for analyzing the cost-benefit analysis of fishways should also be developed considering the costs of construction, operation, and maintenance of the facilities; the expected increased incomes from harvests of the fishery resources; and their benefits to human health, as well as other ecosystem services that could be rendered from the improved connectivity of habitats through the fishways.

It should also be noted that a better understanding of the significant contribution of inland fishery resources on socioeconomic development could influence the direction of general development policies for aquatic systems. Specifically, a better illustration of the roles of inland fisheries in generating livelihoods and ensuring food security of people would result in sufficient consideration by authorities during the development of plans for new civil works on rivers, particularly those that concern hydropower and irrigation investments in the future.

2.1.4 Increased Production through Culture-based Fisheries and Mitigation Impacts from Aquaculture

The fisheries sector of developing countries has been seeking to take up approaches that improve environment-friendly fish production for fishery resource enhancement and/or recovery. In this regard, one of the approaches being considered is the promotion of aquaculture-based capture fisheries or culture-based fisheries (CBF) technology (De Silva, 2003; Lorenzen *et al*., 2001) that could be adopted as a form of fish resource recovery technology (Kartamihardja, 2012). Previously, CBF has been underutilized as means of increasing production from fisheries, but over time, a number of developing countries have started to recognize CBF as among the key strategies in improving food security and household economies. For example, Indonesia promotes and uses the CBF technology in its development programs related to improving fisheries production through fish restocking as well as enhancing the fishery resources (De Silva *et al*., 2015).

Culture-based fisheries in the Southeast Asian region

CBF is a form of stocking of fish that is applied in waters with fish production that is experiencing a decline or in waters with poor fish resources or when the type and stock of fish is not much or is low in diversity but has medium to high fertility. In such cases, the stocked fishes could be managed and owned individually and/or collectively by the fishers or fishers' groups, as the case may be (FAO, 2015a). Examples of great success in CBF development have been observed in small reservoirs in Sri Lanka, which has been promoting CBF since it was first introduced by Mendis and Indrasena in 1965 (De Silva *et al*., 2015). Similarly, in the case of Indonesia, after the CBF model had been implemented in small reservoirs, the fish catch from such reservoirs had significantly increased.

There are strategies for undertaking stock enhancement in lakes, reservoirs, and other inland water bodies, *e.g.* identification of suitable water bodies where fish stocks should be improved, selection of fish species to be stocked taking into consideration their biological, social, and economic aspects, and ensuring that the type of fish to be introduced must be plankton feeders and/or herbivores as the stocked fish should primarily take advantage of natural food and the planktons present in the water bodies. In addition, the development of local hatcheries to provide seeds or seedlings, establishment and promotion of regulations on fishing in stocked areas, development of co-management schemes and strengthening coordination between and among users, preparation of technical instructions for the socialization of fishers (Kartamihardja, 2015) would contribute to the sustainability of CBF. Such strategies could be adapted in other Southeast Asian countries, especially the countries that have similar conditions as those of Indonesia. However, the countries should also consider that the implementation of CBF requires institutional strengthening, clear technical guidance, well-socialized fishers, and strengthened role of seed provider institutions (Kartamihardja, 2015; Aisyah *et al*., 2019).

For centuries, Indonesia has been practicing stock enhancement and restocking of fish in inland waters as a positive fisheries management tool although the country's stock enhancement activities in the past had been technologically based and focused mainly on increasing the production of fish, resulting in limited or no demonstrated successes with respect to the impacts of the stock enhancement. Since 1999 however, the country's stock enhancement and restocking practices had been focused on the establishment of scientific evidence and included the establishment of the bio-limnological characteristics of water bodies, *e.g.* productivity and ecological niche of the water bodies, structure of fish communities, life cycle and biology of the fish stocks. In addition, fisheries co-management had been promoted in the country, focusing on the so-called local wisdom or local knowledge approach. Thus, the fish species used for stock enhancement had been closely reviewed, and the causes of successes or failures were compiled and analyzed to determine the best approach for future restocking. Nevertheless, recent successes in the country's fish stock enhancement activities have been realized through the use of species that can reproduce naturally in inland water bodies.

In Cambodia, free access to the fisheries, establishment of conservation zones, and promotion of feasible strategies have been used as the basis for assessing the need to improve CBF management. The Fishery Regulations of Cambodia allow free access to fish in any type of water body. Equally, and unlike in most other countries in the region, the communities living close to water bodies capable of practicing CBF are not organized to take up water-use management, for example, the practice of fish culture in the downstream areas. As in most countries,

the key to successful CBF is for the already operational community organizations and/or their representatives to be also engaged in CBF management (Wijenayake *et al*., 2005; Nguyen *et al*., 2001; Kularatne *et al*., 2009; Saphakdy *et al*., 2009). Consequently, even though the communities existing in the vicinity of a water body could be organized into suitable CBF management units, as in the case of Cambodia and in other countries, under the existing Fishery Law of Cambodia, such units do not have the power to stop free access to fishing even immediately after stocking or restocking. The situation is further exacerbated by the fact that fishing in relatively easily accessible water bodies, is allowed to meet the daily food fish needs of the communities, a traditional and cultural practice in rural Cambodia. As such, very high proportions of the stocked seeds do not reach the table or marketable size, and in the end, the overall yield is considerably reduced.

Demarcation of the conservation zones in every water body of Cambodia, irrespective of their scientific merits, was introduced in 2010. A conservation zone is indicated very conspicuously with appropriate signages, and overall, the community abides by this regulation by refraining from fishing in the indicated zones. The area of the conservation zone in a water body could vary from 10 % to 30 % of the area at full supply level and is often wooded and/ or planted with rooted vegetation such as water lilies or lotus (*Nymphea* spp.), which should not be harvested. A community belief that the conservation zones provide spawning grounds for some native species is respected, although the explicit scientific evidence in this regard is yet to come forth.

As in the case of Cambodia, any strategy that would enhance CBF production in small water bodies should comply with the existing fishery regulations. Nevertheless, the most direct and logical way of increasing production from CBF practices will be to provide time for the stocked fish seeds to grow to larger or marketable size, *i.e.* reduce the probability of recently stocked fry and/or fingerlings from being captured relatively early in their growth cycle. Accordingly, seed stocks of whatever stage at the time of purchase, which should generally be advanced fry stages or early fingerlings, be released into the conservation zones that are appropriately cordoned off using nettings or fenced. Furthermore, brush parks could also be introduced into such zones prior to stocking. The netting or fence could be gradually removed in stages, based on observations on the rate of growth of the stocked fishes. Needless to say, there are a host of unknowns that have to be researched in order to adopt this strategy to optimize fish yield from CBF in small water bodies. The application of culture-based fisheries in Cambodian waters commenced with the initiation of a project under the auspices of the Australian Centre for International Agricultural Research (ACIAR) and coordinated by the Network of Aquaculture Centres in Asia-Pacific (NACA).

Meanwhile, in Lao PDR, the CBF technology has been sustained over five to six cycles, and there is an increasing number of communities adopting CBF to augment their income and wellbeing (Phomsouvanh *et al*., 2015). In view of the successful promotion of CBF in rural communities, the Government of Lao PDR has incorporated its popularization as a major feature in the country's strategic agricultural development plans (Ministry of Agriculture and Forestry, 2010) and the recently enacted Fisheries Law of Lao PDR (Department of Livestock and Fisheries, 2010). One of the most interesting aspects of the CBF practiced in Lao PDR is the adoption of the different strategies of management and the resulting benefit of sharing protocols, which had been previously dealt with only briefly (Saphakdy *et al*., 2009). Even though communities practicing CBF are in close communication with each other and with the Central Government authorities (NACA, 2013), each of the communities has retained its management protocol and the associated benefits of the sharing procedures. This is perhaps indicative of the fact that each community is satisfied with the management style practiced, which as the data show, has resulted in increased production and monetary benefits with time.

In the case of Lao PDR, as in most countries in Asia that successfully practice CBF (*e.g.* Sri Lanka, Viet Nam), a number of exotic species had been used. However, to date, there is no explicit evidence to demonstrate that the use of exotic species in CBF practices has created negative impacts on the countries' fisheries, including in Lao PDR (Arthur *et al*., 2010). Furthermore, it should be noted that the exotic species currently used in CBF practices in Asian countries have been introduced for other purposes, including other forms of aquaculture.

The positive impacts of culture-based fisheries had been obvious in terms of enhancing production from aquatic resources in their natural habitats. Nevertheless, it is also necessary for countries to put in place appropriate management, *e.g.* appropriate harvesting regulations, equitable sharing of benefits among stakeholders, and with due consideration given to the need to avoid factors that could possibly cause a decline in conditions of the inland fishery resources, *e.g.* environmental impacts, as well as changes in biodiversity and genetic diversity of aquatic species.

Mitigating the impacts of freshwater aquaculture on the environment

It is not only culture-based fisheries in aquatic habitats that could create negative impacts on the environment and aquatic species, but freshwater aquaculture through the culture facilities also creates significant impacts on the environment if not properly managed. Aquaculture is the fastest-growing food production sub-sector and an important component in many programs on poverty alleviation and

food security (Taylor *et al*., 2016). Aquaculture technologies had been developed not only to meet the demands of domestic and export-oriented markets but also as means of preserving the endemic fish for local communities. There are many fish culture techniques that could be promoted in inland water bodies, one such aquaculture system that is widely practiced in the region is cage culture where fishes are stocked and raised in cages in natural waters until marketable size. While it is already a challenge to make this aquaculture activity profitable, such system could also pose risk when the cultured species (which could be non-indigenous) escape into the natural habitats resulting in disruption of the ecological balance of the food chain, as well as changes in biodiversity and genetic diversity of the aquatic species. The rapid development of floating net cages with overfeeding has also caused a lot of leftover food to accumulate at the bottom of the water bodies (Makmur *et al*., 2020). It is estimated that around 50–70 mt of feed are spread per day in water bodies where floating net cage culture systems are practiced. Besides, fish feces also accumulate at the bottom of the water bodies, where the organic materials are then broken down by microbes exposing a lot of oxygen, making the lake bottom run out of oxygen (anoxic) and resulting in the production of toxic sulfides.

Change in the weather also causes the hydrological conditions to be altered, and as the phenomenon lifts the inner layer of the lake bottom (overturn), the fish on the surface will die massively because of depleted oxygen and poisoning. Mass fish kills then repeatedly occur, causing enormous economic losses. Because of the presence of sulfur, the increasing number of leftover deposits and metabolism occurring at the bottom of the lake will cause a slight reversal of the water mass. As the weather changes again, repealing the water mass, it becomes toxic to fish, especially those in the floating net cages.

Nevertheless, inland aquaculture or freshwater aquaculture could still be promoted toward sustainability by taking into consideration environmental and social aspects. Environmental aspects comprise the important factors that should be considered while doing aquaculture. These factors could include the natural systems which consist of fish, ecosystem quality, and biophysical environment. Nonetheless, freshwater aquaculture should not in any way, impact the freshwater environment by the adoption of good aquaculture practices. Meanwhile, the social aspects include the human system that comprises the fishers, processors and the fishing community as a whole. It is necessary that inland aquaculture practices should benefit the stakeholders from the producers to the consumers by producing wholesome cultured fish. After identifying the elements of these two aspects, a fishery management system could be adopted, including the planning of the culture systems, management, and research. Factors that could possibly cause the decline of the condition of the inland fishery resources should be avoided during freshwater aquaculture operations through the adoption of sustainable fisheries management strategies. Such freshwater aquaculture should therefore remain sustainable in order that it would be able to provide beneficial results to all stakeholders.

2.1.5 Conflicts on Use of Inland Water Resources among Various Sectors

In several countries, inland water resources are being tapped for food security, poverty alleviation, cultural services, and the preservation of biodiversity (Funge-Smith & Benneth, 2019). The future of inland fisheries is linked to the successful management of inland waters, such as rivers, swamps, lakes, and other wetlands (Funge-Smith & Benneth, 2019). In this regard, it has become necessary that inland fisheries management be considered as part of a larger environmental and socioeconomic scale that involves multistakeholder and sectors sharing and competing over the same water resources.

The inland fisheries sub-sector has been facing serious challenges between conserving fish biodiversity and fish production for food security. Management of inland fisheries through regulations and interventions can contribute to socioeconomic benefits, increase productivity, and preserve biodiversity. In developed countries, inland waters are used not only by the fisheries sector but also by other sectors that demand water (*e.g.* hydropower, agriculture, tourism, industry, or transportation), and thus, would require a lot of efforts to synergize between freshwater fisheries and other users that compete for the same inland waters through an ecosystem approach that involves cooperation among the stakeholders from all sectors to formulate the most appropriate comprehensive and inherent policies. Conflicts can arise because the users have differences in priorities, as a result, direct conflicts often exist between fisheries and other sectors because they use the same resource base, although many studies indicate that fisheries, agriculture, tourism, infrastructure, and other sectors would be able to co-exist in well-managed inland waters.

Water construction developments like dams and weirs for hydropower generation or agriculture, modification of environmental form and function, industrial and land-use practices including forestry and recreational use, can cause significant impacts on inland fisheries. Dams and weirs can block fish migration and environmental modification for some purposes can eliminate critical habitats, sedimentation, and water quality degradation. Dam construction has almost always created conflicts between energy supply and related economic interests, versus their social and environmental impacts (King *et al*., 2007).

Modern approaches to fisheries management are needed and have proved successful in promoting close integration between the fisheries and irrigation sectors. There is a