

# **Green Asia** Report Series

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**No.6**

## **Sustainable Use of Small Indigenous Fish Species for Nutritional and Livelihood Improvement in Inland Rural Areas of Indochina**

**Shinsuke Morioka, Shintaro Kobayashi**



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# **Sustainable Use of Small Indigenous Fish Species for Nutritional and Livelihood Improvement in Inland Rural Areas of Indochina**

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## **Abstract**

Despite economic growth across Southeast Asia, undernutrition remains a critical issue in rural areas of Indochina, particularly in countries such as Laos and Cambodia. High rates of child stunting and anemia among women are closely linked to limited access to animal protein and essential micronutrients. Community-based production and provision of nutrients is a promising approach to alleviate undernutrition.

There is a clear need for aquaculture models based on small indigenous fish species (SIS), which are not only nutritionally effective and economically feasible for rural populations but also contribute to fishery sustainability. Despite the large number of indigenous fish species distributed throughout inland Southeast Asia, detailed biological and ecological information remains limited and is often fragmented. This lack of knowledge has become a critical bottleneck for effective and sustainable fishery development and aquaculture promotion in this region.

Drawing on field-based case studies, this report examines the development of context-appropriate sustainable management practices for inland fishery resources and practical low-cost aquaculture systems to improve the nutrition and livelihoods of economically disadvantaged communities. A case study of selective fishing and overharvesting of inland fisheries presents the extent of SIS resource depletion in the region, underscoring the urgent need for targeted resource management, while fermentation, a traditional method of preservation, is presented as a promising practice to prevent post-harvest loss of SIS while offering value addition, extended shelf life, and enhanced nutritional quality. In addition to inland fisheries, this report illustrates rice-fish farming, which takes advantage of the local environment, and case studies in Laos indicate the conditions necessary for the profitability of pond-based aquaculture. The report also details the potential of alternative feed sources, such as black soldier fly (BSF) larvae, to improve the economic feasibility and sustainability of small-scale aquaculture, as a substitute for imported feed.

Together, these strategies form an integrated framework for sustainable aquaculture and conservation of SIS. By aligning nutritional goals with ecological sustainability and rural economic feasibility, they offer scalable solutions for sustainable SIS fisheries and aquaculture in inland Southeast Asia.

## 1: Introduction

Southeast Asia has achieved significant economic growth over the past few decades (Samphantharak 2019), accompanied by measurable improvements in food security indicators such as dietary energy supply adequacy (FAO 2025). However, large segments of the population in this region, particularly in rural areas, continue to experience poverty and chronic undernutrition. High rates of stunting in children under five years of age and anemia among women of reproductive age (15–49 years) remain critical health concerns, particularly in countries such as Laos and Cambodia (Smith et al. 2004; Pahlisch et al. 2017; Morioka et al. 2021a). Nutritional deficiencies are closely associated with lower household income and limited dietary diversity in economically deprived regions (FAO 2025; Worldmeters 2025; Hasada et al. 2022).

Nutritional analyses have identified deficits in both macronutrients (e.g., protein, lipids) and micronutrients (e.g., iron, zinc, vitamins) as contributing factors to undernutrition (Lopriore et al. 2004; Lee 2014; Vilain et al. 2016; Gowele et al. 2021). In response to these deficiencies, Southeast Asian countries have promoted aquaculture to increase animal food intake (Hishamunda et al. 2009). Although per capita fish consumption has increased (FAO 2025), this increase has been primarily driven by commercial aquaculture focused on introduced species such as Nile tilapia (*Oreochromis niloticus*), Clarias spp. hybrids, and Chinese carp, as well as some indigenous species such as striped catfish (*Pangasianodon hypophthalmus*) (Phillips 2002).

However, in rural inland regions, this approach faces two major constraints. First, commercial aquaculture systems often require capital-intensive infrastructure and expensive feed inputs, which limit their feasibility in low-income communities (Morioka et al. 2021b). Second, the escape and establishment of introduced species poses risks to native aquatic biodiversity and local ecosystems (Nguyen and De Silva 2006).

Given these challenges, there is a clear need for aquaculture models that are not only nutritionally effective and economically feasible for rural populations but also contribute to biodiversity conservation and fisheries sustainability. This report

outlines a set of technical approaches that emphasize the use of indigenous fish species with high nutritional value and low-input cultivation potential. Drawing on field-based research, the report aims to support the development of context-appropriate aquaculture strategies to improve food security and livelihoods in inland areas in Southeast Asia.

## 2: Background

### 2.1: Status of animal protein intake and human health in Asian rice-consuming countries

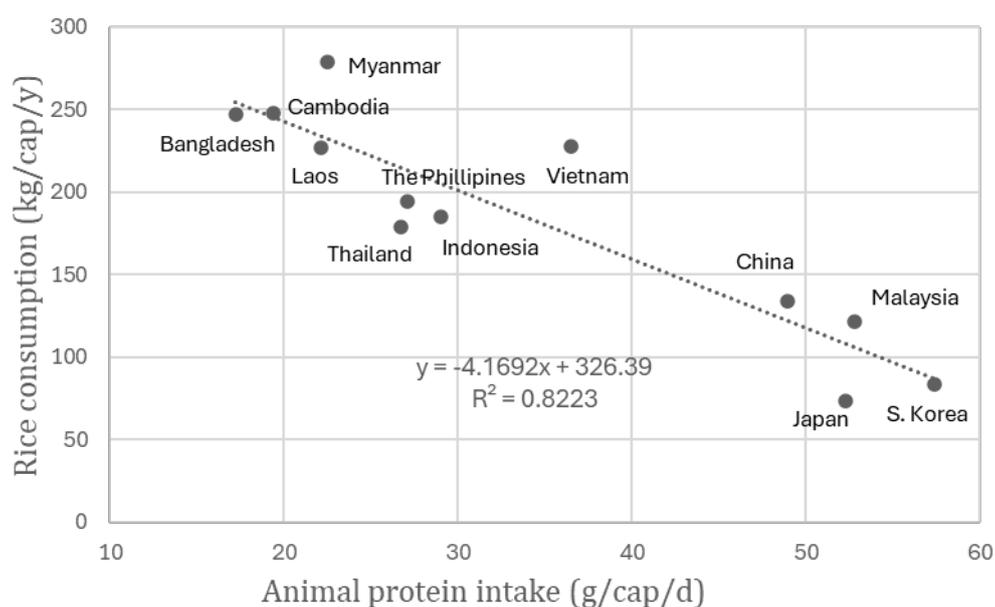
Rice is a staple food in most Asian countries, particularly in Southeast Asia. Myanmar has the highest annual per capita rice consumption at approximately 271 kg, followed by Bangladesh (264 kg), Cambodia (252 kg), and Vietnam (229 kg). Japan has seen a significant decline in rice consumption in recent years, consuming only 73 kg per capita annually (World Population Review 2025). Although Southeast Asia has experienced remarkable economic growth in recent years, Myanmar, Laos, and Cambodia are still classified as least developed countries. Consequently, both the domestic production and imports of livestock and fishery products remain limited, raising concerns regarding chronic deficiencies in animal protein intake at the national level.

This section provides an overview of the key indicators related to animal protein consumption in rice-based dietary countries in Asia, focusing on 12 countries. These countries include Myanmar, Bangladesh, Cambodia, Vietnam, Laos, the Philippines, Indonesia, Thailand, China, Malaysia, South Korea, and Japan. Table 1 shows the annual per-capita rice consumption (in kg) for these 12 countries, based on estimates made by the World Population Review (2025).

**Table 1. Twelve rice-consuming countries in Asia and their annual per capita rice consumption (kg) (based on World Population Review 2025).**

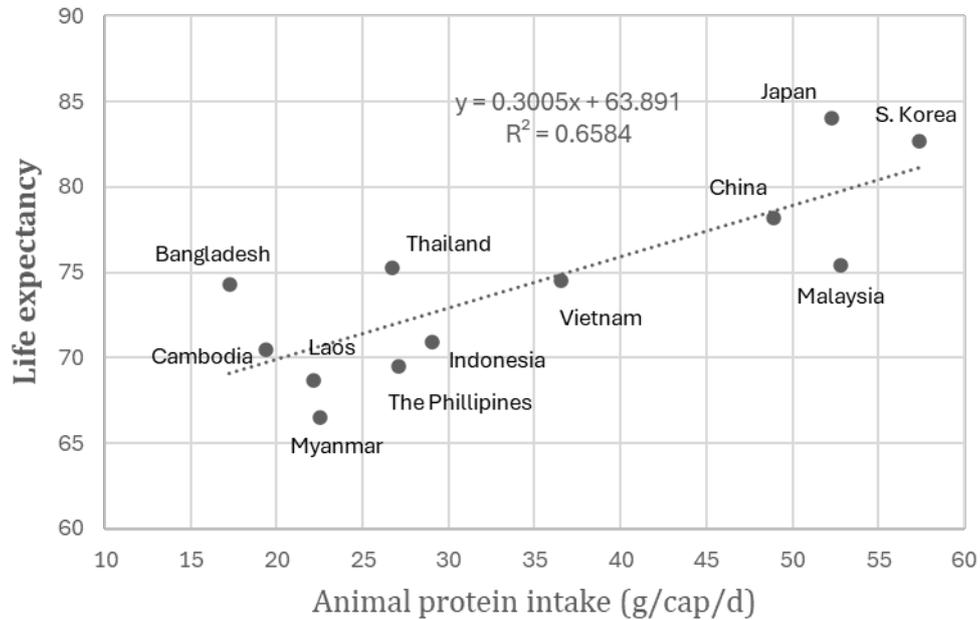
Countries	Per capita consumption	Countries	Per capita consumption
Myanmar	271	Indonesia	181
Bangladesh	264	Thailand	170
Cambodia	252	China	129
Vietnam	229	Malaysia	118
Laos	222	South Korea	81
the Philippines	191	Japan	73

Several important relationships with animal protein consumption were also identified. First, countries with higher rice consumption per capita tended to have lower animal protein consumption (Fig. 1,  $R^2 = 0.82$ ), suggesting a nutritional trade-off between rice and animal protein consumption. Second, life expectancy increased with animal protein intake (Fig. 2,  $R^2 = 0.66$ ). Countries with low levels of animal protein consumption, such as Myanmar, Laos, and Cambodia, also tended to have lower average life expectancies.



**Fig. 1. Relationship between animal protein intake and rice consumption (kg/cap/d) in 12 rice-consuming Asian countries [individual data based on World Population Review (2025) and FAOSTAT (2025)]**

Third, higher animal protein consumption was associated with a lower prevalence of stunting in children under five years of age ( $R^2 = 0.50$ ), indicating the critical role played by animal protein in child growth and development. According to the World Health Organization (WHO 2018), stunting is defined as a height-for-age Z-score  $< -2$ . Finally, countries with low animal protein intake tended to have higher rates of anemia in women of reproductive age (15–49 years) ( $R^2 = 0.48$ ), reflecting the essential role of animal-derived iron and other micronutrients in preventing iron-deficiency anemia.



**Fig. 2. Relationship between animal protein intake (g/cap/day) and life expectancy in twelve rice-consuming Asian countries [data derived from World Population Review (2025) and FAOSTAT (2025)]**

## 2.2: Necessity of community-based animal protein production and provision

In least developed countries, large disparities exist between urban and rural areas. Residents of urban areas generally enjoy better access to diverse food resources, including animal protein, because of their higher incomes and more developed food distribution systems in these regions. Consequently, their nutritional status is relatively stable. In contrast, rural and especially mountainous communities often face economic hardships, limited market access, and underdeveloped cold chain infrastructure. Particularly in rural areas, more than half of all animal protein intake is derived from locally available natural resources such as wild animals, fish, insects, and other foraged foods (Hasada et al. 2022). This dependence on self-sufficiency reflects both cultural practices and the structural limitations of the food supply chain. In these regions, households rely heavily on self-sufficiency through foraging or small-scale livestock farming to meet their protein requirements. However, the total intake remains significantly lower than that in urban areas. While long-term resolution requires broader economic development, short-term measures should prioritize increasing the community-based production of animal protein to improve food security and nutritional outcomes, particularly for vulnerable groups such as

children and women of reproductive age.

### **2.3: Nutritional and functional potential of Small Indigenous Fish Species (SIS)**

Small indigenous fish (SIS) have been gaining attention as a rich source of micronutrients to address malnutrition observed in several Southeast Asian countries. SIS – occasionally referred to as "trash fish" – have attracted attention as a potential source of protein that could help alleviate the chronic deficiency in animal protein intake, particularly in rural areas. Several studies have reported that SIS are richer in essential micronutrients, particularly minerals such as iron, zinc, and calcium, as well as vitamin A, than larger fish species, including those produced through commercial aquaculture. The micronutrient content of various SIS in Bangladesh and Cambodia has also been evaluated (Roos et al. 2003; Roos et al. 2007a, b; Vilain et al. 2016; Rajts and Shelley 2020). Roos et al. (2007a, b) indicated that small Cypriniformes (e.g., Xenocyprididae, Danionidae, and Cyprinidae), which are herbivorous or omnivorous, often contain higher levels of vitamin A, zinc, and iron than larger carnivorous species (e.g., Channidae and Clariidae). The higher vitamin A content in Cypriniformes may be related to their herbivorous or omnivorous feeding habits; however, further research is required to confirm this. These micronutrients are essential to reduce stunting in children and anemia in women. Moreover, small fish are typically consumed whole, allowing for more efficient intake of nutrients, whereas larger fish are generally consumed as fillets, which exclude nutrient-rich parts, such as bones and internal organs.

As mentioned previously, small indigenous fish are a rich source of micronutrients. However, with a few exceptions, little attention has been given to managing or conserving this resource. In addition, other important constraints are postharvest quality loss, mainly caused by inappropriate treatment under insufficient temperature control (Hossain and Barman 2016), and the lower economic value than that of larger fishes. To alleviate the former constraint, infrastructure and techniques for preservation and transportation are required, and value addition by appropriate processing, such as fermentation, should be considered. Furthermore, small fish are often eaten in fermented forms in Southeast Asian countries, such as *Pa-daek* in Laos, *Pra-hok* in Cambodia, and *Pla-ra* in Thailand. According to Marui et al. (2018), who evaluated the dynamics of the amino acid content in *Pa-daek*, various amino acids (such as glutamic acid, lysine, alanine, and ornithine) that contribute to

fatigue reduction, liver protection, and flavor improvement are synthesized during fermentation. These observations suggest the potential of SIS by appropriate processing, for example, fermentation, as a functional food source, facilitating the nutritional improvement of the residents.

### **3: Sustainable management of Small Indigenous Fish Species (SIS) as inland fishery resources**

#### **3.1: Increasing recognition of SIS and limited knowledge**

SIS have increasingly been recognized as a nutritionally important food resource, particularly in inland rural areas of Southeast Asia. Their small body size, high reproductive rate, and nutritional richness make them ideal candidates for improving food and micronutrient security. However, environmental degradation, habitat fragmentation, and biological invasions have led to growing concerns regarding declines in both the abundance and diversity of SIS populations.

Despite the large number of indigenous fish species distributed throughout inland Southeast Asia, detailed biological and ecological information on these species remains limited and often fragmented (Table 2). This lack of knowledge has become a critical bottleneck for effective conservation, sustainable fishery development, and aquaculture promotion in this region.

The amount of available biological data is highly uneven across species. Among the relatively well-studied species is the river sprat *Clupeichthys aesarnensis* (Clupeidae), a dominant target for small-scale fisheries in man-made reservoirs (Sirimongkonthaworn and Fernando 1994; Jutagate et al. 2003; Pongcharean 2006; Morioka et al. 2019) (Table 2).

Other species for which some biological traits have been studied – though often without comprehensive stock assessment – include the Siamese mud carp *Henicorhynchus siamensis* (Suvarnaraksha et al. 2011; Fukushima et al. 2014), *Rasbora rubrodorsalis*, *Brachygobius mekongensis*, *Esomus metallicus*, *Parambassis siamensis*, and *Anabas testudineus* (Morioka 2009; Morioka et al. 2009, 2012a, 2014; Morioka and Sano 2009; Okutsu et al. 2011; Uddin et al. 2017) (Table 2). For osphronemid species such as *Trichopodus pectoralis* and *T. trichopterus*, biological data remain sparse and fragmented (Morioka et al. 2010, 2012b, 2013).

**Table 2. List of example SIS species for which biological and ecological information has been obtained**

Family	Species	Information	Target (fisheries or aquaculture)	Feeding habit	Source
Clupeidae	<i>Clupeichthys aesarnensis</i>	Biological details in the wild	Fisheries	Planktivorous	Poungcharean (2006), Jutagate et al. (2003), Morioka et al. (2019)
Cyprinidae	<i>Henicorhynchus siamensis</i>	Growth, reproductive and feeding aspects, and migration in the wild	Fisheries	Herbivorous	Suvarnaraksha et al. (2011), Fukushima et al. (2014)
Danionidae	<i>Rasbora rubrodorsalis</i>	Biological details in the wild	Fisheries	Omnivorous	Morioka et al. (2014)
	<i>Esomus metallicus</i>	Fragmented biological information in the wild	Fisheries	Herbivorous	Morioka et al. (2012a)
Gobiidae	<i>Amblypharyngodon mola</i>	Feeding habits and breeding biology	Fisheries and small-scale aquaculture	Omnivorous	Mondol et al. (2013), Mondal et al. (2020)
	<i>Brachygobius mekongensis</i>	Biological details in the wild	Fisheries	Planktivorous	Morioka and Sano (2009)
Ambassidae	<i>Parambassis siamensis</i>	Biological details in the wild	Fisheries	Insectivorous / planktivorous	Okutsu et al. (2011)
Anabantidae	<i>Anabas testudineus</i>	Growth and reproduction in the wild, description of larval and juvenile morphology with some biological features in the laboratory	Fisheries and commercial aquaculture	Carnivorous	Morioka (2009), Morioka et al. (2009), Uddin et al. (2017)
Osphronemidae	<i>Trichopodus pectoralis</i>	Detailed description of larval and juvenile morphology with some biological features in the laboratory	Fisheries and commercial aquaculture	Omnivorous	Morioka et al. (2010)
	<i>Trichopodus trichopterus</i>	Ditto	Mainly fisheries with some aquaculture	Omnivorous	Morioka et al. (2012b)
	<i>Osphronemus goramy</i>	Ditto	Fisheries and commercial aquaculture	Omnivorous	Morioka et al. (2013)

### 3.2: Effective SIS resource management from case reviews in Laos and Thailand

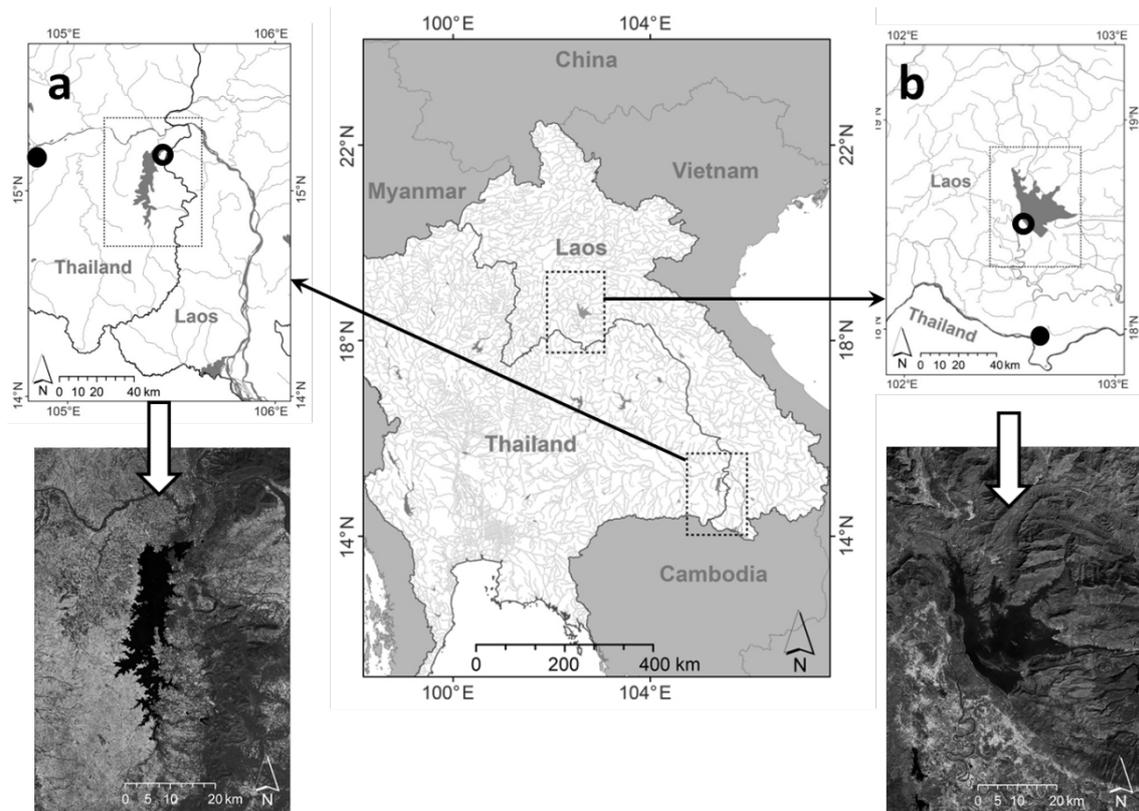
Among SIS, *Clupeichthys aesarnensis* (Fig. 3) is a practical example of a species with both commercial importance and sufficient biological data to support resource management considerations. The species is heavily harvested from artificial reservoirs, notably the Nam Ngum Dam in Laos and the Sirindhorn Dam in Thailand (Fig. 4). An early estimate suggested that annual harvests in Nam Ngum exceed 2,000 tons, translating to over 2.5 billion individuals, based on mean body weight calculations (Mattson et al. 2001; Morioka et al. 2019). This surpasses the approximately 700 tons harvested at the Sirindhorn Dam (Jutagate et al. 2003).



**Fig. 3. An adult *Clupeichthys aesarnensis* (ca. 40 mm standard length) (photo by the author)**

Despite the larger surface area of the Nam Ngum Dam (370 km<sup>2</sup>) and its greater depth (19 m) compared to Sirindhorn (288 km<sup>2</sup>, 5 m), recent declines in catch have been reported by local fishers. Given that the Sirindhorn Dam was identified as overfished more than a decade ago (Jutagate et al. 2003), it is likely that the Nam Ngum population is now similarly or even more severely depleted.

Fishing practices have evolved significantly in recent years. Prior to the 1980s, gill nets yielded less than 100 tons annually. The introduction of nighttime light-assisted scoop-netting rapidly increased catch volumes to approximately 2,000 tons (Mattson et al. 2001). This transition has markedly increased fishing pressure on this species.



**Fig. 4.** Maps showing two man-made reservoirs in Thailand and Laos for sample collection of *Clupeichthys aesarnensis*. a Sirindhorn Reservoir, Thailand, b Nam Ngum Reservoir, Laos. Open and closed circles in a and b represent sample collection sites. Figure reprinted from Morioka et al. (2019)

Simultaneously, *C. aesarnensis* has gained economic value because of its use in the preparation of *Pa daek*, a traditional Lao fermented fish paste (Marui 2019). Demand has surged, and fish processing facilities have expanded sourcing to remote regions such as Attapeu Province (Marui, unpublished data), compounding fishing pressure on wild stocks.

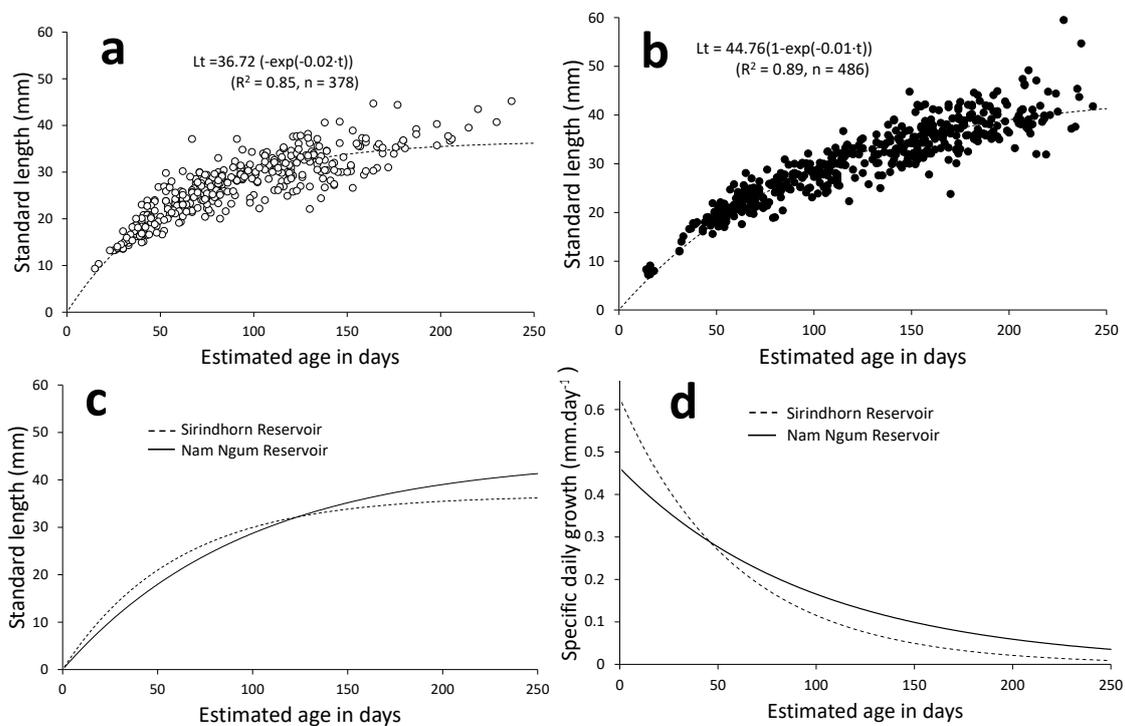
Research comparing populations in the two dams revealed distinct growth patterns, influenced by water temperature and potentially by fishing pressure (Morioka et al. 2019). Growth was modeled using the von Bertalanffy equation (Fig. 5):

$$\text{Sirindhorn Dam: } L_t = 36.72 (1 - \exp(-0.02 \cdot t)), R^2 = 0.85$$

$$\text{Nam Ngum Dam: } L_t = 44.76 (1 - \exp(-0.01 \cdot t)), R^2 = 0.89$$

Sirindhorn fish grew faster early in life and matured to smaller sizes (approximately 20 mm) than Nam Ngum fish (approximately 25 mm), consistent with temperature-

induced life history shifts (Dotsu 1982). However, both populations rarely exceeded 50 mm, although individuals >50–60 mm were commonly observed around 2000 (Baird et al. 1999; Jutagate et al. 2003).



**Fig. 5.** von Bertalanffy growth models [relationships between age in days and standard length (mm)] and relationship between age in days and specific daily growth (SDG) of *Clupeichthys aesarnensis*. a, b Growth models of specimens collected from Sirindhorn and Nam Ngum reservoirs, respectively. c, d Comparisons in growth models and SDGs between Sirindhorn and Nam Ngum reservoirs, respectively. Figure reprinted from Morioka et al. (2019)

This suggests a possible long-term shift, known as evolutionary downsizing, where intense harvesting of large fish provides an advantage to those that grow quickly, mature earlier, and remain smaller as adults. Over generations, this can lead to a gradual decrease in average fish size (Conover et al. 2009; Sharpe and Hendry 2009; Katsukawa and Watanabe 2010).

Given the high exploitation levels and life history changes observed in *C. aesarnensis*, urgent management interventions are required. These may include:

- Effort Control: Regulation of scoop net usage, night fishing with lights, and fishing

intensity.

- Spatial Protection: Establishment of no-fishing zones, particularly in shallow nursery habitats.
- Monitoring Programs: Long-term tracking of size structure, reproduction, and otolith-based growth analysis.
- Cross-border Collaboration: Cooperative frameworks between Laos and Thailand to unify SIS management strategies.

Importantly, owing to the species' short life-span and year-round reproduction, spatial protection (e.g., refugia) may be more effective for conserving this species than seasonal closures.

*Clupeichthys aesarnensis* is critical for the conservation and management of SIS. Its recent population decline, likely driven by overfishing and evolving fishing technologies, signals broader risks to the SIS biodiversity and food security. Management approaches must integrate ecological, socioeconomic, and evolutionary perspectives to ensure long-term sustainability.

### **3.3: Fermentation as a method for sustainable food use of SIS**

SIS are rich sources of protein, essential vitamins, and minerals and contribute significantly to nutrition in rural Southeast Asia. However, SIS are highly perishable, and without immediate preservation through refrigeration, freezing, or processing, rapid spoilage often leads to food waste. This not only results in economic and nutritional losses, but also undermines conservation efforts by amplifying the impacts of overfishing (Kruijssen et al. 2020).

Although cold chains remain vital for postharvest preservation, they are often impractical in remote, inland regions. Fermentation is a culturally rooted, cost-effective, and nutritionally beneficial preservation method. This section of the review explores the potential of fermentation to reduce postharvest loss, enhance value addition, and promote sustainable utilization of SIS, particularly in Laos, Cambodia, and Thailand.

Fermented fish products have long been an integral part of the Southeast Asian diet. Across Laos, Cambodia, and Thailand, numerous SIS species are traditionally

consumed in fermented form, including *Pa daek* in Laos (Fig. 6), *Pra hok* in Cambodia, and *Pla ra* in Thailand. These products are prepared using time-honored techniques involving salting and long-term anaerobic fermentation.



**Fig. 6. The fermented fish seasoning “Pa daek”  
(photo courtesy of Dr. J. Marui, JIRCAS)**

Fermentation not only enhances shelf life but also imparts a distinctive umami flavor and aroma, elevating the culinary value of the product. Modern adaptations of traditional fermentation have gained traction and incorporate food safety protocols, standardized procedures, and hygienic packaging. These improvements have allowed fermented fish products to access broader markets and achieve higher economic value, particularly in niche and premium food sectors.

Fermented SIS has several nutritional advantages. As the fish in this form are typically consumed whole, including the heads and bones, they provide higher levels of calcium and other essential minerals, which are more concentrated in these parts than in the muscle (Marui et al. 2018). Fermentation also increases the presence of umami-enhancing compounds and bioactive peptides, which can improve taste and functionality. Recent research has demonstrated that fermentation enhances flavor compounds and antioxidant potential in small fish (Li et al. 2024), further supporting its role as a nutritional enhancement method.

Despite these benefits, fermentation is not without risks. One concern is the potential accumulation of excess histamine, a biogenic amine that may trigger allergic or toxic reactions. Histamine production in fermented fish is primarily

caused by certain fermentation bacteria, and its occurrence has been documented in several fermented fish products, including *Pa daek* in Laos (Satomi 2016; Marui et al. 2021).

However, these risks are manageable. Studies have shown that adjusting the salt concentration and ensuring an adequate duration for the fermentation process can effectively suppress histamine formation (Marui et al. 2021). These findings highlight the importance of standardized fermentation protocols to ensure food safety while maintaining traditional values.

Based on the reviewed evidence, the following strategies for integrating fermentation into SIS and food system planning are proposed:

- Promote fermentation as a decentralized, low-tech preservation solution in areas that lack reliable cold storage infrastructure.
- Develop and disseminate improved fermentation protocols that optimize salt levels and fermentation times to minimize histamine production.
- Encourage public-private partnerships to support local producers in enhancing hygienic practices, branding, and market access for high-value fermented SIS products.
- Integrate fermentation into SIS conservation and fishery co-management frameworks to reduce harvest loss while increasing resource use efficiency and value retention.

Fermentation is a culturally appropriate, economically viable, and nutritionally advantageous solution for post-harvest losses in SIS fisheries. When applied with careful attention to microbial safety, fermentation can extend shelf-life, increase market value, and support food and nutritional security. With further technical refinement and policy support, fermented SIS products can serve as models for sustainable small fish utilization in Southeast Asia.

## **4: Aquaculture of small indigenous fish utilizing rural environments**

In addition to inland fisheries, SIS aquaculture is a promising source of essential nutrients and rural income. However, systematic reviews on aquaculture technology are limited. This section introduces rice-fish farming, which takes advantage of the local environment and considers efficient farming methods. Based on case studies conducted in Laos, this study examines the conditions necessary for the profitability of pond-based aquaculture.

### **4.1: Potential and optimization of rice-fish farming with climbing perch (*Anabas testudineus*) in rural Laos**

Rice-fish culture, the integration of fish cultivation within flooded paddy fields, has been practiced in Asia for centuries. In Laos, where rice cultivation is a critical agricultural activity and protein supply remains limited in rural areas, this dual-use system represents a promising strategy for enhancing both food security and resource efficiency. Among the candidate species for this system, climbing perch (*Anabas testudineus*, Anabantidae) (Fig. 7) is a native carnivorous fish known for its hardiness and high market value.



**Fig. 7. The adult climbing perch *Anabas testudineus* (ca. 150 mm of total length) (photo taken by the author)**

This section of the review evaluates recent trials on climbing perch-based rice-fish culture in Laos, focusing on biological feasibility, productivity potential, and its

implications for both aquaculture and rice yields.

To assess the suitability of climbing perch for rice-fish co-culture, a series of trials were conducted in two rural Laotian villages (Vongvichith et al., 2018). This study aimed to evaluate the following:

- Fish productivity in 100 m<sup>2</sup> rice paddies without artificial feeding.
- Key variables influencing biomass gain.

Four variables were tested:

- Stocking density (SD)
- Initial body weight of seedlings (BW)
- Presence or absence of feeding (F)
- Stocking period (SP)

Productivity was quantified using the Biomass Gain Index (BGI), defined as

$$\text{BGI} = \text{Total weight of harvested fish} / \text{Total weight of stocked fish.}$$

A comparative analysis of linear regression models with standardized variables incorporating all possible variable combinations revealed that the initial seedling weight was not a significant predictor. Stocking density (SD), feeding conditions (F), and stocking period (SP) emerged as key determinants of productivity (Fig. 8).

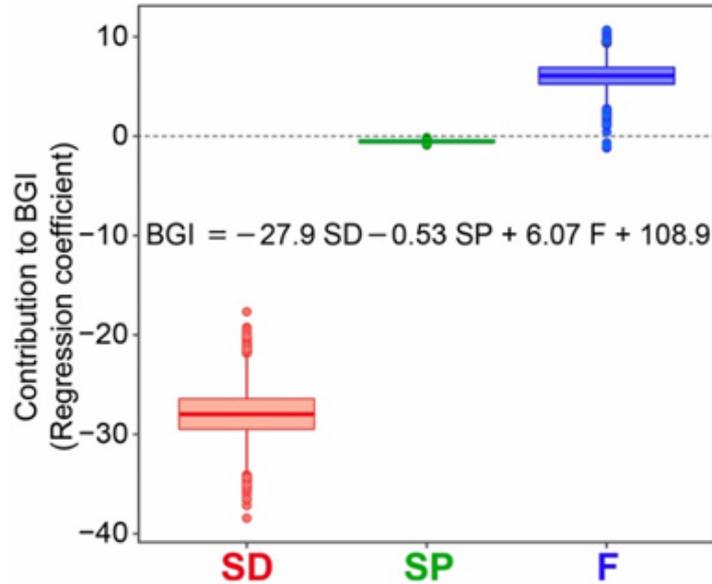
The most robust regression model was:

$$\text{BGI} = -27.9 \cdot \text{SD} - 0.53 \cdot \text{SP} + 6.07 \cdot \text{F} + 108.9 \quad (R^2 = 0.96)$$

In this model, stocking density (SD) was identified as the most influential factor, followed by feeding conditions (F) and stocking period (SP). Notably, lower stocking densities led to significantly higher BGI values, even without supplemental feeding, demonstrating the potential of this species to thrive under semi-natural conditions.

Under non-feeding conditions (F=0) in full-time ponding paddies (SP≥140), a stocking density of ≤0.5 fish/m<sup>2</sup> in 100 m<sup>2</sup> paddies can yield a BGI of approximately 20, equivalent to a harvest of approximately 20 kg per 1 kg of stocked fish. Assuming an 80% survival rate, this translates to roughly 200 kg/ha/year. Scaling this model to Laos's estimated 84,000 ha of water-retaining paddies suggests a potential production increase of 16,800 tons/year from climbing perch alone (Vongvichith et

al. 2018).



**Fig. 8. Evaluation of the contribution of selected parameters [stocking density (SD), stocking period (SP), and feeding condition (F)] to fish productivity (biomass gain index, BGI)**

However, the high metabolic demands of carnivorous species such as climbing perch necessitate low stocking densities for sustainability under natural feed-only conditions. In contrast, omnivorous or herbivorous species can be stocked at higher densities and may achieve higher yields per hectare under similar management systems.

Wider adoption of rice-fish farming depends on improved hatchery infrastructure, reliable fingerling distribution, and technical training for farmers. Nevertheless, rice-fish systems offer a promising pathway for enhancing fish production without competing with terrestrial croplands, contributing to both food security and rural livelihoods.

A common concern among farmers is the potential reduction in rice yield due to the loss of planting area, as rice-fish systems typically involve the construction of refuge channels (~80 cm wide and deep) (Fig. 9) along field margins to provide shelter for fish during low-water periods. However, research findings on the impact of rice yield

are mixed. Although Vromant et al. (2002) reported no significant differences between integrated and conventional paddies, unpublished field studies by Morioka suggested that rice yields may even increase in aquaculture-integrated paddies.

Several mechanisms may explain this phenomenon:

- Biological control: Fish reduce populations of weeds, snails, algae, and other competing organisms.
- Nutrient cycling: Fish excreta may act as natural fertilizer, thereby enhancing soil fertility.
- Pest suppression: Carnivorous fish species may help control insect and crustacean pests.



**Fig. 9. A photo of a rice–fish farming system in Laos, showing the rice planting area and the fish refuge channel (photo taken by the author)**

These ecological interactions suggest that rice-fish systems can maintain or even improve rice productivity; however, further systematic research is required to quantify these effects.

Climbing perch can be effectively cultured at low densities in rice paddies without artificial feeding, thus offering significant aquaculture potential. Given the widespread availability of paddy infrastructure in Laos, scaling up rice-fish farming could substantially increase fish production on a national scale and support rural development.

To realize this potential, the following actions are recommended:

- Prioritize omnivorous species for high-density cultures under natural feeding conditions.
- Invest in hatchery and fingerling supply chains to support reliable stock availability.
- Promote farmer training in integrated rice-fish systems through extension services.
- Encourage participatory research to explore the ecological synergies between fish and rice productivity.

Rice-fish culture represents a biologically integrated and socially inclusive model for sustainable intensification of food production. Appropriate investments and enabling policies can contribute meaningfully to nutritional security, ecological resilience, and rural livelihoods across Southeast Asia.

#### **4.2: Profitability indicators in pond-based aquaculture using indigenous fish species in rural Laos**

In rural Laos, small-scale pond aquaculture is a widespread practice that supports household nutrition and supplemental income. These ponds, often located next to family homes, are typically rain-fed or connected to small streams, and range in size from 200 to 2,000 m<sup>2</sup>. In addition to fish cultivation, they often serve multiple functions such as watering livestock, irrigating gardens, and acting as stores of water during the dry season (Fig. 10).



**Fig. 10. A typical small-scale earthen pond adjacent to a household in rural Laos. These ponds are rain-fed or stream-connected and support multipurpose uses such as aquaculture, livestock watering, and dry-season water storage. (Photo by the author)**

Farmers frequently raise hardy, fast-growing species that match the local environmental and market conditions. In recent years, the Nile tilapia (*Oreochromis niloticus*), an introduced species, has become increasingly dominant because of its broad consumer acceptance and widespread availability of fingerlings from private hatcheries. However, the expansion of tilapia farming has raised concerns about potential ecological risks, including the displacement of native biodiversity. Government reports have acknowledged that aquaculture in Laos remains heavily reliant on exotic species, with relatively limited development in the cultivation of indigenous fish despite their ecological and cultural importance (Khonglaliene 2015). In this context, promoting aquaculture that focuses on indigenous species such as climbing perch (*Anabas testudineus*) or striped catfish (*Pangasianodon hypophthalmus*) is considered more ecologically appropriate. These native species are generally well-adapted to local pond conditions and cultural preferences, though their use remains limited to research trials or specialized community programs. Feed inputs are minimal, relying on natural productivity or rice bran. The infrastructure is simple and inexpensive, making this form of aquaculture accessible even to low-income households.

Although pond-based aquaculture is widely practiced and accessible to low-income households, its economic efficiency remains poorly documented. In the rural areas

of the Indo-Chinese Peninsula, particularly in Laos, pond aquaculture plays a dual role by contributing essential animal proteins and supplementing household income. However, systematic economic evaluations of small-scale operations, particularly those that incorporate feed costs, stocking densities, and market prices, remain limited. As a result, quantitative indicators of profitability remain underdeveloped, making it difficult for farmers to optimize production strategies based on cost-benefit considerations.

To address this gap, pond-based aquaculture trials were conducted using three indigenous fish species with different feeding ecologies: the carnivorous climbing perch (*Anabas testudineus*), herbivorous Java barb (*Barbonymus gonionotus*), and omnivorous striped catfish (*Pangasianodon hypophthalmus*). Trials conducted between 2017 and 2020 in an approximately 1,500 m<sup>2</sup> earthen pond in rural southern Laos explored combinations of feed input and stocking density to identify practical thresholds for profitable operations (Morioka et al. 2021b). Three different regimes were tested: Trial #1 applied high stocking density and daily feeding with commercial feed (June 2017–Feb 2018; 249 days); Trial #2 used low density and minimal feeding with a mix of commercial feed and rice bran (June 2018–Feb 2019; 249 days); and Trial #3 applied medium density with low feeding (Aug 2019–Feb 2020; 189 days). Despite the high operating costs, Trial #1 yielded the greatest biomass and revenue, achieving a net profit 7.6 times higher than that of Trial #2. Trial #3, with intermediate input levels, performed poorly because of low survival and growth rates, resulting in financial losses (Tables 3 and 4).

To assess profitability more precisely, feed inputs were converted into energy (kcal) and monetary costs (Lao Kip, LAK) per fish. Linear regression models were developed to describe the relationship between net income (NI) and feed input:

$$- NI = 16,193 \cdot EA - 6,000,000 \quad (R^2 = 0.93)$$

$$- NI = 3,890.7 \cdot FC - 561,657 \quad (R^2 = 0.99)$$

Where EA represents feed energy allocation (kcal per fish), FC is feed cost allocation (KIP per fish), and NI is net income. These models revealed break-even points at approximately 380 kcal and 150 KIP per fish, respectively (Table 4, Fig. 11), providing clear quantifiable benchmarks for economic planning in small-scale aquaculture.

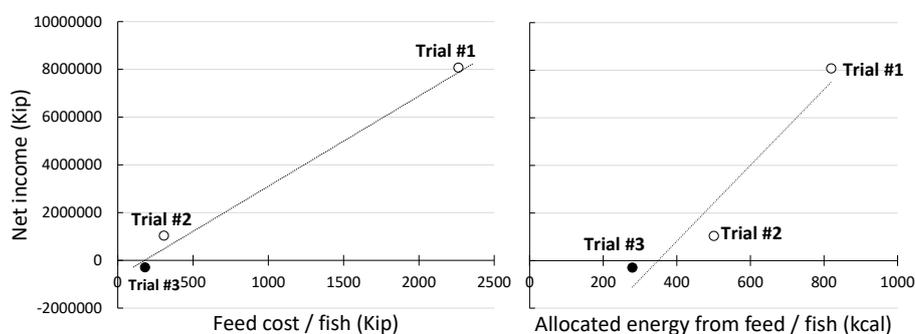
**Table 3. Total cost, yield, survival rate, sales revenue, and net profit, reproduced from Morioka et al. (2021b)**

Trial	Total cost (KIP)	Yield (kg)	Survival (%)	Sales revenue (KIP)	Net profit (KIP)
#1	19,045,000	909	71	27,258,000	8,213,000
#2	3,527,000	154	81	4,611,000	1,084,000
#3	4,804,000	151	51	4,251,000	-283,000

**Table 4. Total feed and per-fish feed energy allocation (kcal), total feed cost and per-fish feed cost allocation, and net income (KIP), reproduced from Morioka et al. (2021b)**

Trial	Total feed energy allocation	Per-fish energy allocation (EA)	Total feed cost	Per-fish feed cost allocation (FC)	Net income (KIP)
#1	4,998,852	819	13,800,000	2,262	8,123,000
#2	1,853,288	501	1,133,000	306	1,084,000
#3	1,424,704	279	925,000	181	-283,000

A comparative analysis revealed that extensive systems, such as Trial #2, generated modest but positive returns with minimal risk, whereas intensive systems, such as Trial #1, required significant inputs but delivered high returns when effectively managed. In contrast, intermediate systems, such as in Trial #3, underperformed because of the inefficient balancing of stocking density and feed, suggesting that small-scale aquaculture is most viable when managed at either clearly defined low- or high-intensity levels, depending on farmers' technical and financial capacities.



**Fig. 11. Feed energy allocation (a) and feed cost allocation (b) per fish, reproduced from Morioka et al. (2021b)**

Based on three years of data, several recommendations emerge to improve profitability in rural aquaculture: (1) adopting EA (~380 kcal) and FC (~150 KIP) per fish as key feed allocation indicators; (2) supporting dual-track strategies, low-input extensive systems for farmers with limited resources, and input-optimized intensive systems for those with better market access; (3) strengthening access to affordable, locally sourced feeds such as rice bran; and (4) providing training in farm record-keeping and financial monitoring to support better decision making.

This study demonstrates that both extensive and intensive pond aquaculture systems can be financially viable in rural Laos if the input levels are aligned with key profitability indicators. By applying feed allocation thresholds based on energy and cost, farmers can more accurately predict outcomes and optimize production strategies to suit diverse socio-economic conditions.

Although this analysis is based on a limited number of trials, it provides a valuable conceptual framework for evaluating feed efficiency and profitability in small-scale aquaculture. The high  $R^2$  values in the regression models suggest internal consistency; however, the limited sample size and lack of environmental variation constrain broader generalization. Further refinement will require the accumulation of additional datasets under diverse ecological and management conditions, including variables such as water quality, seasonal changes, and socioeconomic inputs, such as labor availability or feed-sourcing strategies. Despite these limitations, this approach offers a practical foundation for developing site-specific planning tools and policy frameworks aimed at improving the input-output efficiency and economic sustainability of rural aquaculture households.

## **5: Diversification of feed sources for sustainable aquaculture**

### **5.1: Rising global fishmeal prices: implications for aquaculture**

In recent years, the global price of fishmeal, one of the main protein sources in aquafeeds, has surged, posing serious challenges for aquaculture sustainability. As of April 2025, the average price of fishmeal exceeded USD 1,475 per metric ton, more than doubling in a few years (Index Mundi 2025). Between 2022 and 2023, prices increased by over 30%, driven by a combination of environmental, economic, and geopolitical factors (Aquafeed.com, 2023). A key cause of this price hike is the reduced supply from major producers, particularly Peru. In 2023, El Niño severely impacted anchovy catches off the Peruvian coast, resulting in a 27% decline in global fishmeal production (IFFO 2024). This disruption, coupled with long-standing concerns over overfishing, has made the global fishmeal supply increasingly volatile.

Simultaneously, global aquaculture expansion, particularly in Asia, has fueled a growing dependence on fishmeal. For example, tilapia farming in Asia consumed around 1.7 million tons of fishmeal by 2008, up from 0.8 million tons in 2000 (Macusi et al. 2023). This rising demand, in conjunction with unstable supply, contributes to persistent market volatility and increased production costs. Geopolitical factors, such as the war in Ukraine, have further escalated energy and transportation expenses, increasing the cost of aquafeed ingredients (Aquafeed.com 2023). These combined pressures are particularly burdensome for small- and medium-scale farmers, who often struggle to access affordable, high-quality feed. Given that feed accounts for 60–70% of the total production costs, elevated fishmeal prices present a major barrier to sustainable aquaculture (Macusi et al. 2023).

In response, various efforts are underway to reduce dependence on fishmeal by developing alternative protein sources, such as plant-based meals, microbial proteins, and insect-derived ingredients. Among these, black soldier fly (BSF) larvae have gained recognition for their high protein content, environmental efficiency, and feasibility for the decentralized production of organic waste. Additionally, advances in feed conversion efficiency and tailored feed formulations have enabled farmers to maintain fish growth while minimizing fishmeal inputs. In conclusion, the ongoing fishmeal price crisis highlights the urgent need to diversify protein sources in

aquafeeds, particularly through locally available and sustainable alternatives. Such efforts are essential not only for the economic resilience of aquaculture operations but also for broader goals related to food security and environmental sustainability.

## 5.2: Potential of black soldier fly (*Hermetia illucens*) larvae as a sustainable protein source for aquaculture feed in Laos

Aquaculture has emerged as a key solution for meeting the rising global demand for protein, with production levels approaching those of wild capture fisheries (FAO, 2024). However, the rapid expansion of aquaculture, particularly in emerging economies such as China and India, has drastically increased the demand for aquafeeds, intensifying the pressure on traditional protein sources, such as fishmeal, which is primarily derived from anchoveta (*Engraulis ringens*) (Tveterås and Tveterås 2010; Troell et al. 2014). This has created a sustainability dilemma: wild fish that could be consumed directly by humans have increasingly been diverted into feed for farmed species. In response, global interest has grown in alternative protein sources, including plant-derived meals (e.g., soybean and corn) (Samocha et al. 2004; Cheng et al. 2010), animal by-products such as chicken meal (Wang et al. 2006), and insect larvae (Ido et al. 2015; Sugita et al. 2020). Among these, the BSF (*Hermetia illucens*) (Fig. 12) has garnered attention because of its high protein content, ease of mass rearing, and suitability for waste-to-feed conversion (Magalhães et al. 2017). This review assesses the potential of BSF as an alternative protein source for aquaculture in Laos, with a focus on practical application in small-scale fish farming using climbing perch (*Anabas testudineus*) as a model species (Vongvichith et al. 2020).



Fig. 12. Adult (left) and larvae (right) of the black soldier fly *Hermetia illucens*.

Unlike terrestrial livestock industries, which rely less on fishmeal, the aquaculture sector is heavily dependent on this resource. Consequently, the burden of finding sustainable protein alternatives falls primarily on fish farming (FAO, 2024). However, in countries such as Laos, where no domestic aquafeed industry exists and imported feed is costly and often nutritionally inadequate, the barrier to entry for small-scale aquaculture remains high. Furthermore, long transport and storage times frequently degrade the feed quality through oxidation, especially in hot and humid climates. Thus, locally sourced, low-cost feed alternatives are urgently required to support rural aquaculture development. BSF larvae, which are naturally distributed across tropical and subtropical regions, are now found globally due to increased trade and travel (Marshall et al. 2015). Their large size (>15 mm), high fecundity, and ability to thrive on various kinds of organic waste make them ideal candidates for decentralized feed production. Although industrial-scale BSF production remains costly in developed countries (Sheppard et al. 2007), backyard systems using local resources such as chicken manure for egg laying and fruit waste for larval feed have proven to be viable in Laos (Nakamura et al. 2016). Under subtropical conditions, BSF can be produced throughout the year, further enhancing their suitability for rural use.

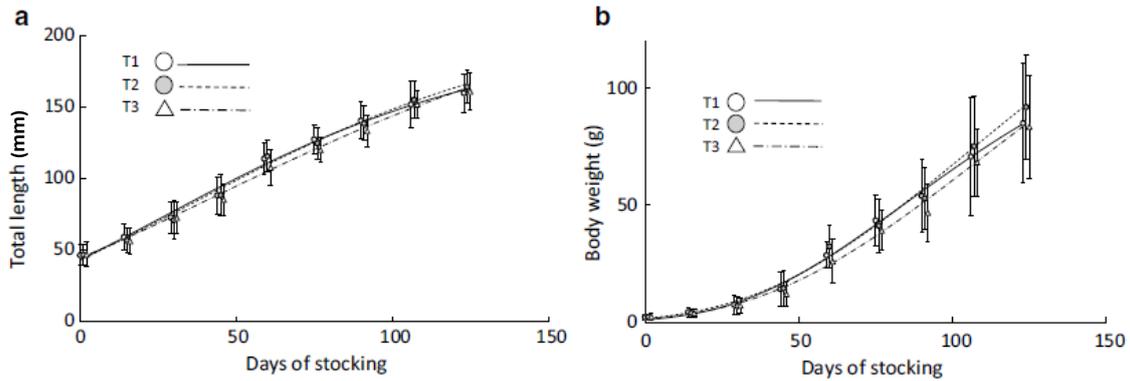
**Table 5. Growth performance of *Anabas testudineus* reared with the feeds T1-T3**

	T1	T2	T3
Initial length (TL, mm)		46.3 ± 7.42	
Final length (TL, mm)	159.9 ± 13.61	164.1 ± 11.67	160.9 ± 12.80
Initial weight (g)		2.2 ± 1.20	
Final weight (g)	85.1 ± 25.50	92.0 ± 22.33	83.5 ± 22.18
Survival rate (%)	82.2 ± 2.02	81.7 ± 9.12	81.7 ± 2.89
Weight gain	31.1 ± 0.73	31.9 ± 3.82	28.1 ± 3.73
Specific growth rate (%)	2.97 ± 0.057	3.04 ± 0.009	2.96 ± 0.002
Feed conversion ratio	3.4 ± 0.15	3.2 ± 0.43	3.2 ± 0.12

No significant differences among the three treatments. (Tukey's HSD test,  $p < 0.05$ )

To evaluate the suitability of BSF larvae as aquafeed ingredients, we conducted feeding trials using climbing perch (Vongvichith et al. 2020), a hardy insectivorous fish native to Laos (Perera et al. 2013). Three experimental diets were formulated: T1, using fishmeal as the sole animal protein (32.5% crude protein); T2, an equal mix of fishmeal and BSF larvae (30.0% crude protein); and T3, BSF larvae as the sole

animal protein (25.0% crude protein). Growth performance indicators, including total length, body weight, survival rate, and feed conversion ratio, showed no significant differences among the three treatments despite the lower protein content in T3 (Table 5, Fig. 13). These findings suggest that BSF larvae are a viable substitute for fishmeal in climbing perch diets, even under reduced protein levels.



**Fig. 13. Growths in total length (a) and body weight (b) of the climbing perch *Anabas testudineus* reared with the feeds T1 – T3. Figure reprinted from Vongvichith et al. (2020)**

**Table 6. Contents of moisture, crude protein, crude fat and ash (% wet matter) in body of *Anabas testudineus* reared with the feeds T1–T3 at stocking and at harvest reproduced from Vongvichith et al. (2020)**

Contents	At stocking	At harvest		
		T1	T2	T3
Moisture	77.6 ± 0.18	63.4 ± 1.48	62.8 ± 1.00	63.1 ± 0.76
Crude protein	14.9 ± 0.33	18.1 ± 0.25 a*	17.8 ± 0.78 a,b	17.2 ± 0.57 b*
Crude fat	2.8 ± 0.12	12.0 ± 0.93 a**	12.3 ± 1.68 a,b	14.4 ± 2.17 b**
Ash	3.8 ± 0.56	5.4 ± 1.03 a,b	5.7 ± 0.68 a*	4.1 ± 0.79 b*
Protein efficiency ratio		0.9 ± 0.04 a*	1.1 ± 0.13 a,b	1.3 ± 0.05 b*
Protein retention		16.4 ± 0.70 a*	18.8 ± 2.32 a,b	21.9 ± 0.84 b*

Different superscripts indicate statistically significant differences. (Tukey's HSD test) (\*  $p < 0.05$ , \*\*  $p < 0.01$ )

However, protein utilization metrics, such as the protein efficiency ratio and retention rate, were significantly higher in fish fed with T3 (Table 6). These findings suggest that climbing perch can assimilate BSF protein more efficiently than conventional fishmeal, enabling a reduced crude protein content in the feed without

impairing growth.

Not all fish species respond equally to insect-based feeds. Growth depression has been linked to limited chitin digestibility in turbot (*Scophthalmus maximus*), rainbow trout (*Oncorhynchus mykiss*), and European sea bass (*Dicentrarchus labrax*) (St-Hilaire et al. 2007; Kroeckel et al. 2012; Xiao et al. 2018). However, climbing perch are naturally insectivorous and likely possess digestive adaptations enabling the digestion of chitin, which is a major component of insect exoskeletons. Similar improvements in digestibility and plant protein assimilation were observed in red sea bream (*Pagrus major*) when housefly larvae were included in their diet, which enhanced the utilization of soybean meal and corn gluten (Ido et al. 2015). The BSF-based diets used in this study also contained plant proteins, suggesting a possible synergistic effect on protein assimilation.

From a practical standpoint, BSF larvae offer multiple advantages for small-scale aquaculture: they can be produced at a low cost using local organic waste, reduce reliance on expensive imported feed, and are well-suited to the dietary preferences of insectivorous species such as climbing perch. However, despite these advantages, several challenges remain unresolved. The protein content of BSF larvae varies depending on the composition of their rearing substrates, potentially affecting their nutritional consistency. Additionally, consumer acceptance of fish reared on insect-based feed remains uncertain in many markets, posing a potential barrier to commercialization. Regulatory frameworks governing the use of insects in aquafeeds are also still evolving in many countries, and clear, standardized processing guidelines are lacking.

Several recommendations can be made to support the broader adoption of BSF-based feeds in aquaculture. First, BSF larvae should be promoted as a complementary, locally produced protein source, especially for insectivorous and omnivorous species. Secondly, training programs for farmers should be developed to support decentralized BSF production using chicken manure and fruit waste. Third, feed formulations should be optimized by combining BSF larvae with plant protein sources to ensure balanced nutrition and cost-effectiveness. Fourth, further species-specific digestibility trials are required to assess broader applicability across aquaculture species. Finally, public awareness and marketing strategies should be developed to improve consumer confidence in insect-based aquafeeds. In

summary, BSF larvae represent a promising alternative protein source for aquaculture, particularly in resource-limited contexts such as Laos. When integrated into local feed systems with appropriate technical support and community engagement, BSF can contribute significantly to sustainable aquaculture development, feed security, and circular resource use.

## 6: Conclusion and future perspectives

This review synthesizes a wide range of interdisciplinary findings to highlight the potential of small-scale sustainable aquaculture systems and technologies for addressing food and nutrition security challenges in rural Southeast Asia, particularly with respect to Laos. Despite economic growth in the region, chronic undernutrition, which primarily manifests as child stunting and maternal anemia, remains prevalent in low-income rice-dependent countries. Nutritional deficiencies are linked to limited animal protein intake and low dietary diversity, particularly in rural mountainous areas with restricted market access.

To address these issues, this review emphasized the critical role of SIS as a nutritionally rich and ecologically appropriate resource. SIS are especially valuable because of their high micronutrient content, ability to thrive in low-input systems, and cultural acceptance in local diets. However, their conservation has increasingly been threatened by habitat degradation, overexploitation, and biological invasion. Species such as *Clupeichthys aesarnensis* are important test cases for biodiversity management, underscoring the need for spatial protection, fishing regulations, and regional cooperation.

Fermentation is a practical and culturally embedded preservation method for reducing postharvest loss. Fermented products like *Pa daek* not only prolong the shelf life but also enhance the functional and economic value of SIS. Standardizing fermentation techniques and improving safety measures, particularly histamine control and microbial safety, can unlock a broader market potential while preserving traditional knowledge.

Integrated rice-fish farming with species such as climbing perch (*Anabas testudineus*) offers an efficient land-use model that enhances both rice yield and protein production without significant external inputs. Similarly, pond aquaculture trials have demonstrated that both extensive and intensive models can be economically viable if feed inputs are optimized according to energy and cost indicators.

The integration of insect-based feed, particularly BSF larvae, represents a transformative innovation. BSF larvae can be locally produced and reared on organic waste and are well-digested by native insectivorous species such as climbing perch. This approach simultaneously addresses feed scarcity and supports circular economic goals.

Looking forward, future efforts should focus on:

- Strengthening biological research and conservation of SIS
- Promoting decentralized fermentation and feed systems
- Scaling integrated rice-fish models through extension services
- Supporting local BSF production and feed formulation training
- Enhancing policy frameworks for sustainable aquaculture.

By combining ecological appropriateness, nutritional impact, and economic feasibility, these multi-faceted technological strategies offer a promising pathway toward resilient, community-driven food systems in Southeast Asia.

## Authors contribution statement

Shinsuke Morioka led the conceptualization and structure of the review, conducted the majority of the literature analysis, and wrote the original draft of the manuscript. Shintaro Kobayashi contributed to selected data analyses and provided overall supervision and critical feedback throughout the development of the manuscript. Both authors reviewed and approved the final version of the manuscript.

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