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Habitat Characteristics of the Indonesian Shortfin Eel (*Anguilla bicolor* McClelland, 1844) in a River System on Java's Southern Coast, Indonesia

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ABSTRACT

The Indonesian shortfin eel, *Anguilla bicolor*, is an economically valuable fishery resource in Southeast Asia, yet it faces significant threats from overfishing, habitat degradation, migration barriers, and pollution. However, limited knowledge regarding its distribution and habitat preferences creates uncertainty in managing and conserving the species effectively. This study aimed to explore the habitat preferences of *A. bicolor*, particularly during its yellow eel stage, by examining its distribution across different environmental conditions. Over the course of 2020, a total of 89 specimens were collected from 18 sites along the Cikaso River System, located on the southern coast of Java, including both the mainstream and coastal swamp areas. Environmental parameters were also recorded at each site, and multivariate Principal Component Analysis (PCA) was applied to assess their relationship with eel occurrence. Although eels were detected year-round, with sizes ranging from 20.1 to 42.2cm, their numbers were notably higher in the coastal swamp areas compared to the mainstream river. The findings suggest that *A. bicolor* demonstrates a broad tolerance to a variety of environmental conditions but exhibits a clear preference for brackish waters over freshwater habitats. Specific characteristics of coastal swamp areas, such as salinity, depth, turbidity, and substrate type, were found to be crucial in determining eel distribution. These results highlight the coastal swamp areas as critical habitats during the yellow eel stage. This study highlights the importance of integrative management approaches to protect these vital habitats, ensuring the sustainable future of *A. bicolor* and other anguillid eel species within the Cikaso River System.

INTRODUCTION

Anguillid eels (*Anguilla* spp.) are widely distributed, both in tropical and subtropical waters including Southeast Asia **(Fahmi *et al.*, 2012; Arai & Chino, 2018,**

2019; Chai & Arai, 2018; Arai, 2020; Kuroki *et al.*, 2020). One of the commonly found species is *A. bicolor* McClelland, 1844, which has been reported to inhabit the waters surrounding the Indonesian archipelago **(Sugeha & Suharti, 2009; Minegishi *et al.*, 2012)**. *A. bicolor* is considered an essential fisheries resource and contributes significantly to national income in several countries in Southeast Asia, including Indonesia, Philippines, Malaysia, and Vietnam **(Shiraishi & Crook, 2015; Gollock *et al.*, 2018)**. In Indonesia alone, fresh and frozen eels are exported to meet global demand, especially in the East Asian market. They are estimated to be worth more than USD 100 million over the last decade **(Noor & Abidin, 2019; United Nations Statistical Division, 2023)**. The increased demand for *A. bicolor* and other tropical eels is due to the inclusion of *A. anquilla* in Appendix II of CITES, which led to a ban on all imports and exports of the species by EU member states in 2010 **(Nijman, 2015)**. In addition, the comparable texture and flavor of *A. bicolor* render it the favored alternative to *A. japonica* **(Temminck & Schlegel, 1846)**, which has a declining stock size in East Asian waters. This is due to overfishing pressures on eels, particularly at the juvenile stage (glass eel), in the wild **(Marini *et al.*, 2021; Wibowo *et al.*, 2021)**.

However, the increasing demand for tropical *Anguillid* eels has led to a significant global decline in their population sizes. This decline has been exacerbated by habitat degradation, migration barriers caused by dam construction, pollution, parasitism, and fluctuating oceanic conditions **(Feunteun, 2002; Kaifu *et al.*, 2021)**. As a result, several species have been classified as threatened or endangered. Currently, *A. bicolor* is listed as "Near Threatened" on the IUCN Red List of Threatened Species **(Pike *et al.*, 2020)**. Conservationists are increasingly concerned about the species' future, especially since wild-captured glass eels continue to be harvested on a large scale, with no hatchery-bred seed stock available to meet market demand **(Tanaka *et al.*, 2014)**.

Future efforts to improve eel stocks may depend on comprehensive fisheries management strategies that address various life cycle stages, including restocking efforts for already depleted populations. If restocking is considered, it is crucial to ensure favorable environmental conditions before introducing eels into ponds, lakes, or rivers. Therefore, understanding the habitat preferences based on the spatial and temporal distribution of all life stages of tropical *Anguillid* eels is essential to gain better insights into their ecological dynamics.

Multiple studies have explored different aspects of *A. bicolor bicolor* in the Indo-Malay Pacific region. These include research on population connectivity **(Arai & Taha, 2021; Marini *et al.*, 2021; Wibowo *et al.*, 2021)**, demography and exploitation in small coastal river systems **(Shanmughan *et al.*, 2022)**. In addition, research has addressed species discrimination, composition, and distribution **(Sugeha & Suharti, 2009; Arai & Abdul Kadir, 2017)**. Additionally, research has examined habitat transitions and migration patterns **(Arai & Chino, 2019; Arai, 2020, 2022)**. However, little is known about the habitat preferences of *A. bicolor*, which tends to favor marine or brackish environments **(Arai & Chino, 2019)**.

This study aimed to investigate the habitat preferences of *A. bicolor*, particularly during the yellow eel stage, by analyzing its spatial and temporal distribution in the Cikaso River system. The Cikaso River flows into the southern coast of Java, which is recognized as one of the primary hotspots for eel distribution and migration **(Haryono & Wahyudewantoro, 2016; Sugianti *et al.*, 2020)**. Our study examined various environmental conditions within a single-unit river system, including both mainstream and downstream areas. This information would help identify favorable habitats and inform effective management strategies for the sustainable use of *A. bicolor*.

MATERIALS AND METHODS

Study area

This study was conducted in the Cikaso River system (7°21'9.00"S, 106°38'0.20"E – 7°25'21.00"S, 106°40'24.24"E), located on the southern coast of Java, Indonesia. The river spans approximately 159.4km. Research locations were selected from 18 stations, expanding upon previous work conducted in seven locations **(Sugianti *et al.*, 2020)**.

During continental migration, *A. bicolor* inhabits river areas from downstream to upstream that are influenced by tidal activity **(Arai, 2022)**. Of the 18 stations, eleven are located in the main channel of the Cikaso River, while the remaining seven are situated in the coastal swamp area, known as Situ Ciroyom. Station 1 (Seungke) is positioned midstream, approximately 10km from the river mouth at Station 11 (Fig. 1). The main channel of the Cikaso River has a depth range between 0.4 and 6 meters. The surrounding coastal zone features riparian vegetation and coconut trees.

Near the estuary, the Situ Ciroyom coastal swamp is characterized by brackish water with ditches lined by mangrove trees, overhanging vegetation, and other aquatic plants along the banks. The area spans approximately 74,000m² **(Sugianti *et al.*, 2020)**. These waters are relatively shallow, ranging in depth from 0.4 to 1.2 meters, with the deepest point at Station 18, the main inundation area of Situ Ciroyom.

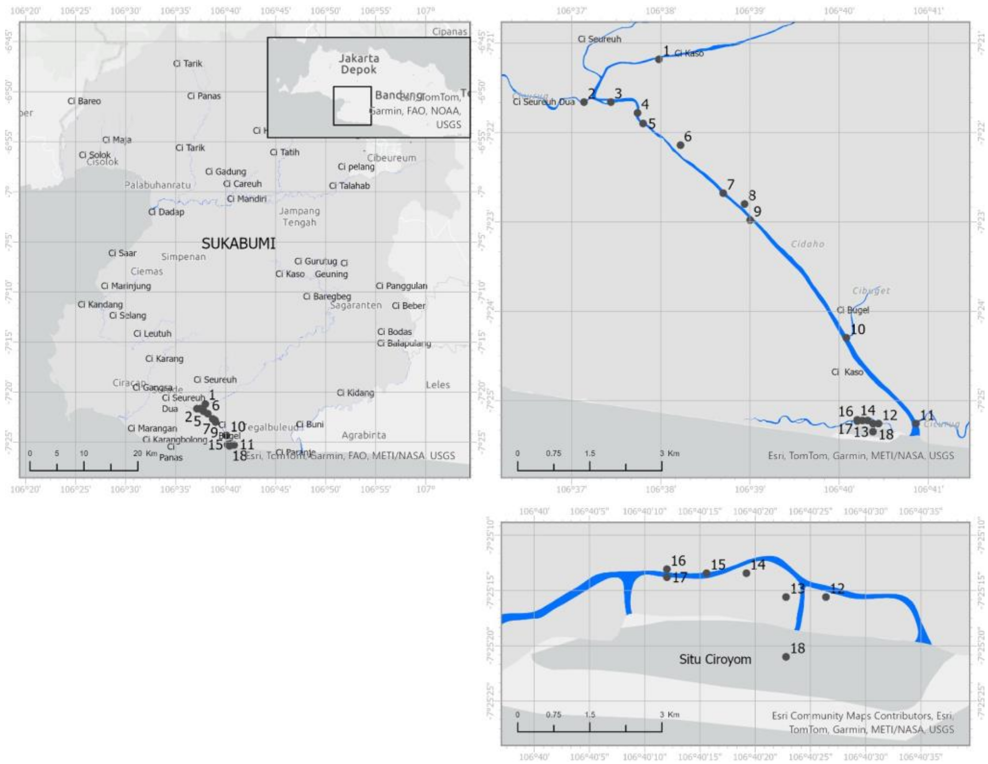


Fig. 1. Sampling site distribution covering 18 stations (black points) along the Cikaso River system in Sukabumi, West Java. Stations 1 to 11 are located in the mainstream, while Stations 12 to 18 are in the downstream or coastal swamp area

Anguillid eels collection

Our research was conducted during the new moon periods from January to December 2020. To collect yellow eel (YE) stage specimens, we used two types of fishing gear: fish traps (locally known as *Bubu*) and hook-and-line gear (locally called *Teger*). Two trap types were deployed in this study: (1) wireframe traps covered with 5 mm mesh nets and (2) PVC pipe traps with 1 mm mesh nets inserted at each end. Traps and hooks were baited with fish, shrimp, worms, or crabs.

The gear was passively set at each research station at night (between 5:00 and 7:00 p.m.) and retrieved the following morning (between 7:00 and 9:00 a.m.). Captured eels were counted, and their total length (TL, measured to the nearest 0.1 cm) and body weight (BW, measured to the nearest 0.01 g) were recorded. The YE stage was defined as immature eels with lengths ranging from 20 to 45 cm **(Rachmawati & Sistina, 2020; Putri & Syamsudin, 2021b)**.

Environmental conditions measurement

Water physicochemical parameters—including temperature (°C), dissolved oxygen (mg·L^{-1}), conductivity (µS·cm^{-1}), total dissolved solids (TDS, mg·L^{-1}), salinity (ppt), oxidation-reduction potential (ORP, mV), and pH—were measured using a YSI water quality meter. Water depth was measured using a depth meter. These eight variables were measured in January, February, June, July, November, and December 2020.

Water turbidity was measured using a turbidimeter in February, June, July, November, and December. No turbidity measurements were taken in January due to unavailability of the equipment. Water velocity ($m \cdot s^{-1}$) was recorded using a conventional floating ball in November and December.

Water samples for nutrient analysis were collected in November and December 2020 using 500ml polyethylene bottles. These were used to analyze concentrations of nitrite, nitrate, orthophosphate, ammonium, sulfate, total suspended solids (TSS), and organic matter (all in $mg \cdot L^{-1}$). Bottom substrate samples were collected using a Ponar grab in December 2020 and placed in containers for lab analysis, which included substrate texture (%), C-organic (%), and organic nitrogen (%).

Eel fishing activities were conducted year-round with the support of local fishermen. However, water quality assessments were limited to six months, and water/substrate sampling for laboratory analysis was conducted only twice and once, respectively. These constraints were primarily due to large-scale social restrictions imposed during the COVID-19 pandemic, which significantly affected fieldwork and data collection.

Rainfall data from the past five years (2016–2020) were obtained from the Water Resources Management Institute of the Cisadea–Cibareno River Basin for the Cigangsa/Surade stations (7°19'32.15" S, 106°32'53.02" E) (Supplementary 1). Based on these data, two-] time groups were established:

- **Time Group 1** (January, February, November, December): high average rainfall (556–950 mm)
- **Time Group 2** (June, July): low average rainfall (125.2–213.8 mm)

Data analysis

Habitat characteristics were determined by analyzing the values of environmental variables using Principal Component Analysis (PCA), conducted in Paleontological Statistics (PAST) software version 4.01. Key habitats for the YE stage were identified based on their presence within preferred habitat types.

Habitat preference of the YE stage was further analyzed using nodal analysis, which examines relationships between eel occurrence, habitat groupings (from PCA results), and sampling period groupings (based on rainfall data). This method, originally defined by **Boesch (1977)** and subsequently applied by researchers such as **Cunha *et al.* (2007)** and **Hedianto *et al.* (2014)**, involves the use of constancy and fidelity indices. These indices describe the habitat type of the YE stage based on its frequency of occurrence and abundance.

RESULTS

Distribution and size of the yellow eel

A total of 89 specimens of the yellow eel (YE) stage *A. bicolor* were collected from the Cikaso River system. Numbers of *A. bicolor* were found mainly in coastal swamp areas (98%, n = 87) rather than midstream (2%, n =2) of the river. The total lengths (TL) of samples from the midstream area ranged from 34.5 to 39cm, with a mean ± standard deviation (SD) of 36.75 ± 3.18cm, and body weight (BW) ranging from 110.85 to 150.59g (130.72 ± 28.10 g). Meanwhile, all specimens were found in downstream areas; TLs ranged from 20.1 to 42.2cm (29.23±5.28 cm), and BWs ranged from 7.20 to 129g (43.06±27.35g). The specimens found in the midstream were generally larger than those from the downstream areas. Further details of the number of eels by station and sampling month are given in Table (1).

Table 1. Occurrence of the yellow eels (YE) stage of *A. bicolor* at each station of the Cikaso River system

Month	Number of eels	Stations	Total length (cm)				Body weight (g)			
			Range	Mean			Range	Mean		
Jan	4	1,12,13,14	26-42.2	36.15	±	7.055	11.73-150.59	97.448	±	61.014
Feb	8	16	21-39.5	28.957	±	6.191	10.30-85.90	39.879	±	27.006
Mar	8	12,13,15,17	21-26	23.875	±	1.808	7.20-14.90	10.663	±	3.012
Apr	14	13,15,16,17	21-36	26.286	±	4.145	14.50-72.20	28.379	±	15.515
May	6	12,13,14	24-38	31.667	±	5.086	20.50-80.10	51.75	±	24.036
June	5	14,15,16	21-34.8	29.26	±	5.713	12.50-61.20	36.1	±	19.186
July	2	16,17	25.4-26.5				17.95-27.80			
Aug	1	14	23.5				21.50			
Sept	6	12,14,15,16	23.7-39.7	33.05	±	5.522	15.90-82.40	51.267	±	23.518
Oct	7	13,14,15,16	25.5-36	31.571	±	3.984	24.40-70.60	49.671	±	17.719
Nov	10	10,12,13,16,17	24.3-34.5	28.64	±	3.317	21.91-110.85	47.652	±	26.527
Dec	18	12,13,14,17	20.1-36.3	23	±	2.449	16.68-108.22	10.525	±	2.443

Environmental conditions at each station during the study

Environmental variables across the study sites illustrated spatial variation, as evidenced by differing aquatic conditions between the river's main channel (Stations 1–11) and the coastal swamp area (Stations 12–18). These differences support the presence and distribution of freshwater eels in the study area. Detailed measurement results of the environmental variables are presented in Supplementary (2).

The Principal Component Analysis (PCA) revealed a significant relationship between the research stations and the measured environmental variables, explaining 69.31% of the total variance. The first principal axis accounted for 47.11% of the variance and was strongly correlated with current velocity, dissolved oxygen, conductivity, total dissolved solids (TDS), salinity, turbidity, sulfate, sand, and clay content. The second axis explained an additional 22.2% of the variance and was strongly associated with oxidation-reduction potential (ORP), phosphate, and ammonium concentrations (Fig. 2).

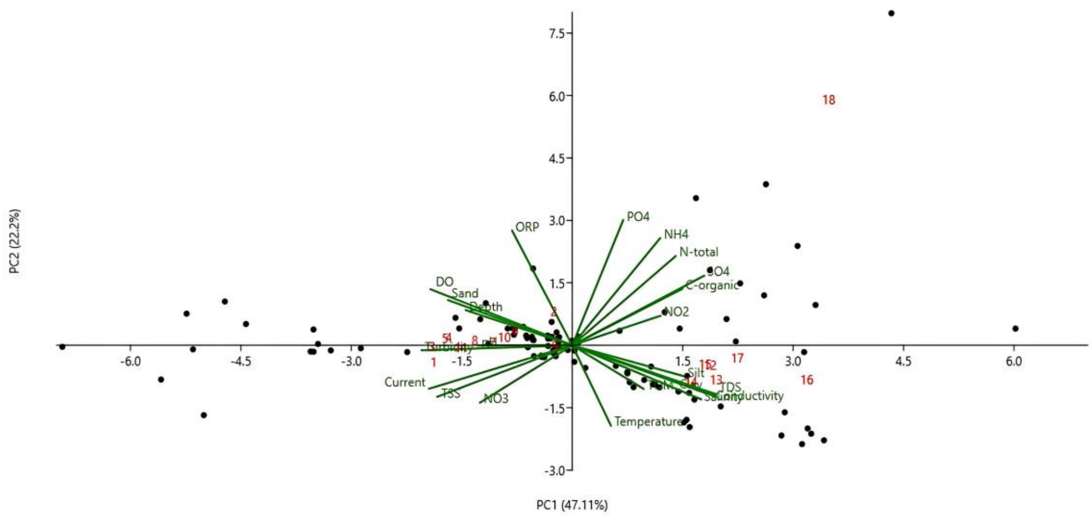


Fig. 2. The relationship between 22 environmental variables and research stations

Habitat characteristics were described based on the environmental variables at the 18 stations. The variables of water current, dissolved oxygen, ORP, turbidity, TSS, and sand substrate were associated with Stations 1 to 11. Conductivity, TDS, salinity, and clay substrate variables were associated with Stations 12 to 17, while sulfate, ammonium, and phosphate were associated with Station 18. These correlated variables are determined by a loading correlation value greater than 0.7 or smaller than -0.7 (Table 2). Bold numbers in Table (2) indicate the correlation loading value that meets the criteria.

Table 2. Loading value of PCA analysis result from environmental variables of two principal components (PC1 and PC2)

No.	Environmental variables	PC 1	PC 2
1	Depth (m)	-0.642	0.257
2	Water current (m.s^{-1})	**-0.863**	-0.318
3	Water temperature (°C)	0.233	-0.588
4	DO (mg.L^{-1})	**-0.855**	0.410
5	Conductivity (µS.cm^{-1})	**0.866**	-0.361
6	TDS (mg.L^{-1})	**0.867**	-0.358

7	Salinity (ppt)	**0.861**	-0.375
8	pH	-0.568	-0.002
9	ORP (mV)	-0.363	**0.839**
10	Turbidity (NTU)	**-0.908**	-0.037
11	Nitrite (mg.L^{-1})	0.532	0.216
12	Orthophosphate (mg.L^{-1})	0.307	**0.917**
13	Nitrate (mg.L^{-1})	-0.556	-0.420
14	Ammonium (mg.L^{-1})	0.530	**0.785**
15	Sulphate (mg.L^{-1})	**0.795**	0.509
16	TSS (mg.L^{-1})	**-0.814**	-0.377
17	Total organic matter (mg.L^{-1})	0.430	-0.319
18	C-organic (%)	0.663	0.413
19	N-Total (%)	0.623	0.652
20	Sand (%)	**-0.750**	0.331
21	Silt (%)	0.676	-0.227
22	Clay (%)	**0.777**	-0.395

Based on the similarity of environmental characteristics at each station, three groups of locations were identified: Group 1 (Stations 1–11), Group 2 (Stations 12–17), and Group 3 (Station 18). By interpreting the environmental conditions at each group of stations as distinct habitat types, three habitat classifications emerged across the 18 stations.

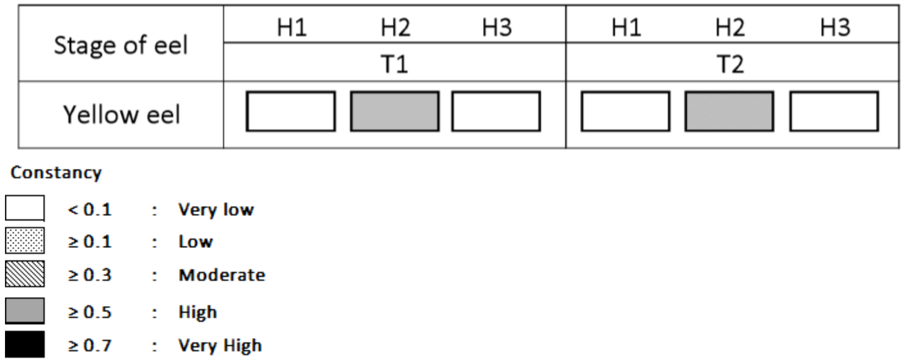
Habitat 1 (H1): Located in the main river channel, this habitat is characterized by deep water (0.4 to 6m), strong currents (0.05 to 5 m·s^{-1}), high dissolved oxygen levels (3.2 to 10.86 mg·L^{-1}), high oxidation-reduction potential (ORP) values (3 to 151.8 mV), and elevated turbidity (4.71 to 799 NTU) and TSS concentrations (11.5 to 1157.33 mg·L^{-1}). The habitat has a narrow salinity range (0.05 to 5.79 ppt) and a substrate predominantly composed of sand (24 to 85%). These features define it as a freshwater habitat.

Habitat 2 (H2): This habitat encompasses stations 12–17, located in the ditch channels of Situ Ciroyom, a vegetated coastal swamp. It is defined by high conductivity (894 to 28,396 µS·cm^{-1}), high TDS (572 to 17,979 mg·L^{-1}), a broad salinity range (0.43 to 16.96 ppt), and a clay-dominated substrate (37 to 56%).

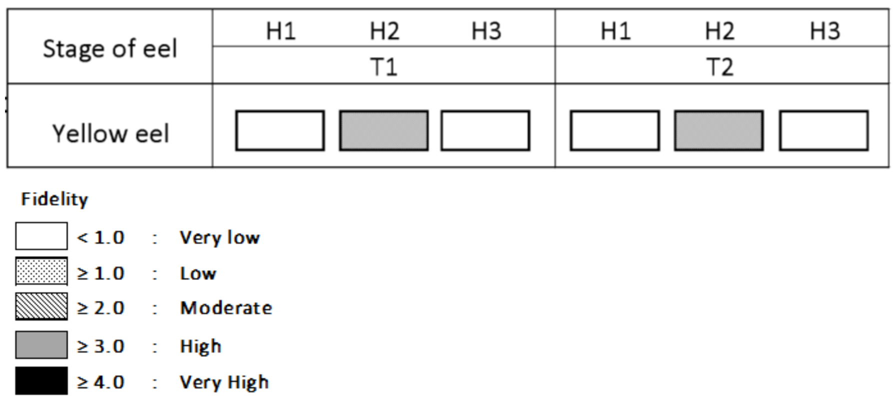
Habitat 3 (H3): Represented solely by Station 18, this habitat corresponds to the main pool of Situ Ciroyom, situated near the inflow from the river mouth. It is characterized by elevated concentrations of sulfate (68.551 to 202.402 mg·L^{-1}), ammonium (0.345 to 1.285 mg·L^{-1}), and orthophosphate (0.002 to 0.158 mg·L^{-1}).

Relationship between environmental parameters and eel occurrence

The presence of the yellow eel (YE) stage, as indicated by the constancy index (CI), ranged from moderate (0.42) to high (0.50) in H2, while it was very low (0 to 0.05) in both H1 and H3 (Fig. 3a). Habitat preference strength, expressed through the fidelity index (FI), showed a moderate association for YE individuals in H2 (FI = 2.25 to 2.7) across all time groups. In contrast, H1 and H3 demonstrated a very weak relationship with YE occurrence (FI = 0 to 0.25) (Fig. 3b).



(a) *constancy index*



(b) *fidelity index*

Fig. 3. Results of nodal analysis using constancy index (a) and fidelity index (b) of the YE and its habitats (H1=habitat 1, H2=habitat 2, H3=habitat 3, T1= time group 1, and T2= time group 2)

The yellow eel (YE) stage showed a clear preference for Habitat 2 (H2), located in the Situ Ciroyom coastal swamp, compared to H1 and H3. This preference was supported by a moderate to high constancy index (0.42 to 0.50) and a moderate fidelity index (2.25 to 2.27). H2 was characterized by a wide range of salinity, elevated concentrations of total dissolved solids (TDS) and conductivity, shallow water depths, and a clay-dominated substrate. Its proximity to the estuary likely contributed to the higher salinity and conductivity levels compared to the main channel of the Cikaso River.

In contrast, the YE stage appeared to avoid Habitat 3 (H3), which corresponds to the main pool of Situ Ciroyom, located near the inlet from the river mouth. Environmental conditions in H3 differed markedly from those in H1 and H2. This area lacked vegetated zones that could provide shelter and food resources for eels, potentially making it unsuitable for the YE stage. Additionally, H3 exhibited higher concentrations of sulfate, ammonium, and orthophosphate compared to both H1 and H2, further distinguishing it as a less favorable environment for yellow eels.

DISCUSSION

In this research, the yellow eel (YE) stage of the Indonesian shortfin eel (*A. bicolor*) was found both in the midstream of the Cikaso River and in coastal swamp ecosystems, indicating that this species can tolerate and adapt to a range of environmental conditions. According to **Shanmughan *et al.* (2022)**, *A. bicolor* typically inhabits the middle to downstream parts of rivers, including areas influenced by tides. The species is also known to inhabit freshwater, brackish, and marine environments **(Arai *et al.*, 2016; Ismail *et al.*, 2017; Arai & Chino, 2019, 2022)**. This broad distribution is closely tied to behavioral differences during the species' continental phase, during which individuals may reside permanently in estuarine or marine environments or shift between marine and freshwater habitats—referred to as inter-habitat shifters **(Rohtla *et al.*, 2023)**.

According to **Arai and Chino (2019)**, most *A. bicolor bicolor* from Indonesia are found in marine or brackish environments. This study supports that observation, as most YE individuals were caught in coastal swamp areas. Similar patterns have been reported in other studies, where the YE stage was commonly found in brackish habitats such as coastal swamps and other coastal areas **(Claus & Malte, 2015; Steele *et al.*, 2018)**.

Environmental conditions are one of the external factors influencing habitat selection by the YE stage **(Arai & Chino, 2019)**. In this study, several environmental features were associated with preferred YE habitats, including salinity below 20ppt, shallow and clear water, vegetated areas, clay-dominated substrate, and the presence of ditches in the coastal swamp. Salinity in the coastal swamp ranged from 0.43 to 16.96ppt, which is higher than that recorded in the main channel of the Cikaso River. A wide salinity range is generally preferred by young eels **(Cumaranatunga *et al.*, 1997; Claus & Malte, 2015)**.

Coastal swamp ecosystems were also favored due to their relatively shallow waters, compared to deeper areas in H1 (the main stream of the Cikaso River). This aligns with conditions described for *A. bicolor bicolor* in Sri Lankan waters **(Cumaranatunga *et al.*, 1997)**. Water depth significantly affects eel presence, particularly among younger stages, as smaller eels tend to be found in shallow habitats **(Matsushige *et al.*, 2020)**. Shallow waters provide refuge from predators, which is especially critical for juveniles **(Degerman *et al.*, 2019)**.

Throughout the year, H2 (the coastal swamp area) was densely vegetated, with mangrove roots extending along ditch banks. Such vegetation provides eels with both shelter and food. Dense vegetation is known to be one of the key factors favored by eels **(Laffaille *et al.*, 2004; Johnson & Nack, 2013; Steele *et al.*, 2018)**. Overhanging vegetation, aquatic plants, and mangrove trees also serve as feeding grounds, especially during the YE stage when eels are actively foraging before reaching adulthood (silver eel stage) **(Tesch, 2003)**. The guts of eels caught in coastal swamps were found to contain primarily crabs **(Putri & Syamsudin, 2021a)**. Crabs and other *Malacostraca* are common brackish-water prey and are also the main diet of other eel species such as *A. marmorata* **(Romanda *et al.*, 2019)** and the critically endangered *A. anguilla* **(Denis *et al.*, 2022)**.

In addition to vegetation, YE individuals were more frequently found in clay-dominated substrates, which support their burrowing behavior and enhance protection from predators. Eels are known to burrow in various substrate types, and their preferences vary with life stage and body size **(Steendam *et al.*, 2020)**. Substrate type is thus essential for young eel survival. *Anguillid* eels use mud, sand, and gravel substrates for shelter during the day, reducing predation risk **(Tomie *et al.*, 2013)**. Small eels also tend to prefer ditches, which offer lower flow velocities **(Matsushige *et al.*, 2020)**. Ditches and ponds in coastal networks are increasingly recognized as important eel habitats **(Steele *et al.*, 2018)**. The preferred habitat of *A. bicolor* observed in this study is similar to that of *A. japonica*, which also occupies relatively stagnant and muddy environments like estuaries, irrigation channels, ponds, and backwater areas **(Kumai *et al.*, 2021)**.

Our findings highlight that coastal swamps, as part of estuarine ecosystems, serve as critical habitats for *A. bicolor* during the yellow eel stage, offering essential conditions for growth, protection, and foraging. Estuarine systems have been shown to offer optimal conditions for eels and may even lead to higher spawner production under favorable circumstances **(Denis *et al.*, 2023)**. Given that habitat quality and foraging behavior are key factors in habitat use, they must be prioritized in eel management and conservation **(Kutzer *et al.*, 2019; Kumai *et al.*, 2021)**. Because YE prefer coastal swamp environments, maintaining habitat quality in these areas is crucial to sustaining eel populations **(Steele *et al.*, 2018)**.

Management and conservation efforts for coastal swamps that serve as YE habitats should be extended to other similar areas used as eel migration routes throughout Indonesia. Conservation strategies must consider the broader population dynamics of eels, especially those sharing the same spawning grounds. Isolated management of a single watershed may be ineffective if population declines occur elsewhere in the species' distribution range **(Kaifu *et al.*, 2021)**. Integrated management is therefore essential for a widely distributed species like *A. bicolor*. Spawning grounds are believed to be located off the southwestern coast of Sumatra, from where larvae are passively transported along the coasts of Sumatra and Java **(Fahmi *et al.*, 2012; Arai *et al.*, 2016)**, before moving into coastal and freshwater habitats to begin their continental life stage.

Based on our findings, several management actions are recommended to protect the coastal swamp of Situ Ciroyom as a key habitat for the YE stage. Establishing an eel sanctuary in this area could serve as a practical conservation measure to support population sustainability. Similar recommendations have been made for other species, such as *A. anguilla* **(Meulenbroek *et al.*, 2020; Denis *et al.*, 2023)**, *A. japonica* and *A. marmorata* **(Kumai *et al.*, 2021)**. Habitat protection is especially important in light of degradation seen in other regions, such as the northwestern coast of Guinea-Bissau, where coastal swamps have suffered significant anthropogenic damage **(Raimundo Lopes *et al.*, 2022)**.

Such conservation efforts would also support existing Indonesian regulations, including the monthly ban on glass eel fishing during the new moon (27–28 Hijri calendar), size limits (no more than 2kg for *A. bicolor*), as set out in The Decree of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia Number 80 Year 2020, and the national catch quota for protected fish species, including eels, as defined by The Decree of the Directorate General of Marine Spatial Management Number 2 Year 2023. Additional local-level controls, such as quota-based catch limits, can also be considered, as suggested for Near Threatened freshwater eels of India **(Shanmughan *et al.*, 2022)**.

However, further local research is necessary to determine appropriate sanctuary boundaries and sustainable harvest limits. Understanding the habitat preferences of the YE stage is essential for successful restocking or translocation programs, as it helps identify the most suitable sites for eel release. The YE stage can be restocked in coastal swamps or other ecosystems with similar characteristics. Ultimately, this study underscores the importance of understanding *Anguillid* eel ecology and habitat relationships in developing effective, sustainable management strategies.

CONCLUSION

This study found that the yellow eel (YE) stage of *A. bicolor* inhabiting the Cikaso River System was found in both freshwater and brackish water, with a higher abundance in the brackish waters located in the coastal swamp areas. These findings suggest that YE exhibit clear preferences for specific environmental conditions, such as water salinity below 20ppt, shallow and clear water, the presence of vegetation, clay substrate, and the existence of ditches in the coastal swamps. Recognizing the coastal swamp of Situ Ciroyom as a critical habitat for the YE stage provides a valuable basis for developing targeted management measures to support the conservation and sustainable use of *A. bicolor*.

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