Promoting Tropical Eel Culture in the Philippines: comparative performance of *Anguilla bicolor pacifica* and *A. marmorata* in captivity

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Eel aquaculture is an important activity in Southeast Asian countries such as Indonesia, Philippines, and Viet Nam. With the decline in the wild fishery stock of cold-water eel species (European eel *Anguilla anguilla*, Japanese eel *A. japonica*, and American eel *A. rostrata* (Tatsukawa, 2003; Gómez-Limia *et al*., 2022), there has been an increasing interest in the culture of tropical eel species as an export commodity. In the Philippines, species of anguillid eels cultured are mainly the Pacific shortfin eel *A. bicolor pacifica* and the giant mottled eel *A. marmorata*. *Anguilla bicolor pacifica* is now being considered as an alternative to *A. japonica* (Muthmainnah *et al*., 2016), being the most preferred eel species for consumption in East Asian countries. However, *A. marmorata*, which comprised the bulk of the wild glass eel catch in the Cagayan River, Philippines, has rarely been cultured as an export commodity. Comparison of performance and feed utilization may provide relevant information on the culture requirements of these two eel species under cage conditions.

The Philippines is not traditionally an eel-consuming country. However, eel culture has already been practiced in the country since the early 1970s. Tropical eels, locally known as 'igat' or 'palos' are snake-like creatures that inhabit marine, brackishwater, and inland waters such as rivers and tributaries. There are about 19 species/subspecies (Froese and Pauly, 2022) of the freshwater eels of the genus *Anguilla*, but only five cold-water species (American eel *A. rostrata*, European eel *A. anguilla*; Japanese eel *A. japonica*; Australian shortfin eel *A. australis*, Australian longfin eel *A. dieffenbachii*) are commonly cultured. In the Philippines, seven species (*A. japonica, A. celebesensis, A. marmorata, A. interioris, A. bicolor bicolor, A. bicolor pacifica, A. luzonensis*) have been identified (Briones *et al*., 2007; Jamandre *et al*., 2007; Teng *et al*., 2009; Watanabe *et al*., 2009; Han *et al*., 2012; Aoyama *et al*., 2015). However, only two species, *A. marmorata* and *A. bicolor pacifica* are predominantly cultured.

The giant mottled eel *A. marmorata* (**Figure 1a**) is naturally distributed in the tropical and subtropical western Pacific and Indian Oceans (Luo *et al*., 2013; Arai, 2016). Considered one of the largest anguillid eel species, it can reach up to a maximum length of 148 cm (Leander *et al*., 2014). In Yakushima Island, Japan, *A. marmorata* inhabits rivers and tributaries with substrates made of large rocks, boulders, and cobbles (Kumai *et al*., 2020). They are also found in crevices in their wild habitat (Valdez and Castillo, 2016).

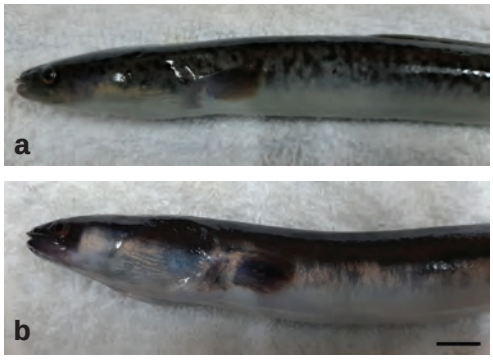

Figure 1. Tropical eels **(a)** *Anguilla marmorata* and **(b)** *A. bicolor pacifica (Scale bar = 10 mm)*

Meanwhile, the Pacific shortfin eel *A. bicolor pacifica* (**Figure 1b**) is one of the commercially important eel species in Southeast Asia, particularly in Indonesia, Philippines, and Viet Nam (Crook, 2014; Gollock *et al*., 2018; Aoyama *et al*., 2018; Marini *et al*., 2021). It is preferred for culture in commercial eel nursery farms as it fetches a higher market price and has the same appearance and flesh quality as Japanese eel (Cuvin-Aralar *et al*., 2019).

Eel collection and culture areas in the Philippines

Eel farming is still dependent on wild glass eels collected from estuaries and tidal rivers (Liao *et al*., 2002). Several fishing grounds in the Philippines (**Figure 2**) are potential sources of glass eels for nursery culture.

Wild eel stocks, mostly *A. marmorata*, are sourced from the Cagayan River (**Figure 3**). This eel species also comprised the bulk of the wild glass eel catch from the Pangi River (Valdez and Castillo, 2016). Lagonoy Gulf is also considered a potential glass eel fishing ground with a higher abundance of *A. bicolor pacifica* than *A. marmorata* (Nieves and Nolial, 2019). In Southern Mindanao, glass eel collection areas for *A. bicolor pacifica* include Rio Grande de Mindanao, Davao Gulf, and Sarangani Bay (E.C. Ame, personal communication, 17 December 2021).

The Philippine Bureau of Fisheries and Aquatic Resources (BFAR) disclosed that eels are cultured in 23 provinces (E.C. Ame, personal communication, 17 December 2021). In these eel culture areas, farming techniques of the Philippine native eels are adopted mainly from the culture of European and Japanese eel species, which are commonly done in concrete

tanks or ponds. A culture of glass eels or elvers in cages inside a concrete pond is not common, although this culture practice has been documented in the southern Philippines (Surtida, 2000). Examining the performance of these two eel species reared simultaneously under cage conditions may offer an alternative culture method.

Figure 2. Glass eel fishing grounds in the Philippines

Figure 3. Glass eels collected *(top)* by eel fishers *(bottom)* from the Cagayan River in the Philippines

Cage as a suitable environment for the growth of *A. bicolor pacifica*

Aya and Garcia (2022) conducted a study to compare the suitability and performance of *A. bicolor pacifica* and *A. marmorata* in cage conditions. They reared the elvers of these two eel species with 1.73 g in weight in hapa net cages measuring 1.0 m × 1.0 m × 1.5 m which were suspended in outdoor concrete tanks. The growth and feed utilization of elvers were monitored throughout the 210-day trial (**Figure 4**) in the grow-out facility of the Binangonan Freshwater Station of SEAFDEC Aquaculture Department in Binangonan, Rizal, Philippines.

Figure 4. Cage set up for rearing *A. bicolor pacifica* and *A. marmorata* elvers

Results of the growth trial showed that both *A. bicolor pacifica* and *A. marmorata* elvers had comparable survival rates of 80.0 % and 74.4 %, respectively, at the end of the culture period. In comparison, the culture of *A. marmorata* glass eels to elver stages in many eel farms in Viet Nam only had a 60.0 % survival rate (Thuc and Van, 2021). However, *A. bicolor pacifica* weighed 64.51 g which was much heavier than *A. marmorata* which only weighed 7.77 g (**Figure 5**). Water quality parameters examined throughout the growth trial were within the acceptable range for the culture of eel species. This result suggests that the growth difference between the two eel species was not explained by environmental factors since they were reared under similar cage conditions. It is reported that *A. marmorata* lives in shallow and fast-flowing water (Itakura and Wakiya, 2020), while *A. bicolor pacifica*, a plain eel similar to *A. japonica*, may stay in areas with deep and slow-flowing water (Kumai *et al*., 2020). Hence, water depth and velocity may have explained the findings described above.

Figure 5. Tropical eels *Anguilla bicolor pacifica* **(a-b)** and *A. marmorata* **(c-d)** reared in hapa net cages

Other growth parameters such as percent weight gain, specific growth rate, and yield were higher for *A. bicolor pacifica*, demonstrating the suitability of this species in cage culture conditions. In the case of *A. marmorata*, the closed environment, such as small hapa net cages and the absence of physical substrate, may have resulted in the poor growth of this species.

Feed acceptability: an important issue for growing *A. marmorata*

A formulated eel powder diet (49.77 % crude protein and 10.21 % crude lipid) made into a paste was given to both eel species during culture. The process of making a paste diet involves adding 700 ml of water to 1 kg of eel powder diet and mixing the dough mixture for 15 min using an electric mixer (**Figure 6**). The proximate composition of the eel powder diet was based on the information available for *A. japonica* (Arai, 1991; Damusaru *et al*., 2018). Aya and Garcia (2022) reported that *A. bicolor pacifica* consumed more feeds than *A. marmorata*, resulting in a faster growth rate of the former species. This means that the paste diet was well accepted and digested by *A. bicolor pacifica* than in the case of *A. marmorata*. Thus, feed acceptability may explain the observed feed intake between the two eel species. The addition of feeding stimulants may improve the feed acceptance of *A. marmorata* juveniles.

Figure 6. Preparation of formulated eel powder to paste diet before feeding to elvers

Way Forward

In comparison to the giant mottled eel *Anguilla marmorata*, information on the performance of the Pacific shortfin eel *A. bicolor pacifica* during culture is limited. The aforementioned findings demonstrated that the faster growth rate of *A. bicolor pacifica* than *A. marmorata* suggests the suitability of this eel species under similar cage culture conditions. Supplementation of feeding stimulants in diets for *A. marmorata* is an area that requires further research to improve the performance of this species with potential as an export or valuable culture commodity.

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