facilitate the formulation of policies that benefit the inland fisheries subsector, as policymakers could optimize the utilization of such updated and real-time data in formulating policies that could be appropriately enforced according to the conditions of each inland resource location.

While the important roles of data in various aspects of fisheries, from planning, policy formulation to evaluation are recognized, the insufficiency of data on inland capture fisheries makes it difficult for policymakers to give due recognition on the importance of this sub-sector. Furthermore, when the data on the importance and socioeconomic value of inland fisheries is unrecorded or under-reported, decision-makers would have the tendency to value more the other water uses with known value to the economy over the inland fisheries sub-sector. Therefore, strengthening data collection and compilation should form part of an important component in policy formulations as good data could be used as a basis for policy-making in every program and activity. Moreover, this would also require the identification of appropriate indicators and compilation of local/indigenous knowledge to back up the information on the status of inland fishery resources. It is also a challenge to come up with novel methods of data collection, analysis, and dissemination, including the use of mobile applications for data collection, as these would make data collection more convenient.

2.1.3 Impact and Mitigation of Impacts of Water Barrier Construction on Inland Fisheries

The role of the inland fisheries sub-sector as a significant contributor to the economic development of many countries, alleviating poverty and ensuring food security in rural communities, has recently been well-recognized. Nonetheless, the sustainability of inland fisheries is dependent on the quality of the freshwater resources, aquatic habitats, and the ecosystem. In attaining such sustainability, strategies are necessary to strike a balance between maintaining the quality of the freshwater fishery resources and aquatic habitats, and utilization of the water resources by the non-fisheries sectors.

One of the important developments that have resulted in drastic impacts on the inland aquatic habitats and ecosystems is the construction of infrastructures along rivers and other bodies of water for economic development, which includes dams and weirs. Large-scale water construction projects such as hydropower structures could promote progress and development such as road construction, deforestation, mining, and urban development in the surrounding areas, but the impacts of such construction on the aquatic biodiversity of the inland water environments should also be taken into consideration (Arantes *et al*., 2019). Environment and socioeconomic impacts are generally assessed only in some areas near the infrastructure projects, *e.g.* hydropower structures, but not in the upstream and downstream areas where many people are dependent on the whole river ecosystem for their livelihoods. Dams and weirs are the main structures that could greatly improve the performance of an irrigation system as they help retain water in catchment areas during the rainy season and store water for utilization throughout the entire year for irrigating the agricultural lands. Constructing dams and weirs in rivers could therefore contribute to economic growth, poverty alleviation, crop productivity, water availability, and electricity generation. However, these water infrastructures could also cause depletion of the inland fishes because as water barriers, they could cause interruptions of the fish migration routes to complete their life cycles. When the fish route is blocked by such barriers, fishes are unable to access their habitats to complete the critical stages of their life cycle. Although species with short life cycles may be able to adapt to such conditions, but as a consequence, other fish populations in the upstream and downstream waters could be severely affected, especially in terms of their genetic makeup. Dams fragment the aquatic ecosystems by blocking the fish migration routes, sediments, nutrients, wood debris, and aquatic organisms in general (Zielinski & Freiburger, 2020). The impact of such ecosystem fragmentation generally affects not only the migratory fish species but also the non-migratory aquatic species as well.

Strategies should therefore be developed and promoted to mitigate such impacts of ecosystem fragmentation, especially through the construction of fish passage that allows the upstream waters of rivers to reconnect with the downstream waters. Fish passage or fishway facilitates fish migration from downstream to upstream or vice-versa. Fish that swim from downstream can enter the fishway inlet located downstream of a dam. Knowledge of fish passage construction has been used globally to maintain river connectivity. However, the appropriate design of fish passage must be based on the local fish that inhabit the particular water systems.

According to Bunt *et al*. (2012), the efficiency of fishways consists of attraction and passage efficiencies and constitutes the proportion of a fish stock present downstream that enters and successfully passes through the fishway with minimal delay. Effective fishway design requires extensive integration of biological and hydraulic data (Castro-Santos *et al*., 2009). As the variation of fish morphology is large among species, the hydraulic structure should consider the morphology of the fish in producing a selective passage. Several morphological characters such as body length, body shape, and structure of fins affect the fish swimming functions and performance. To be effective, a fishway must allow target fish to successfully pass, this implies that good knowledge of the swimming capabilities of the target fish is crucial for an effective and efficient fishway design (Katopodis *et al*., 2019).

Research should therefore be undertaken with the collaboration of fish passage biologists and engineers, emphasizing on the ecohydraulic concepts that consider both biological and hydraulic components relevant to fish passage. Scientists and engineers should implement the fish passage technologies that are developed from past experiments and should be annually monitored, evaluated, and adjusted during the subsequent years. When a water barrier is built, scientists should optimize the various sorting technologies and techniques below the barrier to maximize the passing efficiency of desirable fishes and remove invasive fishes (Zielinski & Freiburger, 2020).

A primary measure of a successful migration is that the aquatic animals arrive at their habitat with sufficient energy reserves to spawn successfully. Stress in fish is known to affect the timing of reproduction, behavior during spawning, and the survival of offspring (Schreck *et al*., 2001). A more generalized approach is to define the ideal fishway, which should aim for the main goal of optimizing designs that consider both biological and operational ideals. Fish passage structures should be designed on a site-specific basis and rely on comprehensive knowledge to adapt the structures to local conditions. Knowledge of fish response to certain conditions and factors that attract and repel them is also critical for a successful fish passage design (Williams *et al*., 2012). A comprehensive assessment of the applicability of the available fishways requires biological monitoring of the current fish assemblages of concern to determine the type, number, and biological characteristics of fish that are expected to pass the fishways. Different species will have different requirements for fish passage and different responses to upstream and downstream conditions.

Fishways that do not take into account the behavior and physiology of the target fish species could lead to poor passage rates of fish as their swimming ability would be quite slow and delayed, and they could end up failing to migrate during their migrating time. These conditions affect the fish survival and reproductive ability. Therefore, it is significant to understand the fish migration behavior and the swimming ability of the resident native fish species. In addition, the selection of fishway type must also be based on priorities by taking into consideration the conditions of the river and the transverse structures or barriers. In consideration of providing a fish passage or fishway, a technical solution should be arrived at ensuring that the negative impact of reduced connectivity between the upstream and downstream waters is avoided.

In the Southeast Asian region, the techniques to install effective fish passage had already been established and largely developed in Lao PDR. However, for other countries in the region, their capacity to adapt such techniques is rather still limited. Therefore, one of the initiatives promoted by SEAFDEC through the SEAFDEC/TD with support from the Southeast Asian countries, especially those in the Lower Mekong River Basin, is the implementation of activities through the Project "Implementing the Lower Mekong Fish Passage Initiative in Cambodia, Thailand, and Vietnam" from 2018 until 2021, which is being implemented by SEAFDEC/TD in collaboration with the US Department of Interior (US-DOI). Through this Project, one demonstration fish passage had been installed in each of the participating countries. The working teams in the respective participating countries, comprising personalities who have expertise in biology and engineering as well as local knowledge, had undertaken barrier assessment procedures followed by construction of the demonstration fish passage with technical assistance from the USAID in partnership with the Australian Centre for International Agricultural Research (ACIAR). The lessons learned from such activities demonstrated that partnership is crucial for the successful implementation of fish passage by engaging the local communities, local officers, local and national governments, and partner agencies (Theparoonrat, 2021).

In Indonesia, the focus has been made on raising the awareness of stakeholders on the importance of the fish ladder, and research is also currently being carried out on this aspect with the support of several donors. In addition to the benefit of fishways to facilitate general upstream and downstream migration of fish, a specific fish ladder is also necessary for certain aquatic species to maintain their survival. For example, a "fish way" for eels in Sulewana Poso functions as a refuge during eel migration, as both migrating parents (adult eel) and chicks (elvers) that go to the sea, will subsequently migrate upstream towards Lake Poso in Sulewana (Krismono, 2012). The design of the "eel ladder" in this case is special and is not the same as the "fish way" which is for other types of fishes such as salmon, but for eels, the fish ladder must be adapted to the biological nature and swimming ability of eels (Porcher, 2002).

Improving interconnectivity of inland aquatic habitats

It is recognized that in the Southeast Asian region, inland capture fisheries are increasingly threatened by riverine development projects including the construction of cross-river obstacles that create barriers to fish migration. As mentioned above, the effect of such barriers could be mitigated by the establishment of fishways or fish passages. Although fishways have been set up in many riverine development projects worldwide and helped mitigate the factors that hinder the sustainability of inland fisheries globally, it is important that the criteria for fishway design are established to cater to local aquatic species, and not just adapted from studies conducted elsewhere. Moreover, it should also be recognized that structures that create disconnectivity to habitats are not only dams and weirs, but also other structures such as roads, flood gates, and the like, that also inhibit fish movements and larval dispersal which should also be investigated, the results of which should be conveyed to relevant agencies and authorities for the development of appropriate mitigation measures.

In promoting the application of fishways or other mitigation measures, an investigation should be made to evaluate and enhance their effectiveness. Furthermore, methodologies 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,