Esteeming the Importance of Comprehensive Data for Sustainable Eel Fisheries in Southeast Asia

JTF 6-2 Pillar III.
Promotion of sustainable development of inland fisheries in Southeast Asia

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Keywords: tropical eel, eel fishery, data collection, hydroacoustics

In recent years, the value of tropical eels has significantly increased due to the decline of temperate eels. As a result, there has been a dramatic rise in the capture of glass eels and the juvenile stage of eels in tropical areas. Six of the 10 ASEAN Member States (AMSs), namely: Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Thailand, and Viet Nam are range States for tropical anguillid eels. The respective AMSs developed their respective national fishery management programs and agreed to collaborate with the vision of developing effective management practices for sustainable use and conservation of tropical anguillid eel resources in the region (Muthmainnah *et al.*, 2023). The conservation and management of tropical eel resources have become crucial in the Southeast Asian region to ensure their sustainability. Therefore, it is necessary to establish a policy that balances the utilization and preservation of these resources.

Acknowledging the limited knowledge about tropical eel species, SEAFDEC/IFRDMD implemented the project "Sustainable Utilization of Anguillid Eels in the Southeast Asia Region" from 2020 to 2024 supported by the Japan Trust Fund VI Phase 2. The Project is relevant to the Resolution and Plan of Action on Sustainable Fisheries for Food Security for the ASEAN Region Towards 2030 (RES&POA-2030), specifically POA no. 5 *Strengthen the collection of data and information, where relevant, on species under international concern, e.g. sharks and rays, sea turtles, catadromous eels, aquatic mammals, etc., and harmonize/standardize data collection methods among countries in the region*. The two main activities of the Project include 1) standardizing the data collection in the region and 2) mapping the genetic population structure of tropical eels in Southeast Asia based on mtDNA approach. This article summarizes the key achievements of the Project from the several activities conducted by IFRDMD including eel catch and effort data, hydroacoustic surveys, genetic studies, and gender integration in eel fisheries.

Anguillid eels are catadromous fish species with a life cycle mainly spent in freshwater environments and migrate to the sea to spawn. Starting from eggs to leptocephalus and then to glass eel, a young freshwater eel is characterized by its transparent, glass-like appearance. It typically measures between 50 to 70 mm in length and marks the final stage of eel larvae development. Initially, these larvae, known as leptocephalus, resemble broad, translucent leaves and inhabit oceanic waters where they are influenced by currents. They look like plankton and are carried by currents toward coastal areas. During metamorphosis, the leptocephalus transforms into the glass eel, which then migrates through rivers to transition into yellow eels and eventually silver eels and becomes an adult within inland waters (**Figure 1**). The recruitment of eels into estuarine environments is influenced by a combination of internal and external factors. Internal factors depend on the reproductive success of adult eels, whereas external factors are shaped by environmental conditions. Various studies have highlighted that the migration of glass eels to freshwater habitats is affected by factors such

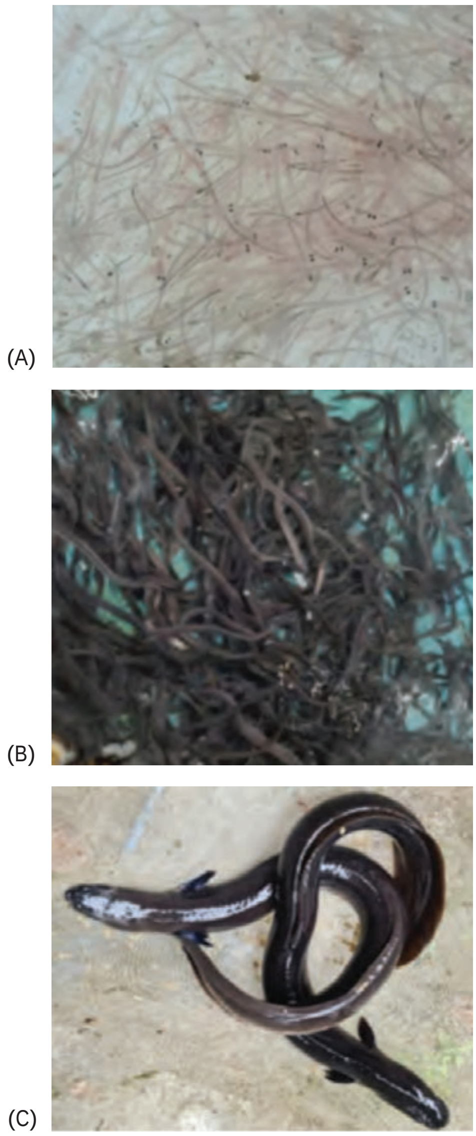

Figure 1. Life stages of anguillid eels: glass eel (A), elver (B), and yellow eel (C)

as temperature, salinity, turbidity, river currents, tidal patterns, and lunar phases.

The eel stands out among fishery products due to its economic significance and rich nutritional profile. It is renowned as a prominent export in the fishing industry. However, glass eel fishing activities are nearing the point of overfishing. The current catch levels have surpassed the maximum sustainable yield, leading to biological overfishing. This can result in a significant decline in fish stocks, potentially halting fisheries activities altogether. However, decreasing fishing activities could negatively impact the livelihoods of fishers. To ensure the long-term sustainability of glass eel resources, it is crucial to manage their capture wisely.

Enumerators in Tentena, Central Sulawesi submitting catch data collected in April-May 2024

The catch statistics of the fishery, which are the most important primary data for assessing the current status and trend of the eel resources, still need to be improved. Since data on catch statistics of Anguillid eels in the region are insufficient, an inventory system needs to be established as soon as possible for the conservation, management, and sustainable utilization of the tropical anguillid eel resources and also for future development of the eel industry in the region (Muthmainnah *et al*., 2016). Engaging eel collectors as enumerators to record data is one method to obtain the necessary information.

Eel fisheries

In the Southeast Asian region, only Indonesia and the Philippines have data on eel production from inland capture fisheries. However, there is no data available on the aquaculture production of eels in the region (Siriraksophon *et al*., 2014). From 2017 to 2023, IFRDMD initiated the data collection of eel catch and effort in Palabuhan Ratu and Cilacap Provinces Indonesia, and Cagayan and Cotabato Provinces in the Philippines (**Figure 2**). However, the COVID-19 pandemic impeded the undertaking of activities; thus, IFRDMD has adapted activities in 2021 by rescheduling the surveys when there was no glass eel catch in Indonesia and Philippines due to the shortfall of demand from eel farms. Also, Indonesia implemented a quota system to manage glass eel resources, only collectors who have a certificate could transfer and receive anguillid eels between different areas in Indonesia.

Figure 2. Study sites for regular data collection on eel catch and effort

Glass eels

The data on glass eels monthly CPUE was collected from 2017 to 2023 in Palabuhan Ratu, Indonesia and Cagayan, Philippines which are famous areas for the glass eel fishing grounds. The fishers collected glass eels by using scoop nets in Palabuhan Ratu and fyke nets in Cagayan which are operated at night in the mouth of the river. The dominant species in Palabuhan Ratu was *A. bicolor bicolor*, while in Cagayan was *A. marmorata*. The glass eel stage is important as the natural seed source for eel farms.

The annual data from 2017 to 2023 is shown in **Table 1**. In 2017 in Palabuhan Ratu, the catch was 1,480 kg with 71,206 units of gear indicating a significant fishing effort. Thereafter, both the catch and gear usage declined, with the lowest catch at 54 kg and 814 gears in 2020 due to the effect of COVID-19.

Growing glass eel to elver size in Palabuhan Ratu, West Java.

Table 1. Total catch (kg) of glass eels and number of gear (unit) operated in Palabuhan Ratu, Indonesia and Cagayan, Philippines

Location	Year	Total catch (kg)	Number of gear (unit)
Palabuhan Ratu, Indonesia	2017	1,480	71,206
	2018	1,528	2,013
	2019	1,876	14,221
	2020	54	814
	2021	321	118
	2022	1,777	9,955
	2023	1,002	3,607
Cagayan, Philippines	2017	32.14	31
	2018	1,205.60	138
	2019	287,594	2,555
	2020	285.38	341
	2021	-	-
	2022	18.93	170
	2023	428.82	1,032

However, there was a gradual increase in subsequent years notably in 2023 a moderate level of activity with the catch of 1,002 kg and 3,607 units of gear. This indicates a significant increase in catch compared to the previous three years, along with a substantial rise in gear usage, reflecting a possible recovery or adjustments in regulatory policies or fishing quotas. However, no data was recorded in 2021 in Cagayan as the COVID-19 pandemic imposed large-scale social distancing measures.

Interview with eel fishers to measure their level of concern for the aquatic environment and the sustainability of eel fisheries in Palabuhan Ratu, West Java, Indonesia

Figure 3 shows the variability of the catch per unit effort (CPUE) from 2017 to 2023. In 2017 and 2018, the CPUE values showed lower medians with a relatively small data spread, though a few outliers suggest occasional higher catches. The year 2019 indicates a rise in the median CPUE and an increased range of data points, along with numerous outliers indicating exceptionally high CPUE. A peak in CPUE was observed in 2020 with the highest median value and a substantial spread, reflecting a year of both high catches and high variability. This peak is followed by a sharp decline in 2021, with a very low median and minimal spread, although outliers point to sporadic higher CPUE values. The year 2022 continued this trend with a low median and few outliers, whereas 2023 showed a slight uptick in the median CPUE and a moderate spread of values. Finally, the plot depicts significant fluctuations in CPUE over the years, with the most pronounced variation occurring in 2020, and suggests that external factors such as the COVID-19 pandemic.

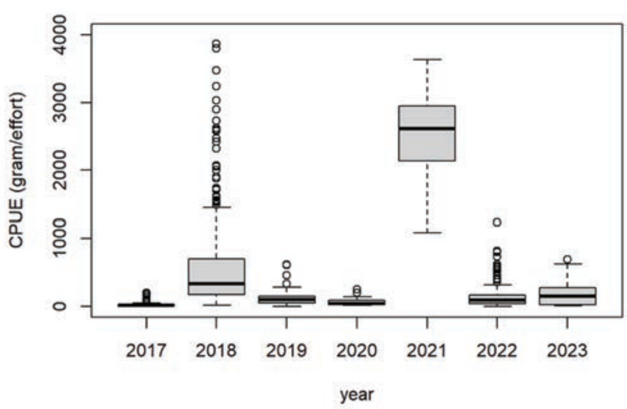

Figure 3. Annual CPUE nominal series (g/effort) of eel from gear operating in the Cimandiri River between 2017 and 2022

A general linear model (Gamma family with an inverse link) (estimated using ML) was fitted to predict CPUE gear with month and effort fishers (formula: CPUE_gear ~ month + effort_fishers) (**Table 2**). The model's explanatory power is substantial (Nagelkerke's R2 = 0.57). The model's intercept,

Table 2. Parameters used for eel CPUE standardization in the Cimandiri River using GLM with gamma distribution

Parameter	Estimate	Std. error	t value	Pr(> Chi)
(Intercept)	3.315e-03	4.057e-04	8.171	1.06e-15***
Month	-2.124e-04	4.149e-05	-5.119	3.78e-07***
Effort_fishers	5.822e-05	6.143e-06	9.479	< 2e-16***

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Table 3. Parameters used for eel CPUE standardization in the Cagayan River using GLM with gamma distribution

Parameter	Estimate	Std. Error	t value	Pr(>Chi)
(Intercept)	-0.200918	0.031332	-6.412	3.62e-10***
Month	0.028004	0.005952	4.705	3.38e-06***
Effort	0.258304	0.024445	10.567	< 2e-16***

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

corresponding to month = 0 and effort fishers = 0, was at 3.31e-03 (95 % CI [2.56e-03, 4.15e-03], t (881) = 8.17, p < 0.001). The result of this model showed the month has a statistically significant and negative impact on the CPUE, meaning the outcome decreases as the months progress. Meanwhile, effort by fishers has a statistically significant and positive impact on the outcome, meaning the outcome increases with greater effort by fishers in Cimandiri.

Figure 4 shows that the median CPUE appears to be lower in the years following 2017, suggesting a potential decline in fish stock abundance or changes in fishing efficiency or effort. The consistency of the CPUE from 2018 to 2023 indicated that the fishery has reached a state of equilibrium or that fishing practices and efforts have become standardized. The decline was affected by limited demand from eel farms and habitat loss due to sand mining activity in the river mouth of the Cagayan River. However, the presence of outliers in 2020 and 2023 indicated that there are still occasional variations in the catch rates.

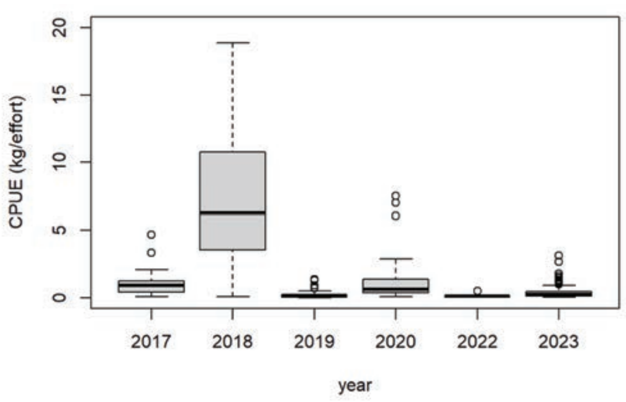

Figure 4. Annual CPUE nominal series (kg/day) of glass eel from gear operating in Cagayan in 2017–2023

Furthermore, a general linear model (Gamma family with an inverse link) (estimated using ML) was fitted to predict CPUE by gear with month and effort gears (**Table 3**). The model's explanatory power is substantial (Nagelkerke's R2 = 0.87). The model's intercept, corresponding to month = 0 and effort gears = 0, is at -0.20 (95% CI [-0.26, -0.14], t (451) = -6.41, p < .001). The result of this model showed that the month and effort gears have a statistically significant and positive impact on the CPUE. This means that increases in either variable are associated with an increase in the CPUE, and these effects are unlikely to be due to chance in the Cagayan River.

Elver and yellow eels

The data on elver and yellow eels was collected from Cilacap, Indonesia which is famous for the elver and yellow eel fishing ground. Fishers collected elver and yellow eels by using PVC traps at night. The dominant species in this area was *A. bicolor bicolor.* The yellow eel stage is important as the natural production for the eel processing around Cilacap while elvers as seed source for the eel farm. **Table 4** shows the data on the fluctuation in catch and gear in Cilacap, Indonesia with a marked increase in fishing efficiency or fish availability in the most recent years. Initially, from 2017 to 2019, there was a consistent decrease in both catch and number of gear. This trend suggests a reduction in fishing efforts or lower fish availability during these years. In 2020, there was a slight uptick in gear usage but the catch still decreased, hinting at possibly less efficient fishing or continued scarcity of fish. However, the trend shifted notably from 2021 onwards. There was a significant increase in the catch, especially in 2022, where the catch doubled compared to the previous year despite a similar increase in gear. In 2023, the catch was more than double even though the amount of gear used decreased from the previous year. This sudden surge could be attributed to changes in demand from eel farms or an increase in the fish population.

Table 4. Total catch (kg) of elver and yellow eels and number of gear (unit) operated in Cilacap, Indonesia and Cotabato, Philippines

Location	Year	Total catch (kg)	Number of gear (unit)
Cilacap, Indonesia (elver and yellow eels)	2017	4,323.80	96,870
	2018	3,178.69	80,630
	2019	1,973.14	33,218
	2020	1,673.78	34,279
	2021	3,200.21	53,991
	2022	7,553.85	124,294
	2023	17,508.22	76,358
Cotabato, Philippines (yellow eels)	2022	537.28	47
	2023	1,362.15	130

Table 5. Parameters used for eel CPUE standardization using GLM with gamma distribution in Cilacap

Parameter	Estimate	Std. Error	t value	Pr(>Chi)
(Intercept)	1.078e+01	3.563e+00	3.026	0.00337**
Month	-2.334e-01	4.000e-01	-0.583	0.56126
Effort	1.737e-05	3.312e-04	0.052	0.95831

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

In Cotabato, Philippines, the yellow eel data was collected from 2022 to 2023. The fishers catch yellow eels by using bamboo traps operated at night. The dominant species in this area was *A. marmorata*. A significant increase in total catch and number of gear used was observed between 2022 and 2023 (**Table 4**). In 2022, 47 units of fishing gear were used with a total catch of 537.28 kg. While in 2023, the number of gear increased to 130 and the total catch was doubled to 1,362.15 kg. The consolidators played a role in exporting yellow eels to Taiwan highlighting the industry's economic importance.

Figure 5 shows the higher median CPUE and greater variability in 2017 as indicated by a taller box and longer whiskers suggesting that there was a wide range of CPUE values with some significantly higher than the median. From 2018 to 2023, lower median CPUE values with a tighter IQR indicated less variability in CPUE. Outliers were present in several years which suggests there were occasional instances of significantly higher or lower CPUE compared to the typical range. Finally, the data for 2023 suggests that while the CPUE has a higher median than in previous years, except for 2017, the overall variability is not as high as in 2017. The presence of outliers above the main body of the plot suggests that an increase in catch efficiency or abundance of catch for that year.

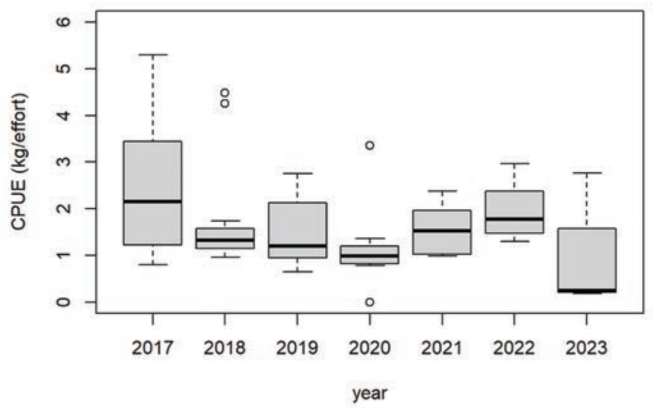

Figure 5. Annual CPUE nominal series (kg/day) of eel from gear operating in Cilacap between 2017 and 2023

Another general linear model (**Table 5**) (Gamma family with a inverse link) (estimated using M) was fitted to predict CPUE_gear with month and effort_gears. The model's explanatory power was very weak (Nagelkerke's R2 = 0.01). The model's intercept, corresponding to month = 0 and effort_gears = 0, is at 10.78 (95% CI [4.40, 18.31], t(77) = 3.03, p = 0.002). The result showed neither the month nor effort gears have a statistically significant impact on the CPUE. The month shows a non-significant tendency to decrease the outcome, while effort gears show a non-significant tendency to increase the CPUE in Cilacap.

Figure 6 shows the CPUE per year in Cotabato for 2022 and 2023. It does not show a clear trend in the catch efficiency between the two years due to the limited amount of data with only two points in time. It is considered to continue this activity to get clear information on the trend of yellow eel fisheries in Cotabato. While the median catch efficiency was slightly lower in 2023, there was more variability and a wider range of CPUE than in 2022.

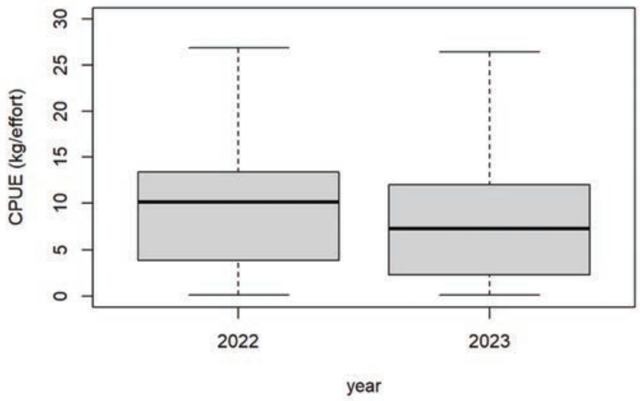

Figure 6. Monthly mean catch and standard deviation of eel caught by gear in Cotabato during 2022–2023

Table 6. Parameters used for eel CPUE standardization using GLM with gamma distribution in Cotabato

Parameter	Estimate	Std. Error	t value	Pr(>Chi)
(Intercept)	0.0924574	0.0233483	3.960	0.000163***
Month	-0.0006603	0.0037936	-0.174	0.862268
Effort	0.0005818	0.0001841	3.161	0.002229**

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

A general linear model (Gamma family with an inverse link) (estimated using ML) was fitted to predict CPUE_gear with month and effort_gears (**Table 6**). The model's explanatory power is substantial (Nagelkerke's R2 = 0.73). The model's intercept, corresponding to month = 0 and effort_gears = 0, is at 0.09 (95 % CI [0.05, 0.14], t(79) = 3.96, p < .001). The results of the models showed the month does not have a meaningful impact to the CPUE, while effort gears have a significant and positive impact on the CPUE in Cotabato.

Installing trap gear 'bubu' in Poso River, Central Sulawesi *(top)* and removing the catch from trap gear *(right)*

Hydroacoustic surveys

The COVID-19 pandemic caused an unprecedented global socioeconomic crisis, including in the fisheries and aquaculture sectors. Large-scale social restrictions were imposed to prevent the spread of COVID-19 in different countries. As a consequence of the COVID-19 containment measures implemented in the country, most fishers and middlemen stopped fishing and aquaculture activities, some continued their farming operations despite the increase in the price of feed and other aquaculture inputs, while only a few continued trading anguillid eels. To supplement their income, they turned to catching, farming, or trading other freshwater fish or doing other work (Muthmainnah *et al.*, 2020). The data collected showed a decline because the COVID-19 pandemic has disrupted the anguillid eel supply chain, and key stakeholders have suffered huge economic losses. The initial challenge during the COVID-19 pandemic was to restore the

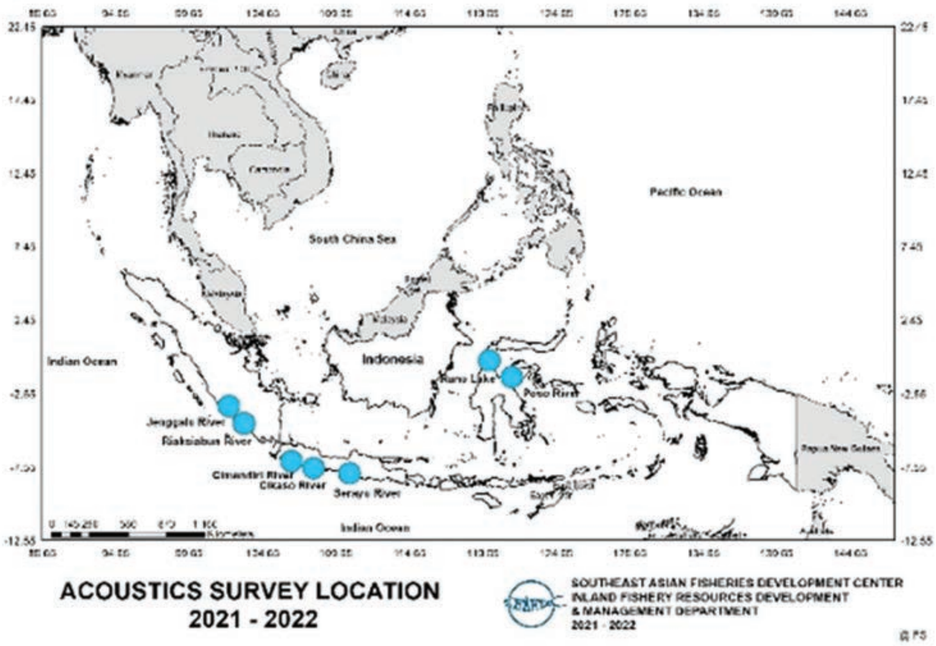

Figure 7. Study sites for hydroacoustic surveys on anguillid eels

supply of anguillid eel fry for farming to maintain the market chain and uphold the livelihoods of people who depend on this fishery. Despite the challenges they face, most respondents expect that the anguillid eel trade will recover soon after the pandemic and hope that prices in the market will stabilize as demand for anguillid eel will pick up again as food service operations resume.

During the COVID-19 situation, IFRDMD continued the data collection to monitor eel production from catch and farming and the enumerators hired by IFRDMD continued to provide the data. Besides, the acoustic survey was conducted for the stock assessment of anguillid eels to assess the current status of anguillid eel resources in Indonesia by estimating the density and measuring the target strength (TS) of anguillid eels (Fahmi *et al.*, 2021). The acoustic surveys were conducted in 2021–2022 in West Java (Serayu River, Cimandiri River, and Cikaso River) and Central Sulawesi (Rano Lake and Poso River) (**Figure 7**).

Fyke nets gear installed in the estuary of Poso River, Central Sulawesi, Indonesia

The TS measurement was conducted by placing the anguillid eel in the cage and recording the return echo prior to measurement, then measuring the morphological parameters of the fish such as length and weight. The data analysis was carried out by using the software Echoview 5.0 with a threshold setting of -70 dB, horizontal grid distance based on time (0.2 min), and vertical grid separation (0.2 m) to obtain the TS. Furthermore, the relationship between TS and observation (backscattering cross-section, m^2) was calculated by the formula based on MacLennan and Simmonds (1992). In addition to the density of fish stocks based on their size composition, the results of the analysis are also presented in the form of a density distribution map for each elementary sampling distance unit (ESDU). The result of the TS measurement showed that the TS value is detected from (-66) to (-77) dB for a length of 34–48 cm of anguillid eel indicating that the relationship between TS and the length of the yellow eel stage is directly proportional where the increasing length was followed by the TS value.

The tracking surveys were carried out by attaching an acoustic transducer to the side of the boat with the tracking path in the horizontal side view at the speed of 3.8 kn. In Cimandiri, the tracking surveys revealed three categories of fish density: low (0–1 ind/m^3), medium (2–3 ind/m^3), and high (> 3 ind/m^3). During the daytime survey, higher density (4 ind/m^3) was observed in the middle part of the survey area, while during the nighttime survey, higher density (5 ind/m^3) was detected in the upstream area near the tributary. Similarly, in the Serayu River, detected density (3 ind/m^3) was found in the middle part of the survey area, with migration patterns predominantly occurring during the day in the middle of the river.

The middle area of the Cikaso River exhibited detected density (2 ind/m^3) of fish both during the daytime and nighttime surveys, attributed to the presence of rice paddy fields and river branches. This pattern suggests that the middle section serves as a critical habitat for eel populations in the river. Moving to the Poso River downstream, differences in fish density between daytime and nighttime surveys were observed. The river mouth, being a glass eel fishing ground, showed density (1 ind/m^3) during the day due to the longer tracking area, while density (2 ind/m^3) near the river mouth facing Tomini bay was noted during the night. In Pandiri Village, located in the middle part of the Poso River, where the TS was the yellow eel, the distribution of anguillid eel was nearly equal throughout the river. The hydroacoustic analysis of anguillid eel in Rano Lake depicted varying fish densities. The highest density (5 ind/m^3) was found in Kuala Sitai, an inlet of the lake, where riparian vegetation remains in good condition and numerous water sources are available. Conversely, the lowest density (1 ind/m^3) was observed near settlements, indicating potential impacts of human activities on fish habitat. These findings provide insights into the spatial distribution and habitat preferences of fish populations in different water bodies, which are crucial for effective anguillid eel fisheries management and conservation efforts.

Measuring the water depth of the Pandiri River, Central Sulawesi.

Genetic study

For the promotion of eel biodiversity conservation, the genetic study was carried out to identify the genetic population structure of the tropical eels (all *Anguilla* spp. except *A. bicolor*) in Southeast Asia using mtDNA D-loop region. The eel samples were obtained from Indonesia. On the other hand, the eel samples from the Philippines collected in early 2020 are still under process.

The results showed the wide distribution of anguillid eel species across several regions in Indonesia. In North Kalimantan, all 40 samples were identified as *A. marmorata*, commonly known as the marbled eel. In Poso, the sample size of 60 was composed of 43 % *A. marmorata*, closely followed by 50 % *A. celebensis* or the Celebes eel, and the remaining 7 % were was categorized as “bad sequence” because the samples had inadequate genetic sequencing data for species confirmation. In Kendari, the 40 samples had 77 % were *A. bicolor pacifica* and 23 % bad sequence. While in Bali, the 47 samples were composed of 65% *A. marmorata* and 35 % *A. bicolor*.

Women’s participation in eel fisheries

Using the gender lens in anguillid eel fisheries, the participation of women is significant where they play important roles as fishing partners with men. Women have more responsibilities in fish marketing including making decisions and involving in buying and selling fish. Women prefer to work in fish processing work but both women and men are working together (Muthmainnah *et al*., 2022). Nevertheless, there is a need to improve their knowledge and skills in modern techniques for capturing, culturing, processing, and marketing. The marketing skills of women should be improved to sustain their livelihoods and income. Better tools and skills in the marketing of fish and fishery products should be developed to address the barriers that women face in entering markets. One intervention is enhancing access to information and communication technologies such as radios, mobile phones, and television regarding updated information on fish prices, banking services, and new fishing technologies. Moreover, the gender roles in anguillid eel fisheries could be strengthened by enhancing the ability (*e.g.* selling skills) of women to access markets, promoting equal access and rights in the utilization of eel fish resources, and adapting to local wisdom that recognizes men as leading actor and partner and not as competitors with women, while women are not considered as supplementary actors in the management and utilization of eels. The eel fishery data collection also involved women as enumerators, as women are heavily involved in all aspects of inland fishing. Women often catch and collect fish throughout the year because of their responsibility for family food security. Women have a more continuous experience, so the information that they provide is essential for building a more accurate picture of inland fisheries (FAO, 2003).

Way Forward

The implementation of a quota system and focus on species-specific data collection is a paradigm for sustainable resource management. This initiative not only aims to protect eel populations but also balances conservation efforts with the socioeconomic needs of local communities.

The integration of acoustic surveys with traditional catch data collection signaled a holistic approach to stock assessment. By utilizing advanced tools and methodologies, such as hydroacoustic equipment, we can improve our understanding of eel populations and their habitats, facilitating more informed management decisions.

The genetic studies underscore the importance of promoting biodiversity conservation in eel fisheries. By identifying genetic population structure and understanding species distribution, we can develop targeted conservation strategies to conserve the genetic diversity of eel populations across Southeast Asia.

Empowering women in their significant participation in eel fisheries highlights the need for gender-responsive interventions to increase their involvement. By addressing barriers to market access, providing skills development opportunities, and promoting gender-equitable participation, we can foster inclusive and sustainable fisheries management.

Acknowledgement

This article is part of the project "Sustainable Utilization of Anguillid Eels in the Southeast Asia Region" implemented by the SEAFDEC Inland Fishery Resources Development and Management Department (IFRDMD) with support from the Japanese Trust Fund. *Mr. Tomohito Shimizu* is the Lead Technical Officer for this Project.

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