Development of Fish Passage Design in Cross-river Obstacles for Sustainable Inland Capture Fisheries in Southeast Asia

Chumnarn Pongsri, Suthipong Thanasarnsakorn, Nualanong Tongdee, and *Saivason Klinsukhon*

In Southeast Asia, inland capture fisheries has always been recognized as an economically important sub-sector of the region's fisheries in view of its contribution to livelihood generation and food security of peoples, particularly the poor and marginalized groups in rural areas. Activities in inland capture fisheries are characterized by large numbers of fishers involved, mostly working part-time, and fishing only for subsistence. Inland fishing activities are also seasonal where composition of the catch is highly diverse in terms of species that rely heavily on the resources available in various habitats for their life cycles, *i.e.* breeding, nursing to grow-out stages. This implies the need for the inter-connectivity of habitats to be maintained so that survival of the species is ensured and biodiversity in the ecosystems is preserved, and as a consequence, for the sustainability of inland capture fisheries. While noting that inland capture fisheries are operated in waters shared by other sectors, *e.g.* irrigation, power-generation, etc., such fisheries could be impacted by the activities of these sectors and *vice versa*. Large numbers of development projects such as construction of cross-river barriers, *e.g.* dams, barrages and weirs that are meant for irrigation, hydro-power generation, and domestic water supply, rarely take into consideration their possible impacts to the fishery resources, especially on the inter-connectivity of fish habitats. Construction of fish passage in those cross-river barriers could address such concern as it maintains the necessary habitats' inter-connectivity. Therefore, with the goal of developing a fish passage design appropriate for the Southeast Asian region, SEAFDEC with financial and technical support from the Australian Centre for International Agricultural Research, embarked on a one-year research study on the "Application of Fish Passage Design Principles to Enhance Sustainability of Inland Fishery Resources in the Southeast Asian Region" in 2015-2016.

Status of Inland Capture Fisheries in Southeast Asia

The Southeast Asian countries recognize the importance of inland capture fisheries to food security for their peoples. In expressing an incessant drumbeat of such concern, the ASEAN Member States (AMSs) had resolved to promote the importance of inland capture fisheries and aquaculture in planning and policy formulations as this could pave the way for improving food security and ensuring stable livelihoods of the rural populace (SEAFDEC, 2001). As a follow-through, the AMSs later agreed that awareness of relevant stakeholders on the contribution of inland fisheries to food security and sustainable livelihoods should be heightened, while the priority actions for the region were recognized to "*Ensure the sustainability of inland fisheries by maintaining ecological health of the ecosystem, particularly the inter-connectivity of habitats and the specific management needs during the dry season; and develop mitigating measures for the adverse impacts on inland fisheries that may be caused by the construction of water infrastructure and alteration of water ways*" (SEAFDEC, 2011).

Inland fisheries that include inland capture fisheries and aquaculture, is a fast growing sector, especially in terms of production, *e.g.* aquaculture production. However, while the region's aquaculture production had been increasing rapidly during the past 13 years as shown in **Fig. 1**, that of inland capture fisheries had lagged behind (**Table 1**). This scenario needs a second look considering that inland fishery resources are bountiful in the region and have the potentials for sustainable fisheries development (Pongsri *et al*., 2015). Specifically, the region's freshwater resources could easily include: more than 3.7 million km of rivers; 2.4 million ha of lakes; 56.0 million ha of floodplains; 3.1 million ha of reservoirs; 26.5 million ha of dams; 29.7 million ha of wetlands; and more than 66.3 million ha of other water bodies.

There are several issues that need to be addressed with respect to the development of inland capture fisheries in the Southeast Asian region. The first and foremost of which is on the need to improve the system for collecting production data and related statistics. As mentioned earlier, the region abounds large areas

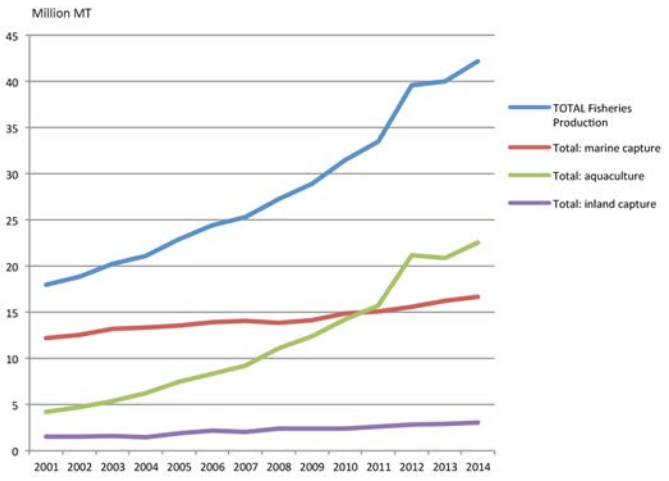


Fig. 1. Trend of fisheries production in Southeast Asia (2001-2013)
Sources: SEAFDEC (2008); SEAFDEC (2010); SEAFDEC (2015); SEAFDEC (2016b)

Table 1. Total production from inland capture fisheries of Southeast Asia from 2001 to 2014 (in million metric tons (MT))

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Brunei Darussalam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cambodia	0.39	0.36	0.31	0.25	0.45	0.56	0.42	0.43	0.39	0.40	0.45	0.53	0.53	0.51
Indonesia	0.31	0.30	0.31	0.33	0.30	0.30	0.31	0.50	0.50	0.35	0.37	0.40	0.39	0.44
Lao PDR	0.00	0.00	0.00	0.03	0.03	0.03	0.08	0.08	0.03	0.03	0.03	0.04	0.04	0.06
Malaysia	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Myanmar	0.26	0.29	0.46	0.50	0.63	0.72	0.72	0.82	0.90	1.00	1.16	1.25	1.30	1.38
Philippines	0.14	0.13	0.13	0.14	0.15	0.17	0.17	0.18	0.19	0.19	0.19	0.20	0.20	0.21
Singapore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thailand	0.20	0.20	0.20	0.20	0.20	0.22	0.23	0.23	0.25	0.21	0.23	0.22	0.22	0.21
Viet Nam	0.25	0.23	0.21	0.00	0.14	0.15	0.13	0.15	0.15	0.19	0.20	0.20	0.21	0.21
Total: inland capture	**1.56**	**1.52**	**1.63**	**1.46**	**1.91**	**2.16**	**2.07**	**2.40**	**2.42**	**2.38**	**2.64**	**2.85**	**2.90**	**3.03**
Total: marine capture	**12.20**	**12.58**	**13.19**	**13.38**	**13.59**	**13.94**	**14.06**	**13.82**	**14.14**	**14.88**	**15.10**	**15.59**	**16.26**	**16.66**
Total: aquaculture	**4.21**	**4.75**	**5.38**	**6.25**	**7.44**	**8.35**	**9.18**	**11.07**	**12.38**	**14.19**	**15.75**	**21.16**	**20.90**	**22.53**
TOTAL Fisheries Production	**17.97**	**18.85**	**20.20**	**21.09**	**22.94**	**24.45**	**25.31**	**27.29**	**28.94**	**31.45**	**33.49**	**39.60**	**40.06**	**42.22**

Sources: *SEAFDEC (2008); SEAFDEC (2010); SEAFDEC (2015); SEAFDEC (2016b)*

of freshwater bodies. Granting that of the total stretch of 3.7 million km of rivers, every 1,000 km produces 0.5 metric tons of fish per year, this could yield about 1,850 metric tons of fish annually. Moreover, for the total of more than 184.0 million ha of water bodies and if for every ha, 0.5 metric tons of fish is produced annually, this would yield 92.0 million metric tons of fish annually compared to only 2.9 million metric tons in 2013 (**Table 1**). In some cases, such trend could be true considering that based on studies conducted by FAO (2016), alternative information and data on habitats, socio-economic among others, indicate that inland capture fisheries substantially contribute to livelihoods and food security of peoples, but the status of fish populations in inland waters could not be easily determined due to insufficient information.

In Southeast Asia, the compilation and reporting of production data from inland capture fisheries had not been efficient in spite of the efforts of SEAFDEC to promote the improvement of the respective countries' fishery data and statistics collection systems (SEAFDEC, 2015). As a result, production data reported by the countries could be insufficient not only in terms of quantity but also in species composition. Specifically, data on production quantity could be very much under-estimated considering that catch of community members as main users of inland freshwater bodies are usually not recorded as these are meant only for domestic consumption. In addition, the source of fish, fishing methods used, gear used, etc. are also not monitored. These issues should be addressed in order to improve the compilation of data and statistics on inland capture fisheries.

Another equally important issue that could impact on fishery resources and habitats, and subsequently on food security in rural areas is on the need to balance water development programs with management of inland capture fisheries and maintaining aquatic biodiversity. This implies promoting fair sharing of the utilization of freshwater resources by all sectors, *e.g.* agriculture, hydro-power generation, domestic water supply, inland fisheries (capture and aquaculture), to address conflicts among multi-users. FAO (2014) suggested that in addressing such concern, changes could take place not only in the management of water resources and ecosystem but also in development and management of infrastructures and adoption of technologies which should allow the aquatic ecosystem to continue producing fish, maintain biodiversity, and provide electricity, water for irrigation and domestic use, and flood control in the midst of climate change. Taking into account the large areas of dams and reservoirs found in the Southeast Asian region, embracing about 30.0 million ha, which are mostly constructed on river systems with potentials for inland capture fisheries development, FAO (2014) suggested that management options for the operations of existing dams and reservoirs as well as future development constructions, should consider the migration needs of economically important freshwater fishes.

Considering that construction of obstacles on river systems tends to disrupt fish migration routes, such infrastructures or plans for construction of similar infrastructures should include facilities that would allow fish to pass in or through the dams and other barriers during migration which is critical

Box 1. Status of fish passage construction in Southeast Asia (Adapted from FAO and SEAFDEC (2013))

Country	No. of dams/weirs		Purpose(s)	Fish Passage		Remarks
	Existing	Planned/ under construction		Existing	Planned/ under construction	
Cambodia	12	8	Irrigation, hydro-power generation, domestic water supply	1	0	Construction of cross-river obstacles complies with national laws, regulations and guidelines, but inclusion of fish passage in such constructions is not compulsory by law as it depends on the EIA of concerned project.
Indonesia	9	1	Multi-purpose including hydro-power generation	1	1	National regulations related to construction of fish passage do not exist, but the environmental management plan in the EIA process could include fish passage construction to sustain the water flow used for fish migration, and that the technology is still unknown especially taking into account the hydrological conditions in each area.
Lao PDR	14	1	Multi-purpose, hydro-power generation	0	1	No specific compulsory legislation related to the construction of fish passage for hydropower and irrigation facilities, however, in planning for water resources development under the Mekong River Commission (MRC), mitigation measures such as construction of fish passage should be promoted.
Malaysia	5	0	Hydro-power generation, irrigation, domestic water supply	0	0	No fish passage constructed due to inadequate knowledge in designing fish passage and lack of awareness on the part of stakeholders on the significance of having fish passage facilities in weirs, barrage, dams, etc. in maintaining fish population and the river ecosystem.
Myanmar	11	6	Hydro-power generation, irrigation	0	0	No fish passage constructed due to inadequate knowledge on design of fish passage and lack of awareness among stakeholders on the necessity of fish passage.
Philippines	7	n/a	Hydro-power generation, irrigation, flood control	0	n/a	No fish passage constructed as this is not usually included in design and plans for construction of cross-river obstacles, and that priority of projects is power generation and irrigation, however, conservation of biodiversity should be included as one of the criteria in designing cross-river obstacles.
Thailand	35	3	Hydro-power generation, irrigation, flood control	1	n/a	Fisheries Act 1947 includes a provision that prohibits a person from erecting, setting up or building dike, dam, screen fence, fishing nets or other implements that obstruct the passage of aquatic animals.
Viet Nam	8	n/a	Hydro-power generation	0	n/a	No fish passage constructed to protect ecosystem and fishery resources, due to insufficient administrative support and many national agencies involved, and fish passage is not a priority concern in the construction of dams.

Source: *Report of the Workshop on Principles of Improved Fish Passage at Cross-River Obstacles, with Relevance to Southeast Asia (FAO and SEAFDEC, 2013)*

to complete their life cycle. This situation has prompted SEAFDEC to carry out a project that would promote the development of fish passage design appropriate for the Southeast Asian region.

Status of Development of Fish Passage in Southeast Asia

As mentioned earlier, there could be not less than 30 million ha of dams and reservoirs constructed in the Southeast Asian region for multiple uses. During the Workshop on Principles of Improved Fish Passage at Cross-river Obstacles with Relevance to Southeast Asia organized by FAO and SEAFDEC in March 2013, it was noted that construction of fish pass or fish passage is not practiced by many countries in the region (**Box 1**). However, the representatives from the countries attending the Workshop were of the view that fish passage to be constructed at dams, weirs or barrages should take into consideration the hydrological and environmental aspects of the water areas, including the characteristics of migrating fish species in the river systems, *e.g.* Mekong River.

The important recommendations from the workshop included the need to collect/compile biological information on important fish species to be used as basis for designing appropriate fish passage, and that construction of fish passages should be incorporated into any dam project at the initial phase of its planning and construction. Methodologies to evaluate the benefits from fish passage are therefore necessary, while relevant information, *e.g.* on potential impacts of cross-river obstacles, and mitigation of impacts through fish passages, should be packaged and publicized to raise awareness on such issues. In addition, it was also emphasized that there are very large numbers of low-head weirs, which created accumulated impacts particularly to the upstream-downstream migration of fish. Thus, appropriate solution(s) should be explored to address and mitigate the impacts of such types of common construction.

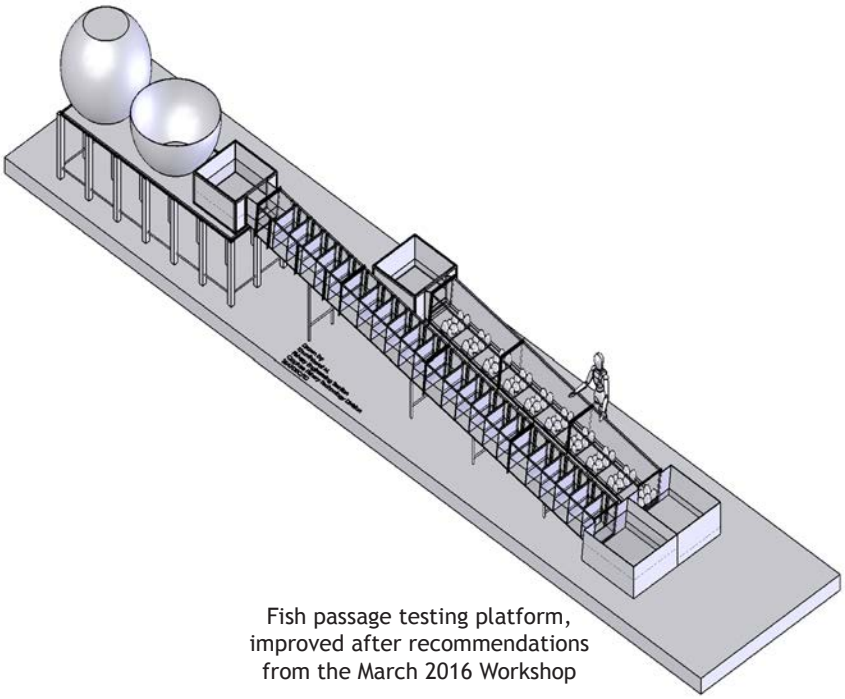
The SEAFDEC-ACIAR Project

To follow-up on the recommendations from the 2013 FAO-SEAFDEC Workshop, SEAFDEC in 2015 proposed to conduct a 16-month project on "the Application of Fish Passage Design Principles to Enhance Sustainability of Inland Fishery Resources in the Southeast Asian Region," with funding support from the Australian Centre for International Agricultural Research (ACIAR) to design and construct an experimental fish-way facility near Bangkok, Thailand. Launched in May 2015, the project takes into consideration the typical situation in the Lower Mekong Basin where inland capture fisheries is increasingly threatened by construction of development infrastructures across the Mekong River system. These include fish migration barriers that are intended to cater to the increasing demand for agricultural irrigation, hydro-power generation, and domestic water supply for the increasing populations. Construction of such infrastructures has been creating changes in the migration routes of freshwater fish species, which are critical for their life cycle, and altering not only their reproduction but also on the overall biodiversity of the aquatic resources, and as a consequence, resulting in unsustainable inland capture fisheries. Nevertheless, the impacts of creating such migration barriers could be mitigated through the construction of fish-way facilities or fish passage. Fish-ways have been constructed in many regions in the world, but it is important that designs of fish-ways for the Southeast Asian region should be developed to suit the characteristics of local and indigenous fish species.

Through the experience from projects supported by ACIAR in relation to fish-way designs in the Southeast Asian region, two general approaches had been considered, *i.e. in-situ* field studies and laboratory-based studies. *In-situ* studies are currently being undertaken in Lao PDR, *i.e.* development of fish passage technology to increase fisheries production from floodplains in Lao PDR. Although these studies are excellent ways to investigate the characteristics of migrating fish, such studies are subject to water level and species diversity fluctuations. The experimental sites are also difficult to showcase to visiting dignitaries, scientists and developers especially when field locations become difficult to access. With such limitations, laboratory-based experiments could be great alternative as these would allow information to be collected in strictly controlled manner, and are generally more accessible. The project undertaken by SEAFDEC therefore seeks to design a laboratory fish-way such that different important parameters could be adjusted during the development stage of the model, and determine the most appropriate design for various conditions. Subsequent to the development of the fish-way model, experiments could also be conducted on-station using selected indigenous fish species.

To start off the project, SEAFDEC through its Training Department (TD) embarked on the construction of a preliminary fish passage model at its premises in Samut Prakan, Thailand, taking into consideration the criteria agreed upon during the 2013 Workshop. Subsequently, a research study is being carried out on station where various parameters are controlled and experimented. The results would provide the basic information on the considerations for designing fish passage that could be applied for different localities of the Southeast Asian region. While the design of the model has been undergoing modifications to assure its practicability, SEAFDEC organized the Experts Workshop on Fish-way Design Principles to Enhance the Sustainability of Inland Fishery in the Southeast Asian Region on 6-10 March 2016 in Thailand and Lao PDR (SEAFDEC, 2016a).

The March 2016 Experts Workshop was meant to compile information on the biology and ecology of fish species in relation to fish migration and fish-way designs, particularly on the criteria for fish-way design that could enhance the



Fish passage testing platform, improved after recommendations from the March 2016 Workshop

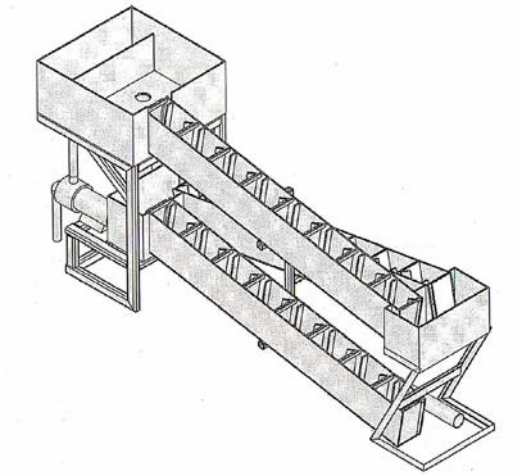
sustainability of inland fishery resources in the Southeast Asian region. After the presentations of the experts and discussions on the issues and constraints, the Workshop came up with recommendations on the appropriate components for a fish-way design as well as on how to improve the preliminary fish-way model developed by SEAFDEC (**Box 2**). The preliminary model designed by SEAFDEC based on the results of March 2013 Workshop is aimed at observing the possibility of various indigenous fish species to pass through the channels, targeting fingerlings of cyprinids that require longitudinal migration. Suggestions on improvements of the preliminary model were therefore welcome in order that the improved model could be used for experiments on various fish species. Moreover, in order to enhance the understanding of the public on the concepts and uses of fish-ways, a smaller prototype model was constructed by SEAFDEC/TD to demonstrate the principles of fish passage, and this has been displayed during several exhibitions.

Conclusion and Way Forward

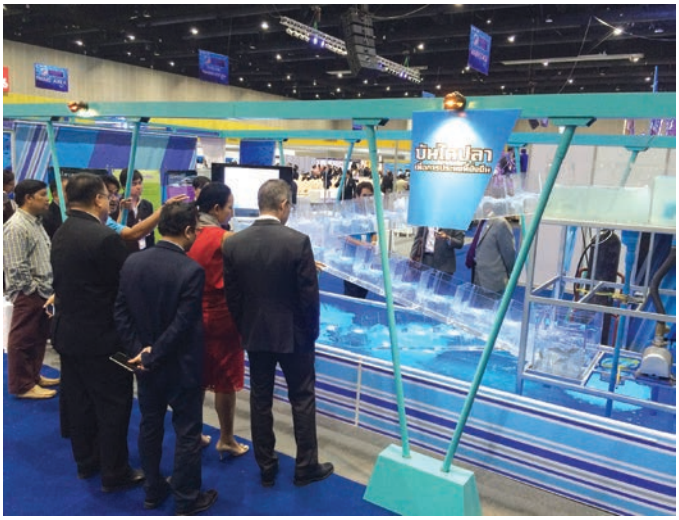
Information Collection and Exchange

The March 2016 Experts Workshop also recommended that activities should be pursued to collect additional biological information on various fish species, including:

- fish swimming performance in different turbulences and water velocities (*high priority*)
- fish behavior in the rivers, approaching the weirs and below the weirs (*e.g.* using acoustic telemetry, radio telemetry, camera), but consideration should be made on the fact that fish in the Southeast Asian region are small-size, large in number and with high species diversity



Prototype of fish-way model for demonstration purposes



Box 2. Recommendations raised during the March 2016 Experts Workshop

Components and Criteria for Fish-way Design

- Designing and construction of fish-ways need to consider both biological aspects of aquatic species (*e.g.* fish species, size, etc.), as well as hydrological aspects of the fish-way (*e.g.* water discharge volume of the river, water head, etc.). Although standard criteria for fish-ways (*e.g.* pool dimension, entrance size) is already available, but this should be tailored to fit the specificity of different localities of Southeast Asia making use of available indigenous knowledge.
- Steps for prioritization of sites for fish-ways could include: (i) Use of satellite data to mark water barriers, observe physical characteristics, position/size of catchment and aquatic habitat; (ii) Conduct of field survey to the site to see the actual barriers, conditions of habitat/species, fishing activities, local/indigenous knowledge; (iii) Evaluation/assessment to determine the potential benefits from fish-ways (based on socio-economic and biological dimensions), give score/rank and prioritize the site; and (4) Allocation of funds to develop a preliminary design, and formulate proposals for donor support. Criteria for prioritizing sites for fish-way could be found at *http://aciar.gov.au/project/fis/2009/041*. Priority should be given not only to fish-ways for upstream migration, but also downstream migration, as fish can migrate into downstream part of the river, and can also migrate upstream later on.
- Attraction of fish to the entrance is important to facilitate migration:
  - Based on the experts' experiences, the need for ~10% of total discharge through fish-way (including auxiliary flow) to attract fish should be considered, and the structure of fish-way should accommodate such condition.
  - Requirements of discharge to attract fish is only during fish migration period, *e.g.* early period of rainy season and not all-year-round (water flow during fish migration peak is not as much as it should be during water flow peak).
  - Entrance position and design are also very important to facilitate/attract fish to find the entrance (should be placed near the bank where fish usually swim).
- Designing fish-ways should also take into consideration migratory requirements of species under international concerns *e.g.* eels (*Anguilla* spp.), which is crucial for SEAFDEC/IFRDMD in designing a fish-way to facilitate eel migration to. In addition, migration of other important species, such as the giant freshwater prawn should also be considered.

Improvement of the Preliminary Fish-way Model of SEAFDEC/TD

- The initial design of on-station fish-way model of SEAFDEC/TD should be improved by increasing the depth as much as possible. It was noted that the existing model still have ~ 30 cm freeboard, and thus water depth could be increased by adding more water pumps.
- SEAFDEC/TD should consider varying the shape of slot opening (*e.g.* using straight slot, wide at the bottom and/or top, blocked at the middle). However, different opening shapes should be designed based on various factors, *e.g.* fish species/size/behavior, amount of water discharge. The shape has to be carefully chosen for specific site/situation.
- Based on research by Mallen-Cooper *et al.*, (2008): i) baffle deflector (small baffle) should be increased to 1.6 times of slot width; ii) large baffle return should be increased to 2.0 times of slot width; iii) sill in the base of the slot should be used and should be equal or greater than the height of the head loss; and iv) pool proportions should be closer to 3:2 (length: width).
- Experiments should be conducted making use of the on-station fish-way model, using different species and size of fish, different water flow rate and fish-way slope, etc. Data should be recorded on the:
  - water depth, pool depth, head loss between each pool, etc.
  - fish species/groups, fish size that could pass through the fish-way (with assistance from the Department of Fisheries (DOF) of Thailand in identifying priority species/groups to be experimented)
  - migration during different times of the day (day/night time)
  - flow measurement details, including spatial and temporal, and equipment used for measurement
- Experts as well as staff of DOF Thailand, Cambodia and Lao PDR should be invited to make use of the experimental model at SEAFDEC/TD to conduct relevant studies.
- In the future, TD should transfer the fish-way model laboratory data to Southeast Asian countries for them to undertake field experiments before publishing the design components and criteria.

- influence of lunar cycle which should also be considered in the data collection

Harmonized methodology for data collection should be developed and used for collection of data/ information on migratory fishes by various agencies/institutions, *e.g.* along Mekong River to the upstream river in China, as this could facilitate sharing/exchanging of information in the future. Existing methodologies developed by the Mekong River Commission (MRC) should also be considered. Regular exchange of relevant information should therefore be sustained, and such information could include not only the success cases, but also the failures.

Data should also be collected on performance indicators of fish-ways, including:

- whether fish population upstream could be maintained,
- proportion of fish that can pass through the fish-ways (entrance attraction), and
- whether fish migrate from bottom to top of the fish-way itself.

Other recommendations include the establishment of e-group by SEAFDEC, comprising experts attending in the Experts Workshop, to facilitate communication and sharing/exchange of information (*high priority*). Creation of working group was considered necessary in seeking approval for the engineering designs of fish-ways. Such working group could comprise engineers, scientists, biologists, etc., to review the construction plans and minimize the chance of making mistakes.

Enhancing Cooperation between the Project and the Royal Irrigation Department of Thailand

Cooperation with the Royal Irrigation Department (RID) of Thailand should be enhanced in the future to ensure that appropriate fish-way designs would be taken into consideration in designing new development projects especially in Thailand. Since it is necessary to have clear standards/ criteria for designing fish-ways (both for upstream and downstream migration), support from RID could also facilitate communication with decision makers, especially in making them understand better the specific criteria/requirements for fish-ways and raising their awareness on the benefits of fish-ways to biodiversity and contribution to nutritional requirements of peoples, and ensure that such aspects would form part in the plans of every development projects.

Moreover, water-gate operators/managers should also be involved in designing fish-ways to be able to enhance their knowledge on the basic principles of fish-ways (*e.g.* water demand for fish-ways, discharge time, etc.), considering that the effectiveness of fish migration also relies on water-gate operations. In addition to the criteria to be considered in construction of new fish-ways, modification of the existing fish-way structure or its operation to facilitate fish migration should also be considered. Finally, for the future actions, the Experts Workshop recommended that: (1) fish-way experiment at SEAFDEC/TD should be continued; (2) funding should be sought for the conduct of field experiments and validation studies (particularly on turbulence and baffle design); and (3) assessment should be made on new design of fish-way comparing its performance with existing design(s).

The Workshop also suggested that as the conduct of experiments using the fish-way model developed by SEAFDEC/TD may take some time, it is necessary to come up with biological information on various fish species/species groups. Therefore, SEAFDEC, DOF and RID should consider developing a proposal for funding support from donors, *e.g.* ACIAR or USAID, for the conduct of field experiments using the fish-way model. Nonetheless, such field experiments could only proceed after obtaining the required biological information on various fish species and their habitats.

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