



Analysis of the Potential Distribution of Eels (*Anguilla* spp.) Along the Luk Ulo River, Kebumen Regency, Central Jawa, Indonesia

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Abstract

Eels are catadromous fish that utilize river systems, especially estuaries, as migration corridors from marine to upstream habitats. This study assessed the abundance potential and spatial distribution of eels in the Luk Ulo River, Kebumen Regency, to support conservation efforts. Sampling was conducted at 10 stations from upstream areas to the estuary. Analyses included morphometric identification, spatial distribution, length–weight relationships, growth modeling, Principal Component Analysis, and cross-correlation with environmental parameters. A total of 30 individuals were collected, consisting of two species: *Anguilla bicolor bicolor* (22 individuals) and *A. marmorata* (8 individuals). Most specimens (93.54%) were in the yellow eel phase, indicating a growth stage dominance, while 6.45% were elvers. The mean length was 49.90 cm (SD = 34.95 cm), with non-normal distribution ($p < 0.05$) and dominance in the 32–48 cm size class. Growth followed a negative allometric pattern ($W = 0.00083L^{2.87}$), where length increases faster than weight, with a high determination coefficient ($R^2 \approx 0.93$), indicating a strong relationship between length and weight. The population structure suggests that the Luk Ulo River primarily functions as a growth habitat with stable environmental conditions. Cross-correlation analysis showed strong positive relationships between eel abundance and salinity ($r > 0.81$), total dissolved solids ($r > 0.79$), and phosphate ($r > 0.61$), indicating that higher values of these parameters are associated with increased eel presence.

Keywords: *A. bicolor*, *A. marmorata*, cross-correlation, distribution, PCA

1. Introduction

Eel fish resemble snakes in shape; however, they are not classified as reptiles but rather as fish (Teleostei: Anguillidae) because they live in water, breathe with gills, possess scales and fins, and can adapt to varying temperatures and salinities of the sea (Kuroki and Tsukamoto, 2012). Eel is a unique fish, living in freshwater habitats, so it is usually called "freshwater eel" and is catadromous; namely, adult eel fish live in freshwater, migrate to spawn far into the open sea, and larvae (leptocephali), which later metamorphose into juveniles (glass eel), return to freshwater (Arai and Kadir, 2017; Arai and Chino, 2019; Tsukamoto et al., 2002). This is in contrast to salmon, which are anadromous; that is, they live in the open sea, migrating upstream to spawn (Kuroki and Tsukamoto, 2012).

For an eel, life is a long journey. A long journey from its spawning grounds in the deep open sea back to estuaries, rivers, lakes, and other public waters. The journey commences and concludes in the spawning grounds. However, the origins of this journey (the spawning locations) were largely unknown for a long time (Kuroki and Tsukamoto, 2012). Therefore, much research remains to be done on eels, especially in Indonesian waters.

Based on taxonomy, eels are classified as follows: Genus: *Anguilla*; Family: Anguillidae; Order: Anguilliformes; Class: Actinopterygii; Phylum: Chordata. The diversity of eel species in the world totals 19 species and subspecies. Six species inhabit temperate waters, namely *Anguilla japonica*, *A. anguilla*, *A. rostrata*, *A. australis australis*, *A. australis schmidtii*, and *A. dieffenbachii*, and 13 species inhabit tropical waters, of which 7 species are found in Indonesian waters, namely *A. marmorata*, *A. borneensis*, *A. celebesensis*, *A. interioris*, *A.*

bicolor bicolor, *A. bicolor pacifica*, and *A. nebulosa nebulosa*, while the other 6 species are outside Indonesian waters, namely *A. nebulosa labiata*, *A. megastoma*, *A. obscura*, *A. mossambica*, and *A. reinhardtii* (Ege, 1939; Watanabe, 2003; Arai and Kadir, 2017). and 1 new species, *A. luzonensis*, which is only found in very limited areas (endemic), namely at the tip of Luzon Island, northern Philippines (Minegishi et al., 2009; Watanabe et al., 2009; Kuroki et al., 2012; Shinoda et al., 2015). Seven species and subspecies of eel found in the West Pacific region and in Indonesian waters make the warm waters of Indonesia the center of global distribution of tropical eel (Tsukamoto and Aoyama, 1998; Kuroki and Tsukamoto, 2012).

In addition to being the global distribution center of tropical eels, Tsukamoto and Aoyama (1998) estimated the possibility that the *A. celebesensis* eel inhabiting the waters around the northern island of Sulawesi (Celebes) is the ancestor of the Anguillidae family. Later, the results of a molecular phylogenetic study of the genus *Anguilla* (18 species) conducted by Aoyama et al. (2001) resulted in the idea that the tropical eel *Anguilla borneensis*, which is endemic to the eastern region of Kalimantan Island (Borneo), is the most basal species on the phylogenetic tree, or in other words, *A. borneensis* can be called the origin/ancestor (the most ancestral species) of the genus *Anguilla*. Aoyama et al. (2001) compared the phylogenetic tree they made to two families of marine eels, namely the Congridae and Serrivomeridae families, as groups of fish outside the Anguillidae family. The results show that the two families of sea eels are clearly distinct and are outside the phylogenetic tree of the eel family.

There are five phases in the life cycle of eels, namely: eggs, leptocephalus/larvae, glass eel/elver, yellow eel, and silver eel (Arai and Kadir, 2017). In the larval phase, eel larvae are called leptocephali (the plural of the word "leptocephalus"), which in Greek means "small and slender head," because it has a small and slender head shape compared to its elongated and flat body, shaped like a leaf, transparent with a gelatin-like material on a thin layer of muscle tissue (Miller et al., 2002).

In this phase, leptocephali are carried away by ocean currents on the continental shelf, which take them on a long journey (tens or even thousands of kilometers) from the spawning site to freshwater habitats and also over a long period of time (4-6 months), as in the case of the Japanese eel, *Anguilla japonica*. The long larval phase until reaching a certain size is a characteristic of eels (Aoyama et al., 2003). Another important fact is that the growth rate of leptocephalus eels is faster than most other fish larvae. This is due to their ability to quickly consume the yolk received from their parents a week after hatching until they reach a size of 6 millimeters (preleptocephali phase), after which they can find their own food (Kuroki and Tsukamoto, 2012). After reaching a size of 50-60 mm, leptocephali metamorphose into glass eels and then leave the ocean current system because they are able to swim independently. Glass eels then migrate to estuary waters and upstream, but before that, they must acclimatize themselves to brackish and fresh waters (Kuroki and Tsukamoto, 2012).

Glass eels in the upper reaches of rivers mature into elvers, which are approximately 4-8 months old and are the same size or slightly larger and pigmented. During their upstream migration, elvers transition into yellow eels, which live in freshwater habitats such as rivers and lakes. Upon entering the early maturing stage, eels then transition into silver eels, and as their gonad maturity increases, they begin to migrate downstream, ready to return to the sea, to the spawning grounds where they die after spawning. Silver eels must first adapt to marine life before migrating to their spawning grounds (Arai and Kadir, 2017). Understanding the life cycle of eels is still very limited. Due to their unique and mysterious nature, eels have attracted the attention of many biologists to research them (Aoyama et al., 2003; Arai, 2014).

Of the 4 species (*A. marmorata*, *A. borneensis*, *A. celebesensis*, and *A. interioris*) and 3 subspecies (*A. bicolor bicolor*, *A. bicolor pacifica*, and *A. nebulosa nebulosa*) of the leptocephali phase of the Indonesian tropical eel, all are found in Indonesian waters, except for *A. nebulosa nebulosa*, so the spawning time/location is unknown. *A. marmorata* and *A. bicolor pacifica* do not spawn in Indonesian waters (Kuroki et al., 2006; Miller et al., 2006; Minegishi et al., 2008; Arai, 2014). Therefore, only *A. celebesensis*, *A. borneensis*, *A. interioris*, and *A. bicolor bicolor* actually spawn in Indonesian waters (Arai, 2014). So there

are only 3 potential spawning locations for tropical eels, namely the Sulawesi Sea and Tomini Bay for the species *A. borneensis*, *A. celebesensis*, and *A. interioris* and to the west of Sumatra Island to the Indian Ocean for *A. bicolor bicolor*.

Eels are exotic animals due to their unique catadromous life history and are also used as a food source. Although many scientific studies have been conducted on eels, there are still many important bio-ecological aspects that remain a mystery. For example, eel spawning is still very rarely observed by people in nature because the spawning location is in the open sea (Dekker, 2003; Arai, 2014). On the other hand, eels are fish that have high economic value because they are consumed in almost all countries in the world (Kuroki and Tsukamoto, 2012). The high and increasing demand for eels has caused this fish resource to experience overexploitation. This has caused the stock of these fish to decline drastically and is beyond safe biological limits so that it can be threatened with extinction, such as the European Eel (*A. Anguilla*), American (*A. rostrata*), and Japanese (*A. japonica*), including a decline in juvenile eel stocks (glass eel/elver) of up to 80-90% for European and Japanese eels (Dekker, 2003; Arai, 2014; Monticini, 2014).

The distribution of eel fish seed is commonly found in river estuaries facing the sea (White and Knights, 1997). This condition indicates that the river ecosystem serves as an access point for the entry and exit of eel fish, making the river mouth the starting point for eel fish migrating from downstream to upstream (Aoyama, 2009). Some pigmented eels will remain in estuarine waters, while others will migrate upstream until sexual maturation (Arai and Kadir, 2017; Rachmawati and Sistina, 2020; Rachmawati et al., 2022). This condition indicates that the river ecosystem plays a significant role as an access point for eel migration. Eel fish seeds are commonly found in river estuaries that face the open sea. Environmental conditions such as water level and water temperature will affect the abundance of elver (McKinnon and Gooley, 1998; Edeline et al., 2006). One of the areas where eels are distributed in Indonesian waters is Kebumen Regency, Central Java Province. There are four major rivers in Kebumen that flow directly into the sea, namely the Luk Ulo River, the Wawar River, the Telomoyo River, and the Bodo River. In addition, there are several small rivers connected to the major rivers, such as the Tolang River and the Kedungbenar River. The presence of these currents is a significant potential for the life cycle of eels. Based on statistical data on Sidak fish catches in Kebumen Regency from 2020 to 2023, the catch results fluctuate, with figures of 777 kg, 660.73 kg, and 95 kg, respectively, and the highest in 2023 at 4,851 kg (BPS Kebumen Regency, 2024). Efforts to catch eel from the wild for human needs are certainly permitted, but they must be carried out considering three aspects of sustainable management: social, economic, and ecological factors (Social Ecological System). When these three aspects are not balanced and excessive exploitation occurs, it will disrupt the ecosystem's balance, which could ultimately lead to a decline in the eel population, potentially causing the eel population in Kebumen to become extinct. Therefore, an in-depth study is needed to determine the potential distribution of eels in Kebumen Regency, particularly in the Luk Ulo River basin, so that it can be used in policy development for the sustainable utilization of eel potential in Kebumen Regency, balancing socio-economic and ecological aspects in the effort to conserve protected fish.

Indonesian tropical eels, despite their low utilization status (Data Deficient/DD), have entered the vulnerable (VU) status due to a lack of data and information regarding their stock status and utilization. *A. bicolor bicolor* and *A. celebesensis* are already categorized as near threatened (NT), particularly *A. bicolor bicolor*, whose glass eel/elver phase has been heavily exploited, including the adult phase of *A. celebesensis* and the glass eel phase, which is beginning to be exploited. Therefore, all stakeholders must work together to complete a comprehensive database and information on all tropical eel species in Indonesian waters before they are suddenly added to the IUCN Red List, while various aspects of these species are still unknown. The IUCN assesses some species of *Anguilla* sp. (e.g., *A. japonica*) as declining in population status. The status for some tropical species may fall into the data deficient or unknown categories, but there are local indications of declining population numbers. Therefore, management must focus on habitat, regulation of glass eel fishing, mitigation of migration barriers, and genetic/population research. The purpose of this study is to determine the potential abundance and distribution of eel in the Luk Ulo River, Kebumen Regency, Central Java Province, as an effort to protect/conserv

this protected fish species. Then, the benefits of this research can be used as a basis for policy-making by both local governments and communities in a sustainable model for managing and utilizing the potential of eel fish.

2. Materials and Methods

2.1. Time and Place of Research

This research was conducted in July 2025 in the Luk Ulo River stream down to the Luk Ulo River estuary, Kebumen Regency, Central Java Province. To increase the chances of finding eel samples in the research area, eel sampling was conducted by placing 10 observation station points, ranging from areas of the river far from the estuary to the mouth of the Luk Ulo River, which borders directly with the Indian Ocean. **Figure 1** displays the research location.

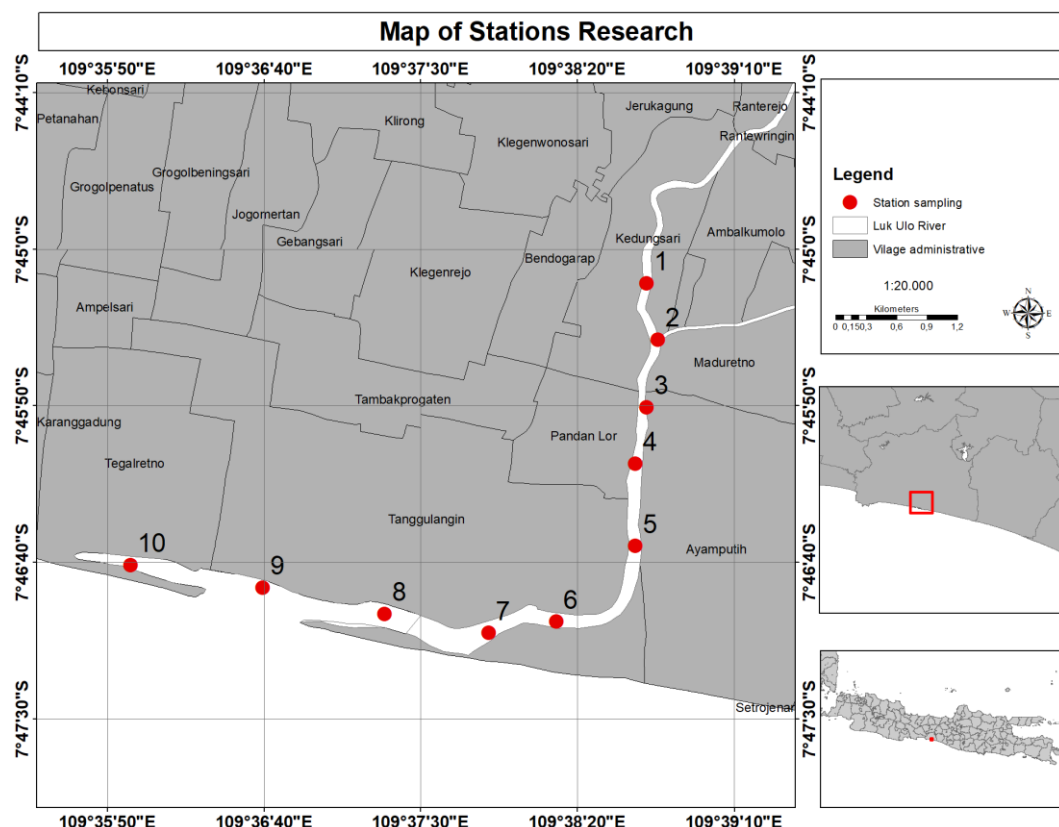


Figure 1. Research Location of Eel Distribution in the Luk Ulo River, Kebumen Regency.

2.2. Data

The data used in this study are primary and secondary data. The primary data used include biological data morphology of eel (total length, dorsal fin length, anal fin length, weight of eel fish) and water parameter data (temperature, salinity, clarity, dissolved oxygen, pH, water depth, Total Dissolved Solids/TDS, sediment type, nitrate, phosphate, ammonia). Meanwhile, the secondary data were taken from several related literature. To obtain eel samples, fishing was carried out using a pole and line and a drift gill net. Eel is one of the nocturnal fish (active in foraging at night), so the fishing method is carried out from late afternoon to evening, starting from 5:00 PM to 3:00 AM Western Indonesian Time for 7 consecutive days in July 2025. The bait used for eel fishing is small shrimp and pellets. From 10 observation station points, a minimum of 10 anglers are needed, spread across each station, with each angler using at least 3 pole and line units. The captured eels are then placed in a bucket of water to keep them alive. Water parameters were measured using a Horiba U-50 Multiparameter Water Quality Meter.

2.3. Data Analysis

2.3.1. Species Analysis of Eel

The measurement of eel body parts, which are often used as a key for species identification, is morphometric length measurement of eel body parts, as shown in **Figure 2**. Based on the ADL/%TL character, Hakim et al. (2015) were able to identify 3 species of glass eel/elver of Indonesian tropical eels, with their distribution in the western waters of Sumatra Island and southern Java, namely *A. bicolor bicolor* (ADL/%TL: 1.72 ± 1.05), *A. nebulosa nebulosa* (ADL/%TL: 6.60 ± 1.79), and *A. marmorata* (ADL/%TL: 15.07 ± 1.04).

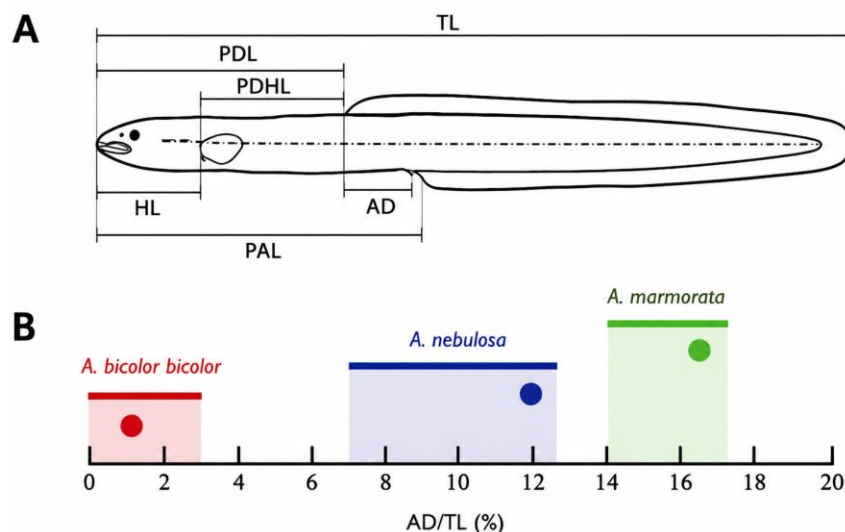


Figure 2. A). Morphometric measurements of body parts of glass eel/elver. TL: Total length, PDL: Pre-dorsal length, PDHL: Pre-dorsal length of head, HL: Head length, AD or ADL: Anodorsal length and PAL: Pre-anal length; B). Identification results of 3 species of glass eel/elver based on comparison between ADL and TL characters. (Hakim et al., 2015).

Determining the type of eel based on measurements of total length (LT), dorsal length (LD), and anal length (LA) and comparing the anadorsal ratio (A/D%) (Réveillac et al., 2009), using the Equations 1 (Watanabe et al., 2004; Watanabe et al., 2008; Astuti, 2023), and **Figure 3**.

$$A/D \% = \frac{(LD - LA)}{LT} \times 100 \tag{1}$$

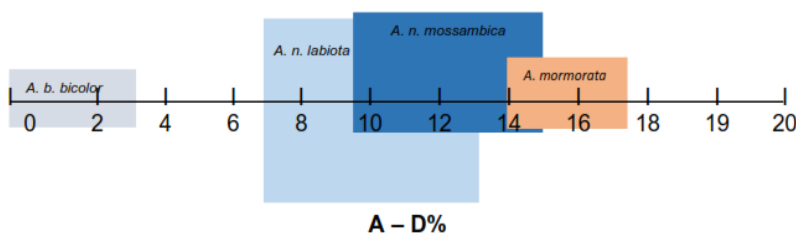


Figure 3. Determination of eel species based on (AD/TL)% value. Each color represents a typical range of A-D% values for one *Anguilla* species: *A. bicolor* (light gray): low A-D% values (approximately 0-4), *A. n. abiota* (light blue): intermediate values (approximately 6-10), *A. n. mossambica* (dark blue): intermediate-high values (approximately 9-14), *A. marmorata* (orange): high values (approximately 14-18), The blue area labeled A-D% emphasizes that the 6-14% range is an important/overlap zone for distinguishing several morphologically similar species, especially within the *Anguilla nebulosa* complex and its relatives.

Length Frequency Distribution Length frequency distribution is used to determine fish size groups based on the assumption that the length frequency of individuals within the same species and group will vary according to a distribution (Effendie, 2002). The calculation of

the length frequency distribution was analyzed according to Sturges (1926) using the Equations 2:

$$k = 1 + 3.3 \log n \quad (2)$$

The variables used in this analysis include **k** as the number of classes and **n** as the number of data points. The class interval is determined using the Equations 3:

$$C = \frac{n_{max} - n_{min}}{k} \quad (3)$$

2.3.2. Growth Model

The relationship between fish length (**L**) and fish weight (**W**) was analyzed using exponential regression, the using the equations 4 (Effendie, 2002):

$$W = aL^b \quad (4)$$

The variables used in this analysis include **W** and **Y** as fish weight (grams), and **L** and **X** as fish length (centimeters). The growth pattern is determined by the value of parameter **b**, where **b < 3** indicates negative allometric growth (fish weight increases more slowly than length), **b > 3** indicates positive allometric growth (fish weight increases faster than length), and **b = 3** indicates isometric growth, meaning that fish weight increases proportionally with length.

2.3.3. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is an analysis of habitat conditions based on water's physical and chemical parameters and environmental conditions. In principle, this analysis will reduce the data dimensions or simplify the existing many variables into a few main components, thus revealing hidden patterns or structures among the correlated variables. This means that PCA seeks a linear combination of the original variables so that most of the variation (information) in the data can be explained by a few principal components. The water parameters used are temperature, salinity, clarity, dissolved oxygen, pH, water depth, Total Dissolved Solids (TDS), sediment type, nitrate, phosphate, ammonia, and the biological parameter is the number of eel catches. To characterize the habitat conditions and their relationship to the eel population in the Luk Ulo River, principal component analysis (PCA) was performed. PCA calculations were performed using the Statgraphics XVII X64 program.

2.3.4. Spatial Analysis of Eel

To determine the distribution of eel fish in the Luk Ulo River flow, Kebumen Regency, a spatial analysis was conducted using a Geographic Information System (GIS) approach with ArcGIS software version 10.3. In a Geographic Information System, it is a framework for acquiring and organizing spatial data and related information so that it can be displayed and analyzed, or explicitly stating that a GIS is computer-based. This aligns with Chang (2018), who stated that a GIS is a computer-based information system designed to work with data that has spatial or geographic coordinate references. To determine the parameter values between station points, an interpolation technique using Inverse Distance Weighting (IDW) was applied. IDW is a spatial interpolation method used to estimate values at unmeasured locations based on data from nearby points, with the principle that the closer a sample point, the greater its influence compared to distant points.

3. Results and Discussion

3.1. Diversity of eel species

Based on the catch of 30 eels along the Luk Ulo River and the results of morphometric identification using the ADL/%TL, the eel species found at the research location were identified as only 2 types of species: *A. bicolor bicolor* (22 eels) and *A. marmorata* (8 eels),

with a total of 28 eels (93.33%) found in the adult stage (yellow eel) and 2 eels (6.67%) in the elver stage, as shown in **Table 1**. Based on the morphological characteristics of the two eel types found, *A. bicolor bicolor* and *A. marmorata*, there are significant differences: *A. bicolor bicolor* has a black or plain brown back and a yellowish-white belly, while *A. marmorata* has a body color that varies from greenish-brown to blackish-gray, with the distinctive feature of a marble pattern on its back, as shown in **Figure 4**. Based on research by Watanabe et al. (2004) and Falah et al. (2023), it is stated that eel species *A. bicolor bicolor* and *A. marmorata* are frequently found in the Indian Ocean, particularly on the South Coast of Java, and are present in the Jali River Estuary (Purworejo Regency), the Luk Ulo River (Kebumen Regency), and the Serayu River (Cilacap Regency). The eel *Anguilla bicolor bicolor* has a complex catadromous life cycle, meaning it spawns in tropical oceans and its larvae migrate to inland waters to grow before returning to the sea as adults for reproduction. After spawning in deep oceanic waters, the eggs hatch into transparent, leaf-shaped pelagic larvae called leptocephali, which drift with ocean currents and feed on organic particles and zooplankton for several months. These larvae then metamorphose into glass eels (about 5-7 cm long) that remain transparent and begin entering estuaries, where they develop into elvers that gradually gain pigmentation and actively migrate upstream into rivers or brackish habitats. The longest growth phase occurs during the yellow eel stage, when eels inhabit rivers, swamps, or lakes for several years (around 5.5-8.5 years in tropical eels) while feeding actively and accumulating energy reserves. Once sexually mature, they undergo a second metamorphosis into silver eels, characterized by a silvery coloration, enlarged eyes, cessation of feeding, and long-distance migration back to the ocean to spawn once in their lifetime before dying, thus completing the life cycle (Tesch, 2003; Arai and Abdul Kadir, 2017; Wouthuyzen et al., 2020).

Table 1. Analysis of Eel Species Based on Morphometric Ratio of (AD/TL)% value. Based on the results of morphological analysis, 2 species of eel were found in the Luk Ulo River, namely *A. bicolor bicolor* and *A. marmorata*.

Sample number	Total Length (TL) (cm)	Dorsal Length (DL) (cm)	Anal Length (AL) (cm)	Weight (gram)	AD	AD/TL	Species
1.	54	41	21	325	20	0.3704	<i>A. marmorata</i>
2.	72	46	43	795	3	0.0417	<i>A. bicolor bicolor</i>
3.	75	43	42	745	1	0.0133	<i>A. bicolor bicolor</i>
4.	84	59	49	1,005	10	0.1190	<i>A. marmorata</i>
5.	80	48	46	890	2	0.0250	<i>A. bicolor bicolor</i>
6.	55	42	32	375	10	0.1818	<i>A. marmorata</i>
7.	53	40	31	310	9	0.1698	<i>A. marmorata</i>
8.	58	43	33	340	10	0.1724	<i>A. marmorata</i>
9.	59	40	30	305	10	0.1695	<i>A. marmorata</i>
10.	38	23	21	80	2	0.0526	<i>A. bicolor bicolor</i>
11.	35	21	20	60	1	0.0286	<i>A. bicolor bicolor</i>
12.	59	44	32	420	12	0.2034	<i>A. marmorata</i>
13.	12	6	5	2	1	0.0833	<i>A. bicolor bicolor</i>
14.	13	8	7	2	1	0.0769	<i>A. bicolor bicolor</i>
15.	33	29	28	85	1	0.0303	<i>A. bicolor bicolor</i>
16.	34	21	20	60	1	0.0294	<i>A. bicolor bicolor</i>
17.	32	19	17	50	2	0.0625	<i>A. bicolor bicolor</i>
18.	33	21	19	60	2	0.0606	<i>A. bicolor bicolor</i>
19.	35	21	20	55	1	0.0286	<i>A. bicolor bicolor</i>
20.	33	20	19	50	1	0.0303	<i>A. bicolor bicolor</i>
21.	29	17	15	40	2	0.0690	<i>A. bicolor bicolor</i>
22.	34	20	19	50	1	0.0294	<i>A. bicolor bicolor</i>
23.	33	20	17	55	3	0.0909	<i>A. bicolor bicolor</i>
24.	37	23	21	75	2	0.0541	<i>A. bicolor bicolor</i>
25.	34	18	17	60	1	0.0294	<i>A. bicolor bicolor</i>
26.	32	19	17	20	2	0.0625	<i>A. bicolor bicolor</i>
27.	35	21	20	20	1	0.0286	<i>A. bicolor bicolor</i>
28.	35	21	20	55	1	0.0286	<i>A. bicolor bicolor</i>
29.	93	63	48	410	15	0.1613	<i>A. marmorata</i>
30.	33	19	18	70	1	0.0303	<i>A. bicolor bicolor</i>

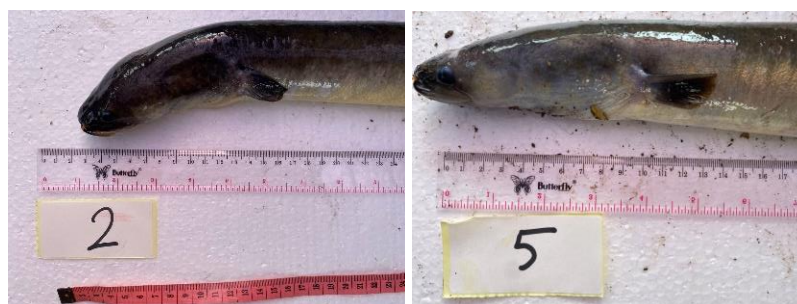


Figure 4. a). Eel *A. marmorata*, b). Eel *A. bicolor bicolor*, successfully caught in the Luk Ulo Riveandr, Kebumen. Very significant differences in length and weight indicate different age groups.

The giant mottled eel *Anguilla marmorata* has a catadromous life cycle similar to other tropical anguillid eels, spawning in the open ocean and growing in inland waters before returning to the sea to reproduce. After spawning in deep marine waters, the eggs hatch into transparent, leaf-shaped pelagic larvae known as leptocephali, which drift with ocean currents and feed on organic particles for several months. These larvae then metamorphose into transparent glass eels that migrate toward coastal and estuarine areas, where they develop into elvers that gradually gain pigmentation and actively migrate upstream into rivers or brackish habitats. The longest growth phase occurs during the yellow eel stage, when individuals inhabit freshwater or estuarine environments for several years while feeding intensively and accumulating energy reserves. Once sexually mature, they transform into silver eels, characterized by a silvery body coloration, enlarged eyes, cessation of feeding, and long-distance migration back to the ocean to spawn once in their lifetime before dying, thus completing the life cycle (Tesch, 2003; Arai and Abdul Kadir, 2017; Wouthuyzen et al., 2020).

Out of a total of 30 eel samples found, the average length of the dominant eel species was in the 32-48 cm size range, with 14 individuals. Based on the distribution pattern of *A. bicolor bicolor* eels in the tropics, particularly in Indonesian waters, *A. bicolor bicolor* spawns in the waters near the Mentawai Trench off the coast of Sumatra Island. The spawning center for *A. marmorata* eels is located in the western part of the North Pacific Ocean and the Indo-Pacific region (Arai, 2014). Additionally, according to Arai (2016), the spawning location of *A. bicolor bicolor* in Southeast Asia is in the open sea west of Sumatra Island, which flows into the Indian Ocean. Additionally, the very close genetic relationship between species is also caused by the migration patterns of most tropical eels, which differ from those in subtropical regions. In other words, the migration distances are much shorter in tropical areas (Arai, 2016).

Based on the catadromous nature of eels, which spawn in the deep open ocean and return to estuarine waters, rivers, lakes, and other public waters for growth and feeding (Kuroki and Tsukamoto, 2012), and based on the results of this study, it can be explained that particularly for the species *A. bicolor bicolor*, it is highly likely that during the spawning process in the western Indian Ocean, specifically in the open waters of the Mentawai Trench, Sumatra, which is during the larval/leptocephalus stage, the glass eel/elver stage will begin to migrate to river estuaries located on the western coast of the Indian Ocean and spread as far south as the Indian Ocean, specifically to river estuaries and into freshwater bodies, one of which is the Luk Ulo River, Kebumen Regency. Ultimately, by the yellow eel and silver eel stages, they are already widely distributed in freshwater bodies.

Based on the location of the spawning center for the *A. marmorata* eel, it is found in the western part of the northern Pacific Ocean and the Indo-Pacific region (Arai, 2014). However, *A. marmorata* is also found in several river estuaries in western Sumatra, southern Java, Bali, and Lombok (Fahmi, 2013), and this research also found *A. marmorata* in the Luk Ulo River Estuary, Kebumen Regency, which is part of the Indian Ocean coast. Therefore, it is highly likely that there is a connectivity between the *A. marmorata* species found along the western and southern coasts of the Indian Ocean and the species found in the Luk Ulo River, Kebumen Regency.

The results of this study indicate that the Luk Ulo River supports the presence of several eel species (*Anguilla* spp.), which is consistent with previous survey results in estuaries and river mouths in Central Java that reported the identification of elvers/juvenile *Anguilla* in the Serayu, Jali, and Luk Ulo estuaries. These findings strengthen the evidence that coastal areas and river mouths in this region serve as migration routes and recruitment areas for eels (Falah et al., 2023). The observed size distribution shows a seasonal/periodic recruitment pattern (e.g., peak arrival of elvers), a pattern often reported in tropical *Anguilla* populations. Based on the size of the eels found, there were 2 eels (6.67%) at the elver stage, with the remaining 28 eels (93.33%) found at the adult stage (yellow eel). This suggests that connectivity between the sea and the river is still ongoing, but if the proportion of juveniles is low, it could indicate migration barriers or fishing pressure at an early stage. Compare the recruitment figures from regional data to assess whether the Luk Ulo River still provides adequate recruitment function. The distribution of *Anguilla bicolor bicolor* and *A. marmorata* eels is found from the mouth of the Luk Ulo River to inland freshwater bodies. This indicates that adult/yellow eels migrate to freshwater areas for growth and feeding, as shown in Figure 5.

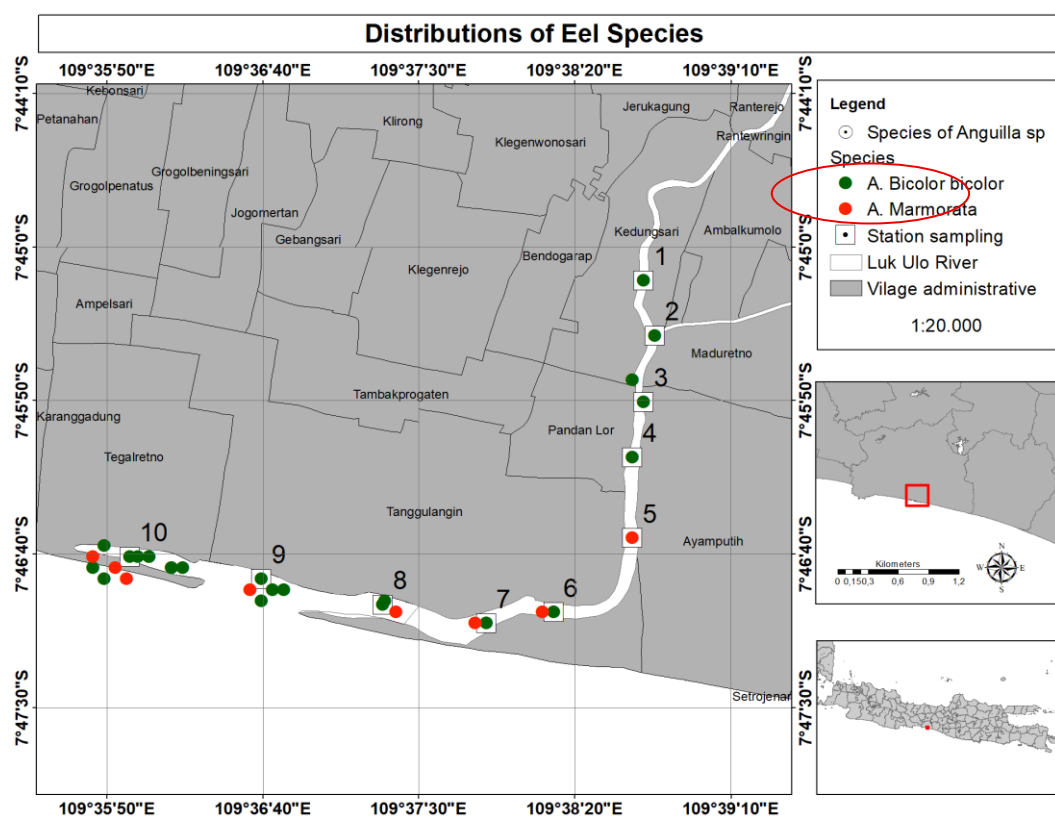


Figure 5. Distribution of Eel Species in the Luk Ulo River, Kebumen Regency. Based on the analysis of the spatial distribution of eels, it shows that the species *A. bicolor bicolor* and *A. marmorata* are often found in transition areas with brackish water characteristics and in downstream areas of rivers with saltwater characteristics.

The discovery of two eel species, *A. bicolor bicolor* and *A. marmorata*, at the mouth of the Luk Ulo River may be due to several factors, including the current moving from West Sumatra to South Java. The western part of Indonesia is influenced by the South Equatorial Counter Current (SECC), which develops throughout the year and is located directly across the equator. This current generally flows southeastward along the coast of Sumatra and continues along the coast of Java/South Java Current (SJC) (Wyrcki, 1973).

3.2. Length Frequency Distribution

Based on the total catch of eel fish in the Luk Ulo River, which amounted to 30 individuals, with 8 being *A. marmorata* and 22 being *A. bicolor bicolor*, and based on the histogram

graph of the length distribution of eel fish measured in centimeters (cm). It can be seen that most of the data is concentrated in the length range of 20-70 cm and is dominated by the size interval of 32-48 cm, and length distribution of *A. marmorata* is concentrated in the length of 51-56 cm and 56-61 cm with the number of frequencies of each being 3 individuals. This uneven distribution pattern indicates that the observed eel population consists of several different size classes, reflecting diverse growth stages, from young individuals (elvers or yellow eels) to adult individuals (silver eels). The majority of points clustered in the 20-70 cm range indicates an active growth phase, where individuals are still experiencing significant body length increases. While one or two points at lengths above 150 cm indicate adult individuals that have reached a size approaching the asymptotic length (L_{∞}) in the von Bertalanffy growth model. The length distribution graph of eel fish of *A. bicolor bicolor* is shown in **Figure 6**, and the length distribution graph of *A. marmorata* is shown in **Figure 7**.

The weight distribution of eel fish from this study shows the distribution of eel fish (*Anguilla* sp.) body weight, measured in grams (g), and presented in the form of a scatterplot. Based on the analysis, the distribution of eel fish shows that most data points are concentrated in the weight range of 0-1,000 grams. This distribution pattern indicates that the observed eel population has high body size variability, but most individuals are still in the young to middle growth stages. The data distribution, which tends to cluster on the left side of the graph, indicates a higher proportion of small- to medium-sized eels compared to large ones. This is commonly observed in natural fish populations, where mortality increases with age and only a small fraction of individuals reach large sizes, is shown in **Figure 8**.

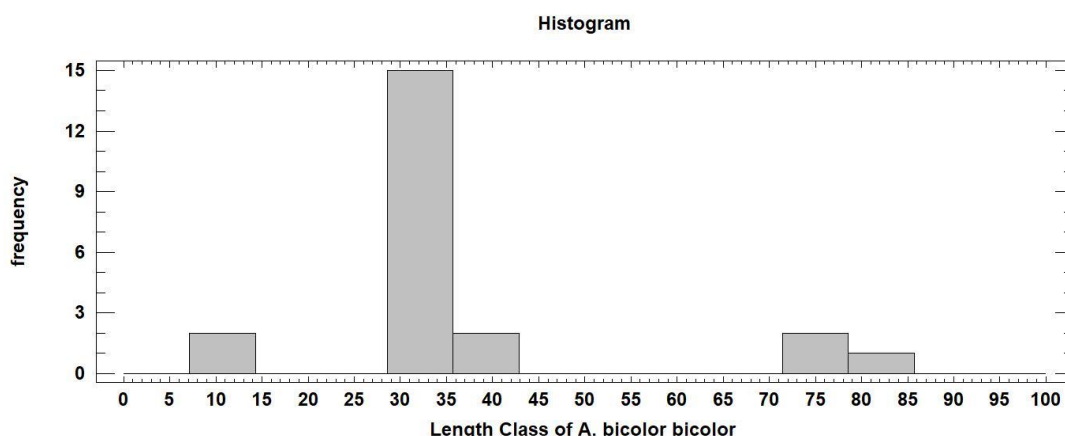


Figure 6. Histogram of Frequency Distribution of Eel Length of *A. bicolor bicolor* in the Luk Ulo River, Kebumen.

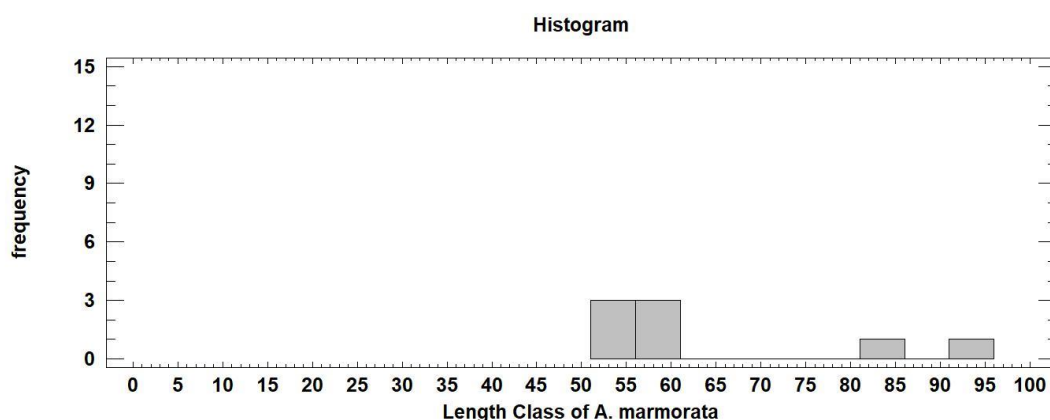


Figure 7. Histogram of Frequency Distribution of Eel Length of *A. marmorata* in the Luk Ulo River, Kebumen.

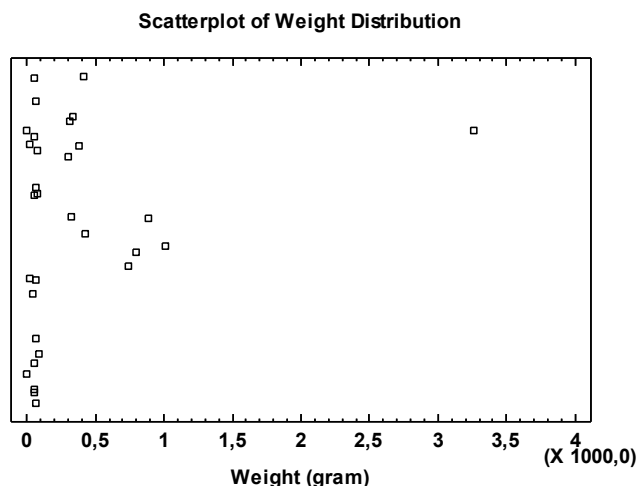


Figure 8. Scatterplot of Eel Weight Distribution in the Luk Ulo River, Kebumen. This distribution pattern indicates that the observed eel population has high body size variability, but most individuals are still in the young to middle growth stages.

3.3. Growth Model

The growth of eel (*Anguilla* spp.), such as the commonly found *A. bicolor bicolor* in Indonesian waters, is a complex biological process influenced by genetic, environmental, and nutritional factors. In fisheries studies, growth models are used to describe the relationship between size (length or weight) and time (age), as well as to understand population dynamics and aquaculture management. Overall, the eel growth model provides an important scientific basis for production planning, stock management, and the evaluation of aquaculture performance.

The growth pattern of eel in the Luk Ulo River follows a negative allometric model $W=0.00083L^{2.87}$, indicating that length increases faster than weight. The high coefficient of determination ($R^2 \approx 0.93$) confirms that body length is a strong predictor of weight. The population structure is dominated by medium-sized individuals (32-48 cm), reflecting a prevalence of the growth phase (yellow eel stage). These findings suggest that the study area primarily functions as a growth habitat, with stable environmental conditions supporting elongation-dominant growth patterns.

The blue curve represents the best-fit model describing the average relationship between length and weight of the eel population and serves as the primary predictor for estimating body weight at a given length. The two red curves located on both sides of the main curve represent the prediction band, indicating the normal range of biological variation within the population. This range reflects natural variability among individuals that may be influenced by environmental conditions, food availability, age, sex, season, and physiological status. Individuals located within the red boundaries are considered to exhibit normal growth variation. Meanwhile, the outer grey curves represent the extreme prediction limits. Data points outside these limits can be categorized as outliers or individuals with markedly different growth conditions, potentially caused by suboptimal environmental conditions, life stage differences, or health-related factors.

The curve pattern shows that weight increases relatively slowly at smaller body lengths and rises sharply at lengths above approximately 60-80 cm. This pattern indicates an energy and lipid accumulation phase characteristic of eels approaching the reproductive migration stage (silver eel phase). Overall, this growth model confirms that eel growth is non-linear and accelerates at larger body sizes, providing important information for stock management, biomass estimation, aquaculture development, and eel conservation strategies.

The curve pattern shows that the increase in fish weight sharply increases with body length, especially after reaching a size of approximately 70-100 cm. In the early growth phase,

weight gain is relatively slow because more energy is used for the process of body length growth. However, after reaching a medium size, the fish begins to show rapid weight gain, reflecting the optimal growth phase. This phenomenon is common in eels, which undergo morphological and physiological changes as they age, particularly when transitioning from the yellow eel phase to the silver eel phase, characterized by the accumulation of energy reserves in the form of fat for spawning migration (Arai, 2016). Additionally, the distribution of data points on the graph shows good agreement with the model, especially for lengths between 40 and 120 cm, which represents a population with varying size structure and stable growth conditions.

From a fisheries ecology perspective, this exponential growth model supports the biological characteristics of eel as a catadromous species, which grows in freshwater or estuaries and migrates to the sea to spawn. During the growth phase in freshwater, eels exhibit a rapid length growth rate up to a certain length, followed by a significant increase in weight as energy begins to be stored for migration (Tesch, 2003). This model aligns with the study by Arai, (2022), which found that the length-weight relationship of tropical eels in estuaries is exponential and shows positive allometric growth, with the growth rate increasing rapidly after reaching a medium size.

From a fisheries ecology perspective, this exponential growth model supports the biological characteristics of eel as a catadromous species, which grows in freshwater or estuaries and migrates to the sea to spawn.

Overall, the growth pattern of eel in the Luk Ulo River follows a negative allometric model $W=0.00083L^{2.87}$, indicating that length increases faster than weight. This indicates a population in good natural growth conditions and supports the application of the exponential model as a representative mathematical approach to describe the morphometric relationships and growth dynamics of eel in estuarine habitats. The growth model graph for eel is shown in **Figure 9**.

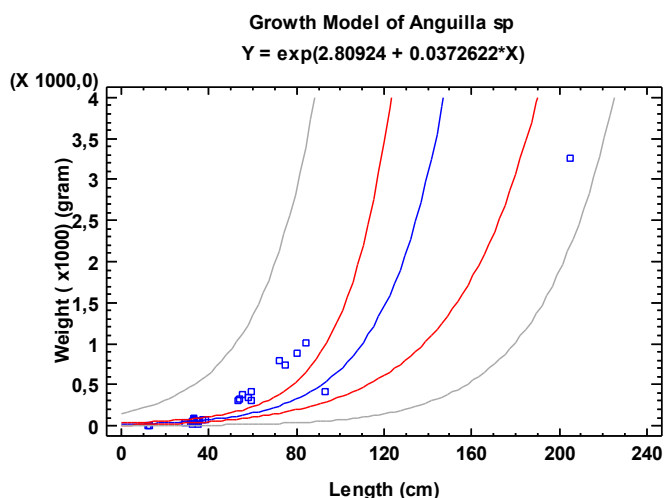


Figure 9. Growth Model of Eel Based on Length and Weight of Eel in Luk Ulo River, Kebumen. Based on the curve shape and equation obtained, this growth model describes a negative allometric relationship between body length and weight, where weight gain occurs faster than length gain.

3.4. Principle Componen Analysis

The Principal Component Analysis (PCA) graph of eel (*Anguilla* sp.) shows a clear relationship between environmental parameters and the abundance of individual eels at various observation stations. Based on the analysis results, the first principal component (PC1) describes the gradient of water's physical-chemical conditions influenced by variables such as salinity, TDS (Total Dissolved Solids), depth, and phosphate, all of which are

positively associated with the number of *Anguilla* sp. individuals. The arrow direction of these variables is parallel to number of eel, indicating that eel abundance increases in water conditions with relatively high salinity and TDS, as well as moderate to deep depths, which are commonly found in estuary regions. Conversely, the second principal component (PC2) represents the condition of water productivity controlled by the variables pH, DO (dissolved oxygen), and nitrate, where a positive PC2 value indicates water with high dissolved oxygen and stable acidity levels, which is suitable for supporting the metabolic activity of eels.

The distribution of station points on the graph shows a spatial separation of eel habitat. Station 10, located on the right side of PC1, is strongly associated with high salinity and TDS, indicating a location with the highest number of eels, likely an estuarine area with brackish water conditions. Conversely, stations 1 to 3 are located on the left side of PC1, showing a negative relationship with eel abundance and salinity, which suggests that this area is freshwater or the upstream part of the river where young eels or glass eels are more frequently found. Stations 5 to 8 are located in the negative PC2 direction, which is associated with increasing temperature and ammonia levels, indicating areas with higher levels of pollution or eutrophication and are presumed to be less supportive for the eel population. Overall, these PCA results confirm that the abundance of eel is highly influenced by environmental factors, particularly salinity, depth, dissolved oxygen, and water nutrient levels.

Ecologically, these results align with the theory of migration and osmoregulation adaptation in eels as described by Arai (2016), which states that eels have the ability to adapt to various salinity levels throughout their life cycle but show a preference for estuarine waters during the growth phase. Lokman and Young (2000) also reported that the metabolism and growth of squid are highly influenced by temperature, oxygen, and ammonia levels, making variations in water quality crucial in determining their population distribution. Meanwhile, Jellyman and Tsukamoto (2010) explained that the spatial differences in eel habitat along the salinity gradient reflect the natural migration process from young stages in freshwater toward adulthood in brackish or marine waters. This result is also supported by Dekker (2003), who stated that the success of the eel population depends on the quality of the habitat along its migration route, including the physical and chemical conditions of the water. Thus, this PCA graph shows that the composition and distribution of eels in an ecosystem are highly dependent on a combination of environmental factors, with habitats having moderate salinity, sufficient oxygen, and optimal nutrient content being the most supportive locations for the growth and abundance of *Anguilla* sp. The PCA graph is shown in **Figure 10**.

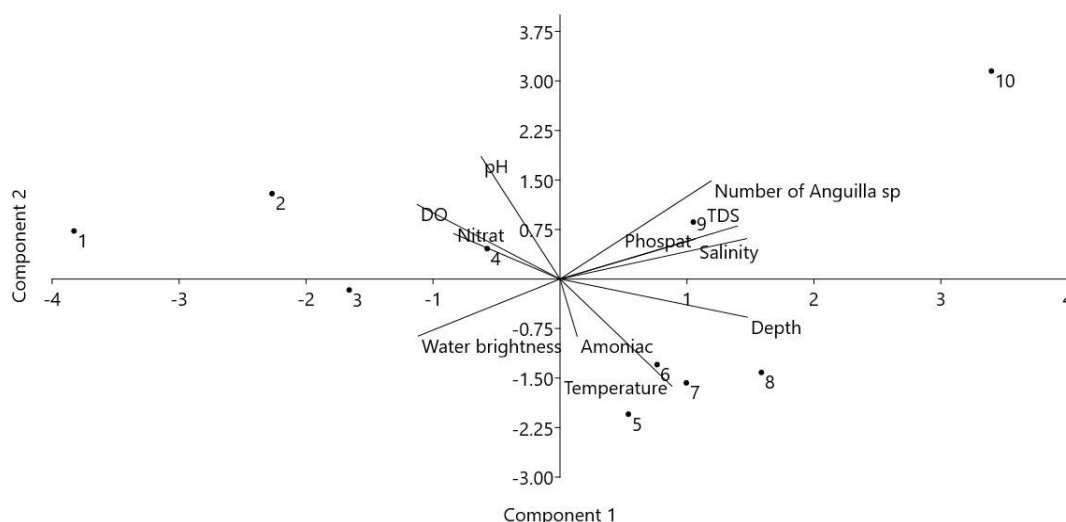


Figure 10. Graph of Principal Component Analysis showing the relationship between water parameters and the number of eel catches in the Luk Ulo River, Kebumen. The arrow direction of these variables is parallel to number of eel, indicating that eel abundance increases in water conditions with relatively high salinity, TDS and phospat.

Principal Component Analysis (PCA) is used to identify the environmental factors that most influence the distribution and abundance of eels (*Anguilla* sp.) by reducing many variables into a few main components. In the PCA graph (**Figure 10**), it can be seen that the variables of salinity, TDS, depth, and phosphate have a significant contribution to Principal Component 1 (PC1), while DO, pH, and nitrate dominate Principal Component 2 (PC2). The relationship between the number of *Anguilla* sp. and the direction of the salinity and TDS vectors indicates a positive association, suggesting that eels are more abundant in brackish water or estuarine conditions with specific chemical qualities. To strengthen these findings, cross-correlation analysis was used to assess the degree of closeness and direction of the relationships between the variables involved, particularly between environmental parameters and the abundance of individual eels.

The results of the cross-correlation analysis usually show a significant positive correlation between the number of *Anguilla* sp. and salinity ($r > 0.81$), TDS ($r > 0.79$), and phosphate ($r > 0.61$), meaning that the higher the salinity, dissolved solids content, and phosphate concentration, the greater the likelihood of finding eels. This indicates that the higher the salinity, the greater the abundance of eels found at the observation site. This is consistent with the results of the PCA analysis, where the vector "Number of *Anguilla* sp." is parallel to the direction of salinity and TDS (Total Dissolved Solids), indicating that brackish or estuarine habitats are the most optimal regions for eel growth and activity.

Conversely, variables such as ammonia ($r < -0.13$) and temperature ($r < -0.14$) showed a negative correlation with clam abundance, indicating that overly warm or polluted water conditions can decrease population density. This result aligns with the vector orientation in the PCA plot, where the direction number of eel is opposite to ammonia and temperature. This indicates that high temperatures and excessive ammonia concentrations can degrade habitat quality, cause physiological stress, and reduce eel population density. This finding is also consistent with the results of PCA, where the direction of the temperature and ammonia vectors is opposite to the vector of clam abundance, indicating a negative influence on the presence of this species. Thus, the integration of PCA and cross-correlation provides complementary insights, where PCA reveals spatial patterns and the dominance of environmental factors, while cross-correlation statistically confirms the quantitative relationships between variables. Additionally, Dissolved Oxygen (DO) also showed a significant positive relationship with eel abundance ($r = 0.654$; $p = 0.004$). These results indicate that increasing the dissolved oxygen level in the water supports the respiratory and metabolic activity of eels, thereby affecting their survival and increasing biomass.

Ecologically, these relationships indicate that the abundance of eels is highly dependent on the balance of water's physical and chemical parameters. Salinity and dissolved oxygen (DO) are two key factors determining the optimal location for eels to migrate and grow, while high temperatures and high ammonia are major limiting factors. This phenomenon aligns with Arai's (2016) report stating that *Anguilla* sp. has high osmoregulatory flexibility, but its distribution is strongly influenced by salinity and dissolved oxygen gradients. Similarly, Lokman and Young (2000) explained that extreme changes in temperature and ammonia concentration can reduce enzymatic activity and metabolic rate in eels, while Jellyman and Tsukamoto (2010) confirmed that adult eels are more commonly found in waters with moderate salinity and stable dissolved oxygen.

Thus, the integration of PCA results and cross-correlation analysis strengthens the conclusion that the environmental parameters most influencing the distribution and abundance of eel are salinity and dissolved oxygen (DO) as positive factors and temperature and ammonia as negative factors. This combined approach not only visually depicts spatial patterns through PCA but also provides quantitative statistical evidence through correlation, resulting in a more comprehensive ecological understanding of the optimal habitat for *Anguilla* sp. in estuarine waters.

This combined approach has been widely used in the study of migratory fish ecology, including eels. Arai (2016) emphasizes that the spatial distribution of eels is highly influenced by environmental gradients such as salinity and DO, which determine the efficiency of osmoregulatory metabolism. Similarly, Lokman and Young (2000) stated that the growth and enzymatic activity of eels are closely related to variations in temperature and water quality. The use of PCA combined with cross-correlation was also applied by

Jellyman and Tsukamoto (2010) to link adult eel habitat preferences to estuarine factors, demonstrating that both methods are effective in explaining complex relationships between ecological variables.

Overall, PCA provides a descriptive framework for viewing multidimensional patterns, while cross-correlation provides an inferential basis for measuring the strength of the relationship between environmental factors and the eel population. The combination of both results in a more comprehensive ecological understanding of how environmental parameters interact in determining the distribution and abundance of *Anguilla* sp. in both natural and semi-natural habitats. Water parameter data is shown in **Table 2**. The cross-correlation graph is shown in **Figure 11**.

Table 2. Data of Water Parameters and the Number of Eel Catches in the Luk Ulo River, Kebumen. The primary data collected includes physical and chemical data on waters that affect eel habitat.

East longitude	South latitude	Sta	Temp	Salinity	Clarity	DO	TDS	pH	Depth	Nitrat	Phospat	Amonia	Anguilla
109.645	-7.753	1	30.62	0.72	93.24	7.29	0.93	7.82	3	10	0.1	0.25	1
109.646	-7.758	2	30.85	1.06	47.87	7.27	1.34	8.26	4	2	0.1	0.15	1
109.645	-7.764	3	31.09	1.43	68.37	6.38	1.74	7.52	3	0	0.03	0.15	2
109.644	-7.769	4	31.27	1.74	33.67	6.27	2.14	7.65	5	10	0.25	0.25	1
109.644	-7.776	5	33.14	2.38	44.03	6.32	2.53	7.01	5	0	0.1	0.5	1
109.637	-7.783	6	32.27	15.37	59.14	6.42	1.91	6.5	6	2	0.25	0.15	2
109.631	-7.784	7	31.81	17.4	51.32	5.96	2.14	6.66	6	0.2	0.03	0.25	2
109.621	-7.782	8	33.44	19.13	69.8	6.3	1.57	7.19	7	2	0.5	0.25	3
109.611	-7.78	9	32.11	24.66	52.3	6.27	2.97	7.73	5	2	0.1	0	5
109.599	-7.778	10	30.99	32.13	15.54	6.59	3.75	7.89	6	2	0.5	0.25	13

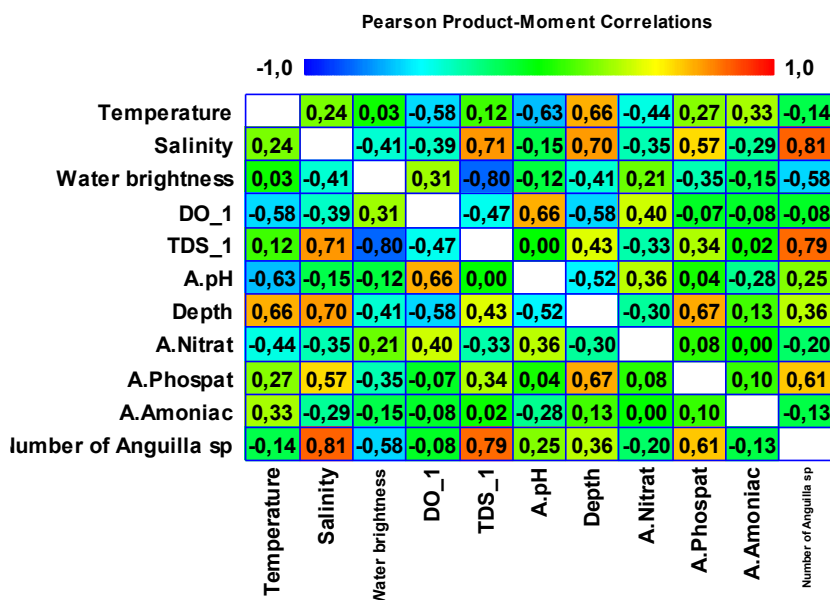


Figure 11. Cross-correlation graph between water parameters and the number of eel catches in the Luk Ulo River, Kebumen. The results of the cross-correlation analysis usually show a significant positive correlation between the number of *Anguilla* sp. and salinity ($r > 0.81$), TDS ($r > 0.79$), and phosphate ($r > 0.61$), meaning that the higher the salinity, dissolved solids content, and phosphate concentration, the greater the likelihood of finding eels. This indicates that the higher the salinity, the greater the abundance of eels found at the observation site.

4. Conclusions

The eel population in the Luk Ulo River is dominated by *Anguilla bicolor bicolor*, with a smaller contribution from *Anguilla marmorata*, and is overwhelmingly composed of individuals at the yellow eel stage, indicating that this system primarily functions as a growth habitat rather than a recruitment area. The concentration of individuals within the medium size class (32-48 cm) further reflects a population structure characterized by subadult dominance and stable growth dynamics. The length–weight relationship follows a negative allometric model ($W=0.00083L^{2.87}$), demonstrating that length increases at a faster rate than body mass. This growth pattern suggests an adaptive energy allocation strategy in which somatic elongation is prioritized over biomass accumulation, potentially enhancing mobility and habitat exploration in river – estuarine environments. The high coefficient of determination ($R^2 \approx 0.93$) confirms that body length is a strong predictor of weight, indicating a consistent and well-defined growth pattern within the population.

From an ecological perspective, PCA and correlation analyses reveal that eel abundance is strongly structured by physicochemical gradients, particularly salinity, total dissolved solids (TDS), depth, and phosphate. The strong positive relationships between these variables and eel abundance highlight the critical role of estuarine conditions in shaping habitat suitability and population aggregation.

Overall, the novelty of this study lies in integrating population structure, allometric growth patterns, and estuarine environmental gradients, demonstrating that eel growth performance and spatial distribution are not solely governed by intrinsic biological factors but are tightly regulated by environmental heterogeneity. These findings emphasize the importance of ecosystem-based management, particularly the conservation of estuarine habitats as essential growth zones for sustaining eel populations.

Conflicts of Interest

There are no conflicts to declare.

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AI Writing Statement

During the preparation of this work, the author(s) used Chat GPT to help paraphrase paragraph and transliterate English. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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