RESEARCH ARTICLE

Mixed Methods Approach in Documenting Aquaculture Practices and Market Dynamics of the Freshwater Eel *Anguilla* spp. Industry in the Philippines

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ABSTRACT

Freshwater eels are emerging high-value species in aquaculture in the Philippines. However, the freshwater eel industry in the country remains under-documented, and most of the culture technologies employed are based on temperate eel culture. This study employed a mixed methods approach in primary and secondary data gathering. Key industry players across the value chain were identified and interviewed from February to October 2017 to gather baseline information on aquaculture practices, glass eel capture fisheries, and trading of anguillid eels. Secondary data from BFAR supplemented interview findings. Industry practices in 25 eel farms across the country were documented, the majority (80–85%) of which were nursery farms found in Regions 3 and 4A. There were five grow-out farms, with the largest production facility in Cabadbaran, Agusan del Norte. Different culture facility designs, glass eel stocking practices, water management, aeration systems, feeding schemes, and disease management were described. Most farms used concrete tanks with flow-through systems stocked at 500–1500 pcs/m^2 and commercial feeds with binders, bloodworm, or trash fish as feeds. Four major glass eel collection sites were identified: Cagayan, the Davao region, General Santos-Sarangani, and Cotabato City-Maguindanao. The glass eel supply chain starts with collectors, followed by stockers and consolidators who consolidate glass eel catch prior to selling to growers or traders. After the desired eel size (6 inches) is achieved through culture, growers or traders sell the eels to exporters, local institutional markets, and local eel processing plants. The results of this study provide essential information that will pave the way for science-based research to improve the existing culture practices and fisheries policies that will help boost aquaculture production and guide proper management programs.

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1. INTRODUCTION

Freshwater eels (Family Anguillidae) are high-valued species often traded in East Asian countries (Shiraishi and Crook 2015). Global demand has been increasing due to market expansion and the increased popularity of gourmet eel dishes, such as *kabayaki* (Siriraksophon et al. 2014). Kabayaki is a Japanese method of grilling, wherein the fish is filleted, deboned, butterflied, skewered, grilled, and glazed with sweet soy sauce. With such demand, a drastic decline in populations of temperate eels (e.g., *Anguilla anguilla*, *A. rostrata*, *A. japonica*) has been reported (Castonguay and Durif 2016), which could lead to extinction if stocks are not properly managed. Shifting the demand toward tropical eels (SEAFDEC 2020) may reduce the fishing pressure on temperate eels. In Southeast Asia, there is an increase in the gathering of glass eels and elvers for aquaculture to produce adult eels, specifically *Anguilla bicolor* (*A. bicolor bicolor* and *A. bicolor pacifica*) from Indonesia and the Philippines (Muthmainnah et al. 2021). This species is an alternative to the Japanese eel (*A. japonica*) due to its similarity in taste and texture (Arai 2015).

The global trade of *Anguilla* spp. is categorized into four main commodities – live, fresh, frozen, and smoked or prepared eels (Crook 2014). The Philippines predominantly exports live eels (HS Code 030192), small quantities of frozen eels (HS Code 030326), and fresh or chilled eels (HS Code 030274). Over the last 20 years, there has been a 39% increase in the volume of live eels exported from the Philippines, from 47.47 metric tons valued at USD 98,889.00 in 2000 to 121.5 metric tons valued at USD 546,764.00 in 2020 (United Nations comtrade 2022). In 2020, the Philippines exported about 2.11 metric tons of frozen eels valued at USD 6,520.00 and 60 kg of fresh or chilled eels valued at USD 190 (United Nations comtrade 2022). The ban on exporting freshwater eels smaller than 15 cm in length was implemented on May 2, 2012, under the Fisheries Administrative Order (FAO) No. 242 to manage and sustain anguillid eel resources. The ban discouraged the export of glass eels and instead encouraged the aquaculture of eels until the legal size (15 cm or 6 inches) for export was achieved.

Anguillid eels are catadromous species. They spawn in the sea, migrate to the shore as leptocephali (larvae), and metamorphose into glass eels (juveniles). As they migrate into estuaries and freshwater, they develop pigmentation (elvers) and remain there as yellow eel until they reach sexual maturity as silver eel and return to the sea to spawn (Arai 2015). There are seven species of freshwater eels from the family Anguillidae in the Philippines, including *Anguilla bicolor pacifica*, *A. marmorata*, *A. luzonensis*, *A. japonica*, *A. celebesensis, A. interioris* and *A. borneensis* (Shirotori et al. 2016; Watanabe et al. 2009). Among these, *A. marmorata* (giant mottled eel) and *A. bicolor pacifica* (shortfin eel) are commonly cultured in the Philippines (Cuvin-Aralar et al. 2019).

Aquaculture of anguillid eels began in Japan, Italy, and France in 1879 (Matsui 1952; Gousset 1990). Commercial production began in the early 1960s when formulated feeds became available (Liao et al. 2002). Although most global eel production comes from aquaculture, the industry entirely depends on wild juveniles due to the lack of hatchery technologies. In the Philippines, eel culture began in the early 1970s in the Cagayan River, where commercial quantities of elvers are collected (Surtida 2000). In 1973, the Bureau of Fisheries and Aquatic Resources (BFAR) evaluated the feasibility of culturing anguillid eels for export (Cremer 1976). The experimental culture showed that *A. bicolor* is suitable for culture, as its elvers grew well on groundfish with vitamin additives at 6:1 feed conversion, while fingerlings and large eels (>3 g) grew well on pelleted feeds. Aside from the Cagayan River, the rivers of Cotabato and Davao del Sur provinces in southern Philippines also have elvers in commercial quantities, and three farms were reported to have eel culture (Surtida 2000). Two farms in General Santos City cultured eels, but the mortality rate was high. Another farm in South Cotabato grows eel in tanks or ponds (5 x 5 m^2; water depth, 1 m) at a stocking density of 200–300 elvers for 9–10 months to get the ideal market size of about 300 g per piece, the size required by Manila exporters who ship to Japan and Taiwan (Surtida 2000).

There are several studies on freshwater eels in the Philippines which mainly involve the biology (Arai et al. 2003), genetics (Jamandre et al. 2007; Lee et al. 2015; Ding et al. 2012), ecology (Tabeta and Mochioka 1988; Briones et al. 2007; Kuroki et al. 2012; Han et al. 2016), and nursery production in eel farms and research institutions (Cuvin-Aralar et al. 2019). Studies have only been conducted in several provinces reporting glass eel occurrence and fisheries, particularly in the Cagayan River in Northern Luzon (Tabeta et al., 1976; Ame et al. 2013; Yoshinaga et al. 2014; Aoyama et al. 2015); Lagonoy Gulf in the Bicol region (Nieves et al. 2021); and Southern Mindanao (Shirotori et al. 2016; Vargas 2016). Ame et al. (2013) investigated the supply chain of anguillid eels from glass eel collection in the Cagayan River to trade with local consolidators and exporters.

The freshwater eel aquaculture industry remains under-documented, and most of the culture technologies employed are based on temperate eels. To the best of our knowledge, there is only one publication on the nursery of anguillid eels in the Philippines (Cuvin-Aralar et al. 2019). In the present study, a mixed methods approach was employed to obtain baseline information on glass eel fisheries and aquaculture practices. The key players in the eel supply chain, from collection to marketing, are briefly discussed, including collectors, stockers, consolidators and growers or traders, buyers, and exporters. Through this study, problems in the industry and gaps in research and policy implementation were identified so that these can be addressed by the relevant research institutions, government agencies, and interested stakeholders.

2. MATERIALS AND METHODS

2.1 Data gathering

The study was conducted from February to October 2017 using a mixed methods approach using two sets of interview schedules, one for eel growers (Annex 1 – aquaculture industry practices) and another for consolidators or stockers, traders, and exporters (Annex 2 – glass eel fisheries).

Information collected for industry practices includes sources of glass eels, farm facilities and operations, marketing, and challenges. The information collected for glass eel fisheries includes glass eel collection (i.e., seasonality, fishing gears used), marketing, and trade. Pilot testing of the interview schedules was done with consolidators in General Santos and an eel culture facility in Guiguinto and Pandi, Bulacan and Magalang, Pampanga in February 2017, while the actual interview started in March 2017. In addition, supplementary data on the volume of eels exported was obtained from BFAR to get insights into the status of freshwater eel production through the years.

2.2 Selection of study participants

Key industry players interviewed in this study were identified based on Ame et al. (2013). The participants were divided into two types based on their involvement in the eel industry. For the first type, eel growers and exporters were considered as one. Eels were mainly exported by growers directly. Some were sold to other growers and eventually exported. Due to their technical knowledge and skills, the head of operations was chosen as the study participant. As for the second type, glass eel collectors and stockers were considered as one because of their role in glass eel collection. The term "stockers" refer to glass eel collectors who serve as community-based consolidators and have direct contact with consolidators in regional centers (i.e., Davao City, General Santos City, Aparri). They, in turn, consolidate glass eels caught all over the region and sell them to growers in various parts of the country. Therefore, stockers and consolidators were chosen as study participants for the glass eel trade interviews.

The regional offices of BFAR and the provincial and municipal agricultural offices of local government units (LGUs) identified key players across the Philippines. Since data on the eel industry is limited, all participants referred by BFAR and the LGUs were interviewed. Eel growers from 25 eel culture facilities in 16 provinces across nine regions in the country, and 13 glass eel stockers and four consolidators in three out of the four major glass eel collection areas in (1) the Davao region, (2) General Santos City and Sarangani, and (3) Cotabato and Maguindanao were interviewed in this study. The LGU in Cagayan, Aparri, did not provide information on local glass eel collectors and consolidators but provided data on glass eel catch production. Figure 1 summarizes the study areas where interviews were conducted.

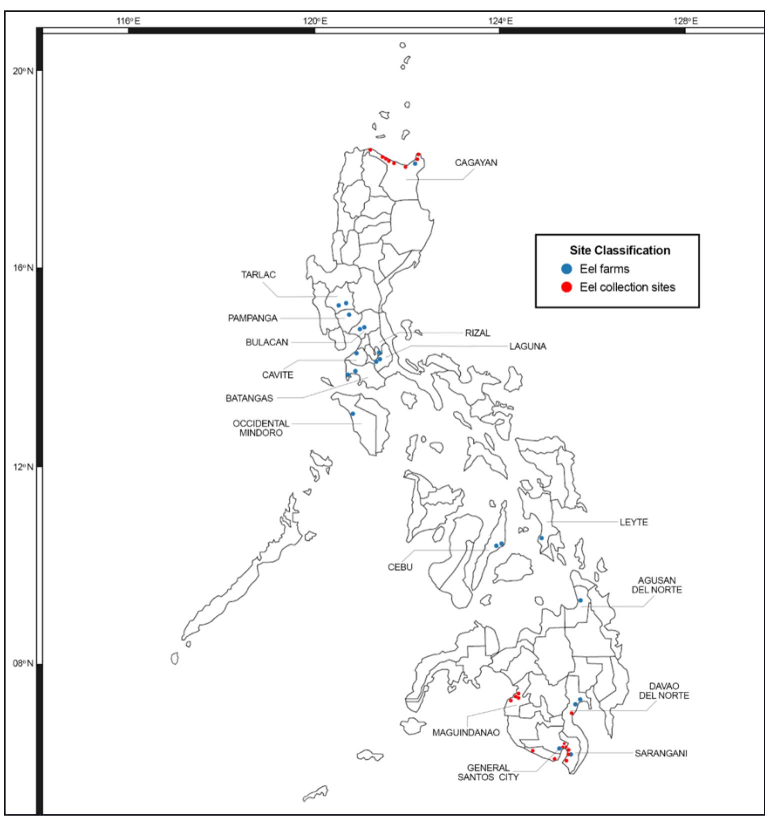

Figure 1. Major eel collection sites and farms in the Philippines.

2.3 Data analysis

Descriptive statistics were used to analyze the data. The farm data was organized in a table according to differences in facility design and farm management systems. The supply chain from glass eel collection, culture, local trade, and export was presented in a diagram.

Production was estimated based on the survey interview on stocking density, survival rate, and average body weight (ABW). For glass eels, production was estimated based on the maximum carrying capacity of the tank system in most farms. For juvenile eels (also called kuroko, a Japanese term for juvenile eels and often used in the industry), production was estimated using the stocking density, average survival rate, and average body weight.

RESULTS

3.1 Supply chain

The freshwater eel supply chain described in this study is summarized in Figure 2. The commodity flow started from glass eel collectors along river mouths. Stockers consolidate the community's catch and sell them to consolidators across the region. The consolidators would then sell glass eels to eel growers, who would culture until the legal size for export. Marketable-size eels were either directly exported, sold to exporters, or sold to local institutional markets or eel processing plants.

3.2 Glass eel capture fisheries

Four major glass eel collection sites were identified (Figure 1). Eel growers directly sourced glass eels from Cagayan (n = 11), Davao region (n = 6), General Santos City and Sarangani (n = 5), and Cotabato City and Maguindanao (n = 3). In Luzon, Cagayan was the largest supplier of glass eels in most eel farms in the country.

Two anguillid eel species typically dominate glass eel catch in the said collection areas, namely *A. bicolor pacifica* and *A. marmorata.* However, due to the small size of glass eels, inexperienced glass eel collectors and farm workers often have difficulty identifying and sorting species, and inappropriate handling leads to stress and mortalities. According to eel farm owners and operators interviewed in this study, only one consolidator based in General Santos City could sort glass eels up to 90 to 95% *A. bicolor pacifica* composition. Such a claim, however, is not supported by molecular data.

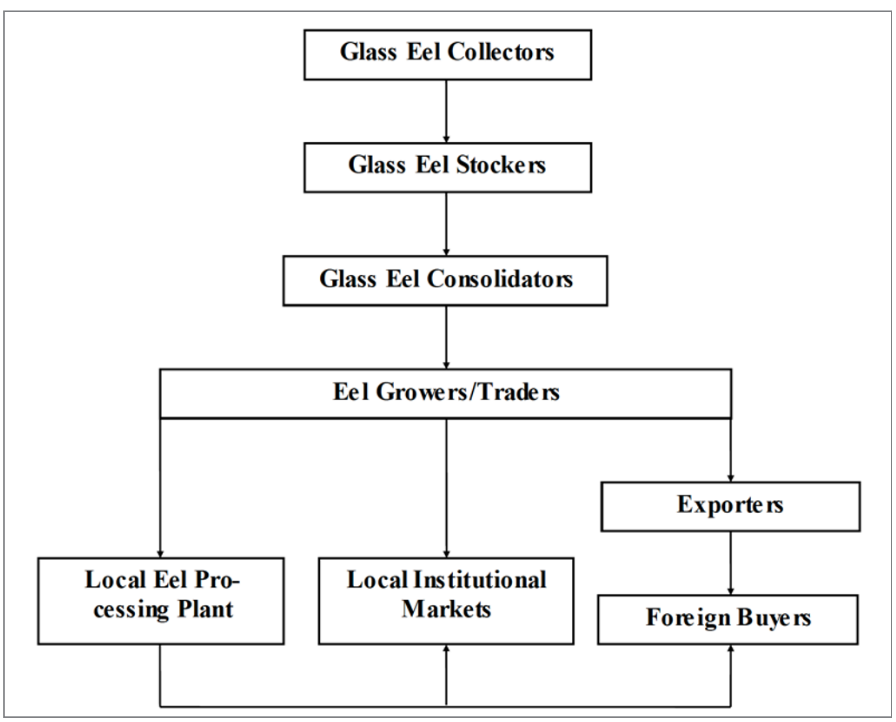

Figure 2. Supply chain of eel from collection to marketing.

In the province of Cagayan, municipalities involved in glass eel collection were located along the Babuyan Channel and the mouth of the Cagayan River, particularly Claveria, Pamplona, Abulug, Aparri, Buguey, Gonzaga, and Sta. Ana (Figure 1, sites in red dots). Glass eels are then sold to consolidators in Aparri. In Davao, glass eels were collected in rivers along the Davao Gulf and are sold to consolidators in (1) Hagonoy, Davao del Sur, (2) Mati, Davao Oriental, and (3) Malita, Davao Occidental.

Eel collection was done all over Saranggani province and General Santos City, particularly in the municipalities of Glan, Maitum, Maasim, Alabel (Ladol River), and Malapitan (Lun Padidu and Lun Masla Rivers), and along the Baluan and Buayan River in General Santos City. In Cotabato City and Maguindanao, glass eel collection was done at the mouth of the Rio Grande de Mindanao, particularly in the municipalities of Sultan Kudarat, Sultan Mastura, and Datu Odin Sinsuat. Glass eels were then sold to the consolidator in Cotabato City.

Glass eels were caught by collectors and sold to growers year-round, with peak season observed during the southwest monsoon season (June to October). The volume of glass eels was also observed to increase during the last quarter of the year as well as several days before and after the new moon. The lean season is from March to April.

A. bicolor pacifica are often collected in areas with rocky substrates, while *A. marmorata* are often found in muddy areas. Fishing gear used includes net traps, scoop nets, fry bulldozers, fine mesh nets, and a simple or a modified form of fish corral (Supplementary Figure 1), as well as other materials, such as light and oxygen tanks, which are often provided by consolidators to glass eel stockers and collectors. Net traps (i.e., fyke net) are primarily used for glass eel collection in the area wherein the fishing gear is made of eight meters mosquito net, rope, and bamboo sticks and consists of a set of net traps to intercept as many eels as possible. These net traps are set in the afternoon, and when the tide turns, the trapped glass eels are collected using a scoop net. After buying glass eels from collectors and stockers, consolidators keep the glass eels until the required amount ordered by the grower or buyer is achieved. Glass eels were packed at around 150–200 g (750–1,400 pieces) per plastic bag and transported to growers either by land or air.

3.3 Anguillid eel nursery and grow-out culture

Among the 25 eel culture facilities surveyed (Figure 1), the majority were in Region III (7 farms in Bulacan, Pampanga, Tarlac, Zambales) and Region IV-A (7 farms in Batangas, Cavite, Laguna, Rizal). The remaining eel farms were in Region XI (3 farms in Davao City and Davao del Norte), Region XII (2 farms in General Santos City and Sarangani), and Region VII (2 farms in Cebu). The distribution of other eel farms was as follows: Region II (Cagayan), Region IV-B (Occidental Mindoro), Region VIII (Leyte), and Region XIII (Agusan del Norte). Most of these eel farms were near international airports (e.g., Metro Manila, Cebu, Davao, General Santos City). Descriptions of identified eel culture facilities in the country are summarized in Table 1.

Twenty of the eel farms surveyed were engaged in nursery culture. Eel nursery culture lasts 5–8 months, depending on the growth rate. According to growers, the feeds used largely influenced the growth rate. The culture period for eels fed with commercial feeds from Japan is five months, while it takes 6–7 months using local commercial eel feeds. The remaining five eel farms were for grow-out culture. Moreover, one eel farm in Cabadbaran City, Agusan del Norte, has an eel processing plant that processes eels harvested from the grow-out ponds.

The majority (n = 10) of eel culture facilities in the country were solely owned by Filipinos who were either experienced in the culture of other finfish species or had been trained in eel culture abroad. Other farms were co-owned by Filipinos with Japanese (n = 8), Taiwanese (n = 4), or Korean (n = 3) partners who have direct contact with buyers abroad or have their own eel grow-out farm or processing plant overseas.

Concrete tanks (Supplementary Figure 2) were commonly used by most eel culture facilities (n = 19), with varying shapes (i.e., rectangular, square, and circular) and sizes (2-100 m3). Smaller tanks (2 m × 1 m × 1 m) were used during the first few months of culture, then transferred to larger tanks when target sizes were achieved. Some farms also used canvas tanks for nursery culture (n = 3). Concrete ponds were commonly used in addition to concrete tanks for eel farms that proceed to grow-out culture (n=3).

Glass eels were usually stocked per kilogram, which may consist of around 6,500 to 7,000 (for *A.*

Table 1. Description of eel culture facilities in the Philippines.

Location	Region	Culture Phase	Type of tanks/ponds	Stocking density (pcs/m2)	Aeration system	Filtration system	Water exchange system	Feeding scheme	Survival Rate (%)
1. Gonzaga, Cagayan	2	Nursery	Square concrete tanks	1000	Air stone diffuser aerator	Sand stone charcoal	Flow through	Tubifex sp. 1st 2 weeks, commercial feeds	50
2. Pandi, Bulacan	3	Nursery	Circular, rectangular, square with dead corner tanks	750-1000	Air stone diffuser & perforated pipe	Biofiltration, sand, stone & charcoal	Flow through	Tubifex sp. 1st 2-3 weeks, commercial feeds	50
3. Guiguinto, Bulacan	3	Nursery	Circular, rectangular, square with dead corner tanks	750-1000	Air stone diffuser & perforated pipe	Biofiltration, sand, stone & charcoal	Flow through	Tubifex sp. 1st 2-3 weeks, commercial feeds	80
4. Magalang, Pampanga	3	Nursery	Circular and rectangular concrete tanks	750-1500	Air stone diffuser	None	Flow through	Commercial feeds w/ minced round scad and Tubifex sp. during the 1st 3 weeks	84
5. Magalang, Pampanga	3	Nursery	Circular and rectangular concrete tanks	750-1500	Air stone diffuser	None	Flow through	Minced round scad mixed w/ commercial feeds	88
6. Concepcion, Tarlac	3	Nursery	Circular and rectangular concrete tanks	750-1500	Air stone diffuser	Sand, stone, charcoal	Flow through	Minced round scad mixed w/ commercial feeds	91
7. Capas, Tarlac	3	Nursery	Circular and rectangular concrete tanks	750-1500	Air stone diffuser	None	Flow through	Minced round scad mixed w/commercial feeds	85
8. Calaca, Batangas	4-A	Nursery	Rectangular and circular concrete tanks	4000	Air stone diffuser	Biofoam, filter fiber & UV light	Flow through	Commercial feeds	70-80 (glass eel) 94 (Kuroko)
9. Calaca, Batangas	4-A	Nursery with Grow-out	Rectangular and circular concrete tanks	4000	Air stone diffuser	Biofoam, filter fiber & UV light	Flow through	Commercial feeds	70-80 (glass eel) 98 (Kuroko)
10. Calatagan, Batangas	4-A	Nursery	Circular, rectangular concrete tanks	4000 (rectangular tanks) 1,500 (circular tanks)	Air stone diffuser	Biofoam, filter fiber & UV light	Flow through	Commercial feeds	50-60 (glass eel) 70 (Kuroko)
11. Pila, Laguna	4-A	Nursery with Grow-out	Rectangular and circular tanks	500-600	Perforated pipe	Sand stone charcoal foam	Flow through	Tubifex sp. 1st 2 wks; commercial feeds mixed w/ round scad	96
12. Pila, Laguna	4-A	Nursery	Rectangular and circular tanks	500-600	Perforated pipe	Sand stone charcoal foam	Flow through	Tubifex sp. 1st 2 weeks; commercial feeds mixed w/ round scad	85

Continuation of Table 1. Description of eel culture facilities in the Philippines.

13. Victoria, Laguna	4-A	Nursery	Earthen and concrete ponds	500-600	Paddle wheels	None	Flow through	Tubifex sp. 1st 2 weeks; commercial feeds mixed w/ round scad	80
14. Jalajala, Rizal	4-A	Grow-out	Earthen and concrete ponds	500-600	Paddle wheels	None	Flow through	Tubifex sp. 1st 2 weeks; commercial feeds mixed w/ round scad	80
15. General Trias, Cavite	4-A	Nursery	Rectangular tanks	80	Air stone diffuser and jet aeration	Reverse osmosis	Recirculating	Commercial feeds	90
16. Sta. Cruz, Occidental Mindoro	4-B	Nursery	Rectangular concrete tanks	3000	Air stone diffuser	Biofiltration	Flow through	Local and imported commercial feeds w/ cassava powder	95
17. Talisay City, Cebu	7	Nursery	Rectangular tanks and square tank with dead corners	500-1500	Air stone diffuser	Sand stone charcoal foam	Recirculating using biofoam, fiberfil and hard coral fragments as filter	Commercial feeds mixed w/ imported feeds, shrimp or Acetes sp.	92
18. Cebu City	7	Nursery	Rectangular tanks and square tank with dead corners	500-1500	Paddle wheels	Biofiltration	Recirculating using biofoam, fiberfil and hard coral fragments as filter	Commercial feeds mixed w/ imported feeds, shrimp or Acetes sp.	90
19. Hindang, Leyte	8	Nursery	Circular tanks	2000	Perforated pipe & shower-type	Sand stone charcoal foam	Flow through	Commercial feeds	85
20. Toril, Davao City	11	Nursery	Concrete tanks	750	Air stone diffuser	Charcoal, pebbles & sand	Flow through	Imported eel feeds	86
21. Carmen, Davao Del Norte	11	Nursery	Canvas tanks	750	Air stone diffuser	None	Flow through	Imported eel feeds	75
22. General Santos City	12	Nursery	Concrete and canvas tanks	850-1000	Perforated pipe	Sand stone charcoal foam	Recirculating system	Commercial feeds mixed w/ fish oil	98
23. General Santos City	12	Nursery	Concrete and canvas tanks	850-1000	Air stone diffuser	Charcoal foam	Flow through	Commercial feeds mixed w/ cassava starch & multivitamins	94
24. Alabel, Sarangani	12	Grow-out	Concrete and canvas tanks	850-1000	Perforated pipe	Filter fiber	Recirculating	Commercial feeds mixed w/ fish oil	95
25. Cabadbaran City, Agusan del Norte	13	Nursery with Grow-out	Concrete tanks (nursery), Concrete ponds (transition and grow out)	600 (tank) 200 (pond)	Paddle wheels	Biofiltration	Flow-through for tanks	Commercial feeds mixed w/ fish oil	98 (nursery) 50 (grow-out)

bicolor) and 6,000-6,500 (for *A. marmorata)* individual eels, ranging from 0.5 kg (for a 1 m × 2 m tank) to 20 kg (for 15 m × 15 m tank) per tank. Most of the eel farms (n = 19) have stocking densities ranging from 500 to 1,500 pcs/m^2, while others stock at more than 1500 pcs/m^2 (n = 5) or less than 500 pcs/m^2 (n = 1), suggesting that cultured eels were often stocked at high stocking densities. Thinning out was periodically done by separating by size to avoid cannibalism, overcrowding, and food competition, possibly leading to lower growth and survival rate.

Freshwater eels were transported and cultured at 0 ppt salinity. During stocking, however, salinity was raised to 0.5 to 3 ppt to prevent diseases for up to three to seven days. Ambient temperature during culture usually ranged from 25 to 30°C. During stocking, glass eels were maintained at low temperatures (18–20°C) using ice to lower metabolism and reduce stress. Temperature is gradually increased after acclimation by removing the ice and adding flow through water from the reservoir tank. The pH of the water was maintained at 7.5 to 8.5 through water change. The water level was kept low from 10 to 60 cm depending on the glass eel size during nursery culture and increased to 1 to 1.5 m during the grow-out culture. Table 2 summarizes the water parameters maintained in the eel farms.

Three common types of aeration systems were used in eel culture: (1) air stone diffuser aerator, (2) perforated pipe aerator, and (3) paddle wheels (Supplementary Figure 3). Seventeen farms used air stone diffuser aerators which consist of air tubes suspended above the tank with an air stone at its end. Perforated pipe diffuser aerators consist of perforated PVC pipes in the tank bottom. Among grow-out culture facilities, paddle wheels were typically used in concrete ponds (n = 4), while others (n = 7) used perforated pipe aerators in concrete tanks. Two eel culture facilities also had other types of aeration systems, which include shower-type aeration and a jet-type aeration system (Supplementary Figure 4). A shower-type aeration is an improvised design wherein perforated pipes are hung several meters above the tanks. Aerated water is then introduced into the tanks from these pipes, simulating a bathroom shower. A jet-type aeration system involves rapidly flowing water from pipes with narrow openings.

All the eel culture facilities were located inland and sourced their water through deep wells. Majority of the eel culture facilities (n = 16) do not employ a filtration system. Facilities with mechanical filtration (n = 6) use sand, charcoal, coral rubble, and pebbles as filtering materials (Supplementary Figure 5).

Different water management systems were employed, such as flow-through, recirculating, and standing water (zero or minimal water exchange). When the water supply was sufficient, a flow-through system was employed; otherwise, recirculating systems were utilized. Many eel culture facilities (n = 16) use flow-through systems. A flow-through system consists of an elevated water tank reservoir, perforated pipes, and a central valve with a regulator to maintain desired water depth, which is 10–40 cm for the nursery and 50–60 cm for grow-out. A recirculating system consists of a filtration system with water being reused and returned to the culture system. The water exchange rate is 100% and 20–30% daily for nursery and grow-out, respectively. During water exchange, culture tanks were cleaned by wholly or partially draining the water, after which the tank bottom was cleaned using a siphon. Eels were temporarily transferred to separate containers during cleaning.

Eel growers used four different feeding schemes (Supplementary Figure 6), namely (1)

Table 2. Summary of water parameters for eel culture.

	Water Parameters
Temperature	Ambient/warm (25–30°C) Low temperature during stocking of glass eels (18–20°C)
Salinity	Freshwater (0–0.5 ppt)
pH	7.5–8.5
Water Depth	10–40 cm (nursery in tanks) 50–60cm (grow-out in tanks) 1.0–1.5 m (grow-out in ponds)
Dissolved oxygen	> 4.0 mg/L

commercial eel feeds with a binder (n = 14), (2) commercial eel feeds with bloodworm *Tubifex* sp. as initial feed (n = 5), (3) trash fish with commercial feeds as a binder (n = 5), and (4) trash fish with commercial eel feeds as binder and bloodworm as initial feed (n = 1). Given the nocturnal nature of eels, tanks and ponds are covered or provided with PVC pipe shelters to reduce light exposure during the day. During the first few weeks of culture, glass eels may or may not be fed with the bloodworm *Tubifex* sp. for several weeks. However, several growers discourage using blood worms for sanitation and health purposes, as blood worms are usually obtained from nearby piggeries. After about three weeks, commercial feeds or "trash fish" (usually round scads *Decapterus sp.*) are introduced to the eels by gradually incorporating them with blood worms to supplement protein requirements further. All farms use commercial feeds bought locally or abroad (Japan, Taiwan, Korea), of which 13 farms use blood worms as initial feed. Most commercial feeds used in culture are bought from Japan (n = 8), produced locally (n = 7), imported from China or Taiwan (n = 6) or Korea (n = 4). Based on data provided by the eel farms, feeds from different sources and manufacturers contain varying amounts of nutrients, specifically crude protein (CP). Locally produced feeds have a CP content ranging from 48% to 50%. Feeds from Taiwan have 45% CP content, Korean feeds have 49–50% CP content, while Japanese feeds have CP content as high as 72–74%. The Feed Conversion Ratio (FCR) obtained at the end of the culture ranges from 1.5 to 2.

Eels are cultured until they reach the legal export size of 6 inches. The culture period may last six to eight months, depending on the growth rate. For table-size eels, it takes almost 1.5 years to achieve 200 to 300 g. Full and partial harvests were both practiced. In partial harvesting, eel farmers segregated the "shooters" or larger eels using graders or manual separation by handpicking. When segregated, eels can achieve the target size faster. Scoop nets are also used to minimize human contact and stress in fish, avoid cannibalism and minimize competition for food. Production of *kuroko* per cycle in each farm is about 1.27 metric tons, based on the average survival rate of 65%, stocking density (30 kg), and average body weight (length = 15 cm, weight = 7 g). The stocking density used is the tank system's maximum carrying capacity in most farms (30 kg or 150,000–210,000 pcs) per production cycle.

The majority of the eel farms (n = 16) recorded low (< 50%) to moderate (50–70%) survival, while only nine farms had survival rates higher than 70%. Most of the mortalities identified were caused by diseases (n = 10) from bacteria, fungi, and parasites, which include gill parasite infestation, fin rot, and white spot (Ich). Other factors include improper water management (n = 3), change of feed type and brand (n = 3), improper aeration (n = 2), low fry quality (n = 2), cannibalism (n = 2), and inexperienced workers and growers using improper technology in culture (n = 2).

Salt bath was the most common practice to treat and prevent diseases in eel farms (n = 14). During the first three weeks of glass eel, salt baths were used as a prevention method to avoid infection with bacterial diseases and mortality. Antibiotics and chemicals (n = 2) and antibiotics in combination with salt bath (n = 3) were only used during severe cases. Diseased eels were segregated in separate tanks during treatment. Notably, about six of the eel culture facilities do not use a prevention method (i.e., salt bath) during culture. Low survival was observed in farms that do not employ regular salt baths.

The study documented the affiliation of local eel growers with professional associations. Nine farms surveyed in Luzon were members of the Integrated Growers and Traders Association of the Philippine Eel Industry (IGAT), Eel Growers and Traders Association of the Philippines (EGAT), and Philippine Association for Livelihood Opportunities and Stewardship (PALOS). Membership is open to eel growers, glass eel traders and consolidators, scientists from the academe and government institutions, and feed companies. IGAT is a Securities and Exchange Commission (SEC) registered association of eel industry stakeholders and aims to promote the eel industry in the Philippines. It is affiliated with the East Asia Eel Resources Consortium (EASEC) and other Asian eel organizations to promote trade and species conservation. PALOS was initiated and founded by the provincial government of Davao Occidental in 2007 to reduce poverty and inequality by generating livelihood opportunities among fishefolks to become entrepreneurs and moving highly vulnerable households into sustainable livelihoods and toward economic stability. It has two tracks: (1) the micro-enterprise development track provides members access to government funds and training to set up their microenterprise on freshwater eel, and (2) the employment facilitation track provides employment access to locally available jobs through public-private partnerships. The associations mentioned are no longer active, and a new group was organized in 2022 – the Philippine Eel Association.

3.4 Post-harvest practices, trade, and marketing

The price of freshwater eels from glass eel collection up to export is summarized in Table 3. The price may still exceed the usual range depending on the available supply. The price of glass eels and *kuroko* were often dictated by the buyer (e.g., stocker, consolidator, grower, exporter), although negotiations between the buyer and seller can be done in several instances.

After six to eight months of culture, *kuroko* (*A. bicolor pacifica*) may be sold directly abroad or to other grower-exporters. The legal size for export is 15 cm or 6 inches, weighing approximately 7 g or at 150 pcs/kg. It was a common practice in the industry that when the grower or exporter failed to reach the minimum volume for export, they would opt to buy *kuroko* from other growers. On the other hand, the *kuroko* price range remains constant throughout the year. The buying price is PHP 24.00–35.00 per piece. The price of *A. marmorata* is 60% lower than *A. bicolor pacifica*. The primary market for *kuroko* is Japan, followed by Taiwan, Korea, and China, with small volumes.

In local restaurants, eels at 200 to 300 g were sold at around PHP 700.00/kg. *A. marmorata* was sold at a lower price (PHP 300.00 or less per kg) due to low consumer preference. Consumer preference towards *A. bicolor pacifica* is higher due to its appeal and acceptable texture than *A. marmorata*. Eels are served in restaurants as *kabayaki*. At present, only one grow-out farm in the country prefers to culture *A. marmorata*, which is sold to restaurants in Metro Manila upon reaching 300 g size. The price list of *A. marmorata* in different sizes is summarized in Table 4. Generally, the price of *A. bicolor pacifica* in the market is three times higher than that of *A. marmorata*.

Only one eel postharvest processing plant in the country, located in Cabadbaran City, Agusan del Norte, produces grilled eel products such as *kabayaki* and *shirayaki*. The preparation of *shirayaki* is similar to *kabayaki*, but the fish is roasted without the sauce and seasoned only with salt. Glass eels (*A. bicolor*) from General Santos City and Cotabato are grown on their farm and processed in the plant. The roasting process includes exposure to high temperatures and applying sauce four times to ensure the taste penetrates the fish meat. The grilled eels are vacuum-packed and frozen. The plant also sells live eels (230–490 g) to Cebu and institutional markets in National Capital Region (NCR).

4. DISCUSSION

4.1 Glass eel capture fisheries

The study identified seven key players in the Philippine eel industry, which corroborates with the results of Ame et al. (2013) on key players in the eel fisheries in the Cagayan River. In Mindanao, the

Table 3. Prices of freshwater eels across different key players as of December 2017.

Month	Collector (Price per kg, glass eels)	Stocker (Price per kg, glass eels)	Consolidator (Price per kg, glass eels)	Grower/Exporter (Price per piece, *kuroko*)	
				Buying price from other growers	Selling price abroad
January	₱ 2,000-3,000	₱ 5,000-7,500	₱ 8,000-10,000		
February	₱ 2,000-3,000	₱ 5,000-6,000	₱ 7,000-8,000		
March	₱ 1,000-2,500	₱ 4,500-5,500	₱ 6,000-7,500	₱ 24-35[a]	₱ 45
April	₱ 1,000-2,500	₱ 3,500-4,500	₱ 5,000-6,500		
May	₱ 1,000-2,500	₱ 3,000-3,500	₱ 4,000-5,000		
June	₱ 500-1,500	₱ 2,500-3,500	₱ 3,500-4,500		
July	₱ 500-1,500	₱ 2,500-3,500	₱ 3,500-4,500	₱ 300[b]	
August	₱ 1,000-2,500	₱ 3,000-4,000	₱ 4,000-6,000	₱ 700-1,000[c]	
September	₱ 1,000-2,500	₱ 4,000-5,000	₱ 6,000-8,000		
October	₱ 2,000-3,000	₱ 5,000-7,500	₱ 8,000-10,000		
November	₱ 2,000-3,000	₱ 6,000-7,500	₱ 9,000-10,000		
December	₱ 2,000-3,000	₱ 7,500-8,500	₱ 10,000-12,000		

[a] price of *A. bicolor* pacifica at 6 inches for export
[b] price of table size *A. marmorata* in local restaurants
[c] price of table size *A. bicolor pacifica* in local restaurants

Table 4. Price list of *A. marmorata* at different sizes.

No. of pieces per kg	**Price per kg**	**Price per piece**
3[a]	₱ 300.00	₱100.00
10	₱ 350.00	₱35.00
20	₱ 400.00	₱20.00
30	₱ 500.00	₱16.67
40	₱ 600.00	₱15.00
50	₱ 700.00	₱14.00
75	₱ 850.00	₱11.30
100[b]	₱ 1,000.00	₱10.00

[a] at table size 200-300 g
[b] at 6 inches size

term "stocker" corresponds to local consolidators in Cagayan (Ame et al. 2013) but doubles up as glass eel collectors and community representatives.

As hatchery technologies for the captive breeding of freshwater eels are still underdeveloped, glass eels used for culture are still sourced from the wild. Knowing the species composition of glass eel catch is vital in the eel industry, especially when there is a preference for *A. bicolor pacifica* in the market. Results corroborate previously published findings on the peak season of *A. bicolor pacifica.* In Cagayan River, Yoshinaga et al. (2014) reported the presence of five anguillid species, which include *A. bicolor pacifica, A. marmorata, A. japonica, A. celebesensis,* and *A. luzonensis.* The study noted that long-finned species (*A. marmorata, A. celebesensis,* and *A. luzonensis*) had higher relative abundance compared to *A. bicolor pacifica* in January 2009. However, the relative abundance of *A. bicolor pacifica* increased the following month. No additional data on species composition in succeeding months are available. Aoyama et al. (2015) showed a more complete seasonal catch data, showing that *A. marmorata* and *A. luzonensis* dominated catch composition in Cagayan from 2008 to 2009. However, the relative abundance of *A. marmorata* decreased in 2011–2012, while the relative abundance of *A. bicolor pacifica* increased. The highest relative abundance of *A. bicolor pacifica* was recorded in November and December 2011, drastically declining in January 2012. Relative abundance began to increase again by October and November 2012. Meanwhile, seven species or subspecies were identified by Shirotori et al. (2016) from the Buayan River in General Santos City, which include *A. marmorata* as the dominant species (76.1 %), *A. bicolor pacifica* (19.5 %), and *A. celebesensis*, *A. interioris*, *A. luzonensis*, *A. borneensis*, and *A. japonica*. Based on catch data from April 2014 to March 2015, the highest seasonal percentage of *A. bicolor pacifica* was found in August and September. Valdez and Castillo (2016) also showed that *A. marmorata* is more dominant than *A. bicolor pacifica* in the Pangi River, Maitum, Sarangangi, from October 2014 to February 2015. Further, the data provided by an eel farm showed that peak seasons for *A. bicolor pacifica* in General Santos City started from July until August and from December until the first quarter of the year (January to March; Supplementary Figure 8). In Davao City, *A. bicolor pacifica* and *A. marmorata* were also previously identified by Melgar et al. (2021) using DNA barcoding, although no seasonality has been established. Studies on glass eel composition in Cotabato and Maguindanao are still lacking and subject to future studies. Despite the lack of published studies, data on the glass eel catch in Cotabato and Maguindanao provided by BFAR (Supplementary Figure 9) showed that the peak months of glass eel collection are January, May to July, and October to November. On a weekly basis, the collection of glass eels reaches up to 15 to 20 kg during peak seasons, while 100 to 500 g per week during lean seasons (Supplementary Table 1). Aside from the four major collection sites identified in this study, the presence of glass eels in the Balsa River in Malinao, Albay and Sabang-Lagonoy River in Camarines Sur, and Bato River in Catanduanes was documented by Nieves et al. (2021). Other collection areas identified by eel farm owners, eel traders, and LGUs but were not covered in this study include Aurora, Misamis Oriental, Surigao del Sur, and Zamboanga. Future studies can focus on the above mentioned areas.

A. marmorata was the dominant species among all sites (82.3–99.7%), followed by *A. bicolor pacifica* (0.3-–17.5%) and *A. japonica* (0-0.3%). The study, however, did not establish the seasonality of catch. Similarly, the composition of glass eels recruited to Palu River in Central Sulawesi, Indonesia showed no significant season variation within each year based on catch data from January 2009 to December 2011 (Serdiati et al. 2013). In Vietnam, glass eels are collected throughout the year, with peak seasonality depending on the area but generally starts in October to May (Tuan and Van 2021).

The lunar phase may affect catch abundance. Results of the present study corroborate with Valdez and Castillo (2016), showing that glass eels are more abundant during the new moon than during the full moon. In their study conducted from October 2014 to February 2015, a total of 4,249 glass eels were collected during the new moon, while only 13 were collected during the full moon. Long-term monitoring across different collection sites must be conducted, given variations in the findings of previous studies, to fully establish the seasonality. This could help in formulating conservation measures to prevent overexploitation of wild stocks. Establishing the seasonality of glass eels, particularly *A. bicolor pacifica*, can also help eel growers identify the best time to buy glass eels.

At the time of the study, it is not a common practice in the industry to sort glass eels by species. However, to date, the industry already uses single species culture, indicating an effective knowledge transfer and research conducted through the years.

4.2 Anguillid eel nursery and grow-out culture

Location is strategic in establishing an eel culture facility. Through the farm visits, it was observed that (1) proximity to an international airport, (2) availability of good water quality, and (3) accessibility to commercial feeds were the common factors considered in choosing the location of an eel culture facility. Most eel culture facilities in the Philippines only culture eel until the juvenile stage at 6 inches. These juvenile eels would have to be transported to the airport for export. Proximity to an international airport would therefore be strategic as it reduces travel time and stress associated with transport, thus preventing glass eel mortality upon arrival at the farm. Additionally, good water quality is essential in the culture of eels. As all the farms surveyed in the study source their water underground, careful site selection ensures that the area will not run out of groundwater. Lastly, accessibility to quality feed ensures good growth of cultured eels. Freshwater eels require high levels of protein in their diet (Djajasewaka 1999; Tibbetts et al. 2000; Okorie et al. 2007; Degani 1987); thus, the availability of locally or internationally produced formulated feeds, as well as live feeds and trash fish would ensure proper nutrition for the fish.

Since technologies for tropical anguillid eel culture have yet to be established, foreign nationals, which include Japanese, Korean, and Taiwanese, co-owned and served as consultants in many eel culture facilities in the country. However, technologies were based on prior experience culturing temperate species (e.g., *A. japonica*). Meanwhile, Filipinos who solely own their eel farms were either trained abroad or have prior experience in the culture of other finfish. This demonstrates that the current technology employed in culturing freshwater eels in the Philippines still needs to be developed and may also be inappropriate for the species.

Eels are commonly reared at 10–40 cm water depth during the nursery stage and at 50–60 cm during the grow-out stage in tanks. Those in ponds may be cultured at 1–1.5 m water depth. This range still falls under the range of other previously published studies wherein eels are cultured at 20–35 cm under laboratory-scale production and 50–200 cm under commercial-scale production (Harianto et al. 2021). Freshwater eels are typically cultured in freshwater, although salinity may be increased up to 0.5 ppt during the first few weeks of glass eel culture. Increasing the salinity (50% sea water) enhances the growth, survival, and activity of *A. japonica* larvae (Okamura et al. 2009). Cadiz and Traifalgar (2020) observed increased growth of *A. marmorata* elvers cultured at 15 and 20 ppt. Culture facilities surveyed near the sea, like Gonzaga, Cagayan, and Cabadbaran, Agusan del Norte, may consider nursery culture under higher salinities. Water exchange is regularly employed in the farms surveyed. Water quality is maintained using a recirculating system in five surveyed farms, resulting in a 90–98% survival rate. Previous studies have shown that water exchange of up to 200% d^{-1} in a recirculating system led to a higher feeding rate and growth performance (Taufiq-Spj et al. 2017). In Indonesia, recirculating systems include physical (i.e., synthetic cotton or dacron, shell fragments), chemical (zeolite stone), and biological filters (nitrifying bacteria placed on biofoam). Nitrifying bacteria, such as *Nitrosomonas* sp. and *Nitrobacter* sp. help reduce ammonia levels, which can accumulate due to the high protein feed requirement of eels (Budiardi et al. 2022). Biofloc technology resulted in low total organic nitrogen and nitrite content during the grow-out phase, without water exchange until the 11th week (Sadi et al. 2022).

Freshwater anguillid eels are carnivorous species that feed on a wide range of diets. They are generally nocturnal benthic feeders that feed on insect larvae, annelids, crustaceans, mussels, and small fishes (Dorner and Berg 2016). While most eel farms rely heavily on commercially available formulated feeds, some still practice feeding live food (i.e., bloodworm *Tubifex sp.*), especially as an initial diet for glass eels during the first stages of culture. Reddy et al. (1977) previously suggested that *Tubifex sp.* may not be able to provide sufficient nutrients for eel growth despite its high nutritive value to other fish. Bloodworms (*Tubifex sp.*) are mixed with 60% protein paste feed in Indonesia (Bulkini 2021). Paste feed is a mixture of commercial ingredients, water, and oil. Chilmawati et al. (2021) suggested that adding earthworm (*Lumbricus rubellus*) flour in artificial feed resulted in a significant growth rate and nutritional value. Insect larvae meal (i.e., black soldier fly or BSF) is also a potential replacement for fishmeal. Since 2003, the United Nations Food and Agriculture Organization (FAO) has promoted insects as a high-quality, cost-effective, energy-efficient, and sustainable alternative protein source. The protein content of BSF larvae may range from 40% to 60% (Barragan-Fonseca et al. 2017). Previous studies have found that optimal protein requirement of anguillid eels was achieved at 55% for *A. bicolor* (Djajasewaka 1999), 47% for *A. rostrata* (Tibbetts et al. 2000), 44% for *A. japonica* (Okorie et al. 2007), and 45% for *A. anguilla* (Degani 1987). Degani (1987) also suggested that a high sucrose diet coupled with a low protein diet elicited better protein retention than a low sucrose and high protein diet in *A. rostrata*.

Since eels rely largely on odor, feed stimulants and attractants can be added to the feed formulations. The physiological regulator of appetite is not fully developed at the glass eel stage; therefore, the intake of commercial feed comes with difficulties. In Japanese farms, paste feed commercial diets which contain 20–45% dry matter, extruded, and pelleted feeds are used for juvenile and adult eels (Hamidoghli et al. 2019). Another area of feed development is increasing feed digestibility, especially at larvae and elver stages. Murashita et al. (2013) demonstrated that the activity of protein digestive enzymes such as trypsin and chymotrypsin is highly dependent on water temperature and pH, suggesting that environmental conditions influence the synthesis and secretion of protein-digesting enzymes. When feed companies and research institutions develop locally produced formulated diets for anguillid eels, these should be considered. Methodologies such as gene expression analysis, growth, and immunity analysis can be used to understand the nutritional requirements of eels in every developmental stage.

Aside from the type of feed, another practice employed that is important in the feeding behavior of anguillid eels is covering the tanks to maintain dark conditions as anguillid eels are nocturnal animals that are often more active and feed at night (Dou and Tsukamoto 2003). Therefore, by maintaining dark conditions, anguillid eels remain feeding during the day.

Most of the farm's mortalities were brought about by diseases caused by bacteria, fungi, viruses, and parasites. Bacterial infection among farm-cultured eels is often caused by *Edwardsiella tarda* (Mo et al. 2015), *Aeromonas spp* (Dewi and Koesharyani 2017), and *Vibrio vulnificus* (Marco-Noales et al. 2001). High water temperature, high stocking density, improper handling, poor nutrition, and poor water quality increase the risk of such bacterial infections. Monogeneans, *Trichodina sp.*, and *Ichthyopthirius multifilis* are common parasitic agents (Madsen et al. 2000; Jessop 1995) that can affect survival. Monogeneans are a group of ectoparasitic flatworms commonly found on fish's skin, gills, or fins. They invade the gills and stretch out the gill filament with excess mucus, resulting in anemic and dull eels, indicating respiratory distress. An initial salt bath at 35 ppt can be done to remove parasites and pathogens (Cuvin-Aralar et al. 2019). The three commonly detected viruses that cause disease in anguillid eels are Eel Virus European (EVE), rhabdovirus Eel Virus European X (EVEX), and Anguillid Herpesvirus 1 (AngHV1) (van Beurden et al. 2012). Viral diseases in eels are usually triggered by stress due to mishandling, poor water quality, and increased temperature. Good management of culture systems and elimination of stress factors can control the occurrence of these diseases, especially during the first few weeks of culture.

Modulation of environmental factors such as temperature and salinity can be used for disease management. The virulence of various eel viruses is temperature-dependent (van Beurden et al. 2012). The optimal temperature for the development of EVE and EVEX has been established at 15°C and 23°C and 10°C and 15°C, respectively (Haenen et al. 2009). Viruses can survive in a dormant state outside these temperature ranges, but the disease does not develop in the host. This strategy of modulating the rearing conditions is a quick, easy, and inexpensive way to control pathogens and may be sufficient for the short term.

Importantly, there is a need to develop new treatments that do not induce pathogen resistance, do not alter fish physiology, and have no environmental impact. With the increasing antimicrobial resistance, alternatives such as the use of phages, probiotics, vaccination, and diet supplementation can be used to treat or prevent diseases. Vaccines against several species of bacteria and parasites, including *V. vulnificus*, *E. tarda*, *A. hydrophila*, *A. sobria* and *A. crassus* have been developed (Parchemin et al. 2022). Glass eels are vaccinated by immersion at three different times after the arrival of the glass eels in the farm. Oral and anal intubation has been shown to be effective in protecting eels against vibriosis (Esteve-Gassent et al. 2004). With the occurrence of multiple infections in culture systems, bivalent and multivalent vaccines can be developed to provide protection against different pathogens. To date, no vaccine has been developed against eel viruses. Diet supplementation with probiotics or other compounds or stimulants has shown promising results in boosting eels' immune system and increasing resistance against *V. anguillarum*, *E. tarda*, *A. hydrophila* and *P. fluorescens* (Parchemin et al. 2022).

4.3 Post-harvest practices, trade, and marketing

Depending on supply and demand, prices of glass eels vary per season. While glass eel supply is stable throughout the year, the species composition determines its price. There are instances of "no buying" season due to very low *A. bicolor pacifica* composition, the preferred buyer species. Since data on seasonal species composition are lacking, overpricing sometimes occurs. In 2017, the buying price of glass eels from collectors and stockers ranged from as low as PHP 500.00 to as much as PHP 8,500.00 per kg. Currently, the range is from PHP 2,500.00 to PHP 10,500.00 per kg (Table 5), indicating that the price appreciated greatly in terms of the base price, but the range remains relatively stable. Consolidators will then sell glass eels from PHP 3,500.00 to PHP 25,000.00/kg, depending on species composition. One consolidator sells glass eels as high as PHP 25,000.00 with 90-95% *A. bicolor pacifica* composition. Prior to the implementation of FAO 242 in 2012, prices for glass eels reached as high as PHP 55,000.00/kg. In 2022, the price disparity significantly decreased to PHP 5,000.00-PHP 14,000.00 per kg (Table 5). While the buying price of *kuroko* per piece remained stable from PHP 24-25.00 in 2017 to PHP 22-38.00 in 2022. Hence, stockers and consolidators profit the most instead of the eel collectors. Information campaigns on the eel industry value chain could increase market awareness of eel collectors. This added capacity opens opportunities to explore more economical pricing strategies, which could be explored in future studies.

Freshwater eel production in the Philippines is primarily export-driven, while some are locally sold. The only existing processing facility in Cabadbaran, Agusan del Norte, can help boost eel production in the country as this can encourage local growers to pursue grow-out culture along with the improvement of technologies. Furthermore, processing other eel species, such as *A. marmorata*, which is less preferred for export, could help add value to the product. Almost all parts of the eel are processed into products depending on the country. Eel meat products include smoked, jelly, and steamed or grilled fillets. The skin of the eel can be used to make wallets and bags. In Europe, only frozen, fresh, or vacuum-packed meat products are marketed. In Japan, the head is sold as a snack; the offal is grilled in soy sauce or canned; and the spine is dried and seasoned and sold as a snack. *Anguilla* eel can be grilled, baked, or smoked as the end product (Rickards 2000). In the Philippines, research and development must be initiated to process eels in various ways to create new products and markets.

Export data provided by BFAR revealed a 92% drop in production volume from 2013 to 2021 (Supplementary Figure 7), decreasing to 6,878 kg and USD 38,868.00 in 2021. Some of the eel culture facilities surveyed (n = 2) have already stopped operations during the study in 2017, and three more stopped operations in 2018, coinciding with the drastic decline (~76%) in production.

Exporters reported problems related to the implementation of FAO 242. Manual sorting of eels is prone to human error as sorters may unintentionally include undersized eels. Several exporters reported being barred from exporting when a small percentage (e.g., 10%) of undersize eels were found upon inspection at Customs. In this case, the eels were transported back to the farms, eventually leading to stress-related mortality. A certain percentage error should be

Table 5. Prices of freshwater eels across different key players as of December 2022

Month	Collector (Price per kg, glass eels)	Stocker (Price per kg, glass eels)	Consolidator (Price per kg, glass eels)	Restaurants (Price per kg, table sizes, 330-490g)	Grower/Exporter (Price per piece, kuroko)	
					Buying price from other growers	Buying price exporter
January	₱3,800	₱4,500	₱5,500	₱750-850	₱30	₱30
February	₱4,000	₱5,000	₱6,500	₱800-850	₱32	₱32
March	₱5,500	₱8,000	₱9,500	₱900	₱34	₱35
April	₱4,500	₱6,500	₱8,500	₱950	₱32	₱32
May	₱5,000	₱6,000	₱7,500-8,000	₱850-950	₱35	₱35
June	₱8,500	₱10,500	₱14,000	₱850-900	₱35-40	₱40
July	₱7,500	₱9,500	₱13,000	₱900	₱38	₱38
August	₱7,500-8,000	₱9,000-10,000	₱10,000-12,000	₱900-950	₱25-35	₱30-40
September	₱5,500-6,500	₱7,500-8,500	₱9,000-10,000	₱900	₱22-30	₱30-35
October	₱4,500-6,500	₱7,000-8,000	₱8,500-9,500	₱750-850	₱25-27	₱30
November	₱3,000-4,000	₱5,000-6,000	₱6,000-7,000	₱750-850	₱25	₱23
December	₱2,500-3,500	₱3,800-4,500	₱5,000-6,000	₱750-850	₱20-25	₱23

allowed to prevent mortalities, which can be discussed between the exporters, BFAR, and other concerned government agencies.

5. CONCLUSION

This paper provides a comprehensive overview of the supply chain from glass eel fisheries, aquaculture, post-harvest, and trade practices. Several problems were identified in aquaculture as well as in glass eel fisheries, which could serve as the basis for future studies to improve aquaculture technologies and implement fisheries management programs for wild eel populations. In addition, a roadmap for research and development must be institutionalized to integrate the eel supply and market chain. Linkages must be strengthened with state universities, research, and development institutions (RDIs) to harness the potential of eel culture further. Pilot nursery sites could be established near the major glass eel collection areas in collaboration with concerned government agencies or Technology Business Incubation Programs. Further, advocacies with potential investors can be done to expand grow-out areas.

With the aquaculture sector's heavy reliance on wild-caught glass eels, an integrative approach must be implemented to conserve and manage anguillid eels. BFAR, LGU, RDIs, and other stakeholders must implement scientific and effective fisheries management measures on fishing grounds identified in this study (e.g., Cagayan River, Rio Grande de Maguindanao, and rivers along Sarangani Bay and Davao Gulf) to conserve wild eel populations. In addition, research on breeding and hatchery should be initiated. It is essential to determine the abundance and distribution of anguillid eels using traditional capture surveys in combination with molecular techniques to have an effective conservation strategy, which could serve as a basis for identifying priority areas for conservation and management. Another management scheme is to keep a registry of active eel collectors, consolidators, stockers, and traders and strictly implement the issuance of local transport permits that indicate the source and additional invoices from the LGU. Enhancing the capacity of collectors can aid the collection of more accurate catch and effort data on anguillid eel fisheries. Additionally, existing policies on local glass eel trade (i.e., glass eel collection) and *kuroko* export (i.e., percentage error) must be reviewed to determine if such policies are still applicable or need amendments. Overall, integrating efforts in research, marketing, logistics, infrastructure, regulation, and consumer education is the key to sustainable eel farming.

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SUPPLEMENTARY MATERIAL

Below is the link to the electronic supplementary material.
Supplementary file

AUTHOR CONTRIBUTIONS

Santos FF: Conceptualization, Funding Acquisition, Project administration, Supervision, Methodology, Investigation, Writing - review and editing. **Baure JG:** Investigation, Data curation, Visualization, Writing - Original draft preparation, review and editing. **Santos MNM:** Data curation and analysis, Validation, Writing - Reviewing and Editing, Visualization

CONFLICTS OF INTEREST

The authors declare that there was no conflict of interest with respect to the research, authorship, and publication of this article.

ETHICS STATEMENT

The authors declare that this study was conducted with the local governments' permission of the cities and municipalities involved. Participants were asked for their consent before the conduct of the interviews. No capture nor experimentation of animals was involved in this study.

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