., 2010) have been employed to ascertain the sustainability of self-governing institutions over the globe.

Institutions of beach seine and brush park fisheries assessed through modified design principles show very high to low compliance with most of the modified design principles (Deepananda *et al*., 2016b; Gammanpila *et al*., 2019), and those of stilt fisheries, kraal fisheries and stake net fisheries also appear to be having high compliance with most of the modified design principles, while having low or no compliance with some of the design principles. Evidently, in beach seine fisheries, clearly defined user and resource boundaries exist with higher compliance with modified design principles, but in the contrary, brush park fisheries do not comply with those modified design principles. The monitoring compliance is higher in beach seine and brush park fisheries. Graduated sanctions are not existing in brush park fisheries, albeit they exist in beach seine fisheries with high compliance. All design principles exist in beach seine fisheries from subtle to very high compliance, but compliance with all modified design principles does not exist in brush park fisheries (Table 4). Institutional robustness of the beach seine

Table 4. *Compliance of institutional arrangements in beach seine and brush park fisheries with modified design principles*

Modified design principle	Level of compliance	
	Beach seine fishery (Deepananda *et al*., 2016)	Brush park fishery (Gammanpila *et al*., 2019)
1A: User boundaries	High	No-compliance
1B: Resource boundaries	Very high	No-compliance
2A: Congruence with local conditions	Very high	Low
2B: Appropriation and provisions	High	Higher
3: Collective-choice arrangements	Very high	Moderate
4A: Monitoring users	Very high	Higher
4B: Monitoring the resource	High	Higher
5: Graduated sanctions	High	No-compliance
6: Conflict-resolution mechanisms	High	Low
7: Minimal recognition of rights to organize	High	Low
8: Nested enterprises	Subtle	Low

and brush park fisheries confirmed that beach seine fisheries consist of robust institutions over the brush park fisheries. Stilt, kraal and stake net fisheries are yet to be evaluated for institutional robustness.

However, the institutional architecture and subsequent regulations imply that these fisheries should exhibit institutional robustness with varying degrees of compliance with modified design principles, because without such compliance, those CBFM systems could not sustain over a long period. According to Steenbergen *et al*. (2021), programs seeking spread in participatory natural resource management, rural livelihood enhancement, participatory conservation, remote health care provision and community development, all rely on synergetic collective organization at local levels.

The small-scale fisheries sector in Sri Lanka that plays a key role in enhancing the livelihood of fishers and the economy of the country, is by and large governed by centralized management through state legislations. However, empirical studies confirm that some coastal fisher communities manage fisheries commons through self-governing institutions that vested fisher community the property right for the fisheries commons. Change of property rights from state property and/or open access to common property help fisher communities to provide solutions for the excludability and subtractability problem through customary institutions, averting commons dilemma. Empirical studies on coastal CBFM systems in Sri Lanka through the lenses of principal organizational characteristics of CBFM systems for coastal fisheries have propounded that beach seine fishery, stilt fishery, brush park fishery, kraal fishery and stake net fishery are CBFM systems in which traditional fishers exercise LEK in fishing activities. In this context, fishers precisely use LEK to decide the commencement date of the fishery in seasonal beach seine and stilt fisheries and, to make and set fishing gear and fishing methods in brush park, kraal and stake net fisheries, all of which essentially require highly skilled fishers. In active fisheries, *i.e*., beach seining and stilt fishing, traditional fishers accurately use LEK for day-to-day fishing activities in order to confirm the arrival of fish schools at fishing territory and quantify the harvest, before operating the fishing gear. In this context, fishers utilize clues from the changes of colour of sea surface water, behaviour of sea terns, and behaviour and smell of the fish schools that arrived at the fishing territory. An empirical study to ascertain the veracity of the predictions of the fishers engaged in beach seine and stilt fisheries confirm that fisher knowledge base is strong and accurate and, the decision-making process of the traditional fishers with the aid of LEK is at par with the expert system, highlighting that traditional fishers are experts in decision-making process. Accurate decision-making on the composition and quantity of fish schools arrived at fishing territory help fishers to

change their fishing strategy as well as to proceed with gear modifications. Consequently, proficient LEK in traditional fisher's community uplift community revenue through maximized harvest and minimized gear damages with least fishing efforts. Evidently, LEK of fishers on commons highly complements scientific information for efficient management and exploitation of CBFM systems in coastal fisheries of Sri Lanka. Fishers can predict the most profitable days for fishing in stake net fisheries and how and where they need to construct kraals and brush park to gain maximum profit. Further, fresh and high quality harvested fishes increases the demand from buyers and excels the profit from CBFM systems. Comparative studies reveal that the use of LEK improves the livelihood standards of fishers compared to those engaged in other fisheries, leading to socio-economic development of the community. This, however, provoked disputes between appropriators and non-appropriators that led to imposition or proposal of government regulations in kraal and stake seine or brush park fisheries.

In addition to the direct benefits, CBFM systems provide indirect benefits to the appropriators, which include minimum waste of resources, minimum economic waste and minimum depreciation cost, all of which reduce the likelihood of disputes. The institutions governing the beach seine and brush park fisheries show the existence of compliance with all design principles, amidst the customary institutions in stilt, kraal and stake net fisheries have not been evaluated with modified design principles. Nevertheless, institutional architecture should comply with the modified design principles for enduring the system in Sri Lanka. In order to empirically confirm the institutional robustness essential for sustaining the system in the long run, institutional architecture of stilt fisheries, brush park fisheries and stake net fisheries systems should be evaluated through the modified design principles. The review confirms that fishers' LEK is an integral part in CBFM systems in coastal fisheries both of which strengthen the collective action of the fishers and are inevitable for long-term sustainability for the CBFM systems. Present review indicates that CBFM systems governed through robust customary institutions evoked by traditional authority and LEK of fishers are vital for the sustainability of the coastal fisheries. Thus, LEK as an integral part of CBFM systems can be hailed as a smart and better management option alternative or supportive to the centralized fisheries management in Sri Lanka.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest. Two authors have equally contributed to the preparation of the manuscript.

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