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Seasonal Catch and Sustainable Responsibility of Java Eel in the Cilacap Estuaries, Indonesia

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ABSTRACT

The IUCN and CITES have recognized the Java eel species, *Anguilla bicolor bicolor*, and *A. marmorata* as significant species requiring conservation efforts. Thus, the objective of this study was to document seasonal catches and assess their sustainability in the waters of Cilacap, which is situated in the southern estuary of Java, Indonesia. This study employed survey methods and collected research data from three eel collectors located in distinct riverine areas. Additionally, annual fisheries bycatch data were obtained from the Fisheries Office of Cilacap District in Central Java. Levene's test was conducted to evaluate variance equality, followed by a T-test to examine mean equality. Several factors, including the number of eels caught, their potential growth, eel fecundity, and risk factors, must be taken into account when releasing eels back into their natural habitat. The findings revealed the presence of four distinct classes of eel sizes during both the dry and wet seasons. Notably, two sizes of elvers and glass eels were not captured in either season. The highest monthly catch, recorded at CA I (760.6kg), occurred during the wet season in December, while the lowest, with no eels found at CA II (0 kg) was in the dry season of June. The combined catch from three collectors averaged 429.63± 47.95kg/ month during the wet season and 103.57± 40.04kg/ month during the dry season. From yearly catches, 5.1% of the eels should be released back into nature. Therefore, the comparison of eel catches between wet and dry seasons at three riverine locations in the Cilacap estuaries showed significant differences ($\alpha < 0.05$). In summary, eels caught in the Cilacap estuary were significantly larger during the wet season compared to the dry season.

INTRODUCTION

Aquatic organisms, particularly finfish, often face population declines **(Able *et al.*, 2015; Taufiq-Spj *et al.*, 2017a)**, primarily as a result of either overexploitation or stochastic factors associated with their environment and intrinsic traits. The migratory patterns of diadromous fish depend on the safety they encounter during their migration journey, especially during their spawning season or when returning to their growth areas **(Tafiq-Spj *et al.*, 2022, 2023)**.

Anadromous species, such as salmonids, return to inland areas for their spawning season when they reach maturity, whereas catadromous species, like anguillids, return to inland regions during their juvenile phase **(Taufiq-Spj *et al.*, 2017a, 2018, 2022, 2023)**.

Despite having a magnetic imprint of tidal currents' direction **(Cressi *et al*., 2019)**, anguillids face more challenges during migration to upper estuarine areas (upstream) compared to anadromous species viz. salmonids **(Taufiq-Spj *et al*., 2023)**. Additionally, in terms of energy expenditure, adult salmonids appear to deplete their final energy reserves while swimming upstream in rivers after their oceanic journey. In contrast, anguillids, initially drifting in ocean currents in the leptocephalus form, and subsequently metamorphosing into glass eels, seem to struggle against river currents as they swim upstream

The abundance, spatial and population distribution, as well as temporal (seasonal) patterns of anguilla species, have been widely studied worldwide. **Prchalova *et al*. (2013)** introduced a new tool, the gill net, for assessing the European glass eel (*Anguilla anguilla*) abundance and distribution patterns. **Bardonet *et al*. (2005)** investigated the role of glass eels (*A. anguilla* L) in response to light concerning recruitment abundance estimation. Additionally, **Maitra *et al*. (2018**) collected temporal data on exploited fisheries and their trophic levels. **Jacoby *et al*. (2015)** assessed the population size of 13 threatened species of Anguillids. **Miller (2015)** focused on the nighttime vertical distribution and regional species composition of eel larvae in the western Sargasso Sea. Furthermore, **Pous *et al*. (2010)** explored the spawning area of tropical eels, while **Pangerang *et al*.** (**2018**) studied the population dynamics of *A. marmorata* in Southeast Sulawesi waters. Recently, **Taufiq-Spj *et al*. (2023)** reported new perspectives on eel conservation.

The Java eel has been listed in both CITES and the International Union for Conservation of Nature (IUCN) red list, with *A. marmorata* being classified as a least concern (LC) species since 2012, and *Anguilla bicolor bicolor* as a near-threatened (NT) species since 2014 (source: http://www.iucnredlist.org). Furthermore, anguillid, as a catadromous species, represents one of the 2.5% of migratory species worldwide that requires special attention for biodiversity preservation **(Binder *et al*., 2011)**. Nevertheless, continuous research is needed to monitor the seasonal abundance of tropical species and determine how to ensure their population sustainability, particularly in Central Java, Indonesia.

The estuarine area in the river system is divided into three sections, which are ecologically interconnected: the low, mid, and upper estuarine areas **(Cornu, 2005; Hamilton *et al*., 2010)**. The low estuarine area typically exhibits salinity levels similar to those of the coastal area and is dominated by saline water organisms. The mid-estuary, considered a brackish water area, hosts both saline and freshwater organisms, including euryhaline species. The upper estuarine area consists of freshwater only and is dominated by freshwater organisms. **Bardonet *et al*. (2005)** also noted that, the riverbank point in France used for their glass eel sampling is located 22km from the river mouth and is now referred to as the Adour estuary. Subsequently, watershed management related to forestry as a water resource for the riverine ecosystem also needs to be taken into consideration **(Taufiq-Spj *et al*., 2023)**.

There are seven rivers that have downstream estuaries at Segoro Anakan (Fig. 1) and exhibit a significant eel production **(Taufiq-Spj *et al*., 2017b, 2023)**. Some of these rivers boast large and wide stream areas with ample freshwater supply, while others do not. The largest of these, the Citandui River, features a dam situated 25.4km from the river mouth

(Fig. 1). It's important to note that this dam lacks a fishway, but it does have a steep flushing canal, which results in an intermittent water flow during the dry season. In contrast, the other rivers possess smaller stream areas and maintain a consistent water flow even during the dry season. Notably, catadromous species, especially anguillids, require freshwater soon after their metamorphosis into glass eels **(Colombier *et al*., 2007; Taufiq-Spj *et al*., 2023)**. A steady to strong flow of freshwater plays a pivotal role in attracting and guiding glass eels to swim upstream. Wet and dry seasons serve as indicators of the quantity of freshwater entering the ocean, thereby influencing eel populations.

The primary objective of this research was to conduct a study on the seasonal catch of Java eel (*Anguilla* sp.) to comprehend how both seasons impact the eel population and develop strategies for managing the catch systems to preserve their population sustainability. As part of responsible eel resource management, a new calculation is introduced to determine the quantity of eels that should be released back into their natural habitat.

MATERIALS AND METHODS

Study area

This study employed a survey method to gather data from three eel collectors situated in different riverine locations. The survey involved conducting in-depth interviews with these collectors within the Cilacap estuaries. Collector I is in the Patimuan District, where fishermen catch eels from the tributary of the Citandui River. Collector II is based in the Bantarsari District, collecting eels from the tributary of the Cimeneng River. Meanwhile, collector III operates in the Kedungreja District, where eels are caught from the tributary of the Cibeurem River. Additionally, data regarding the riverine identity and water quality were collected at these tributaries during both dry and wet seasons, which serve as eel capture areas (Fig. 1).

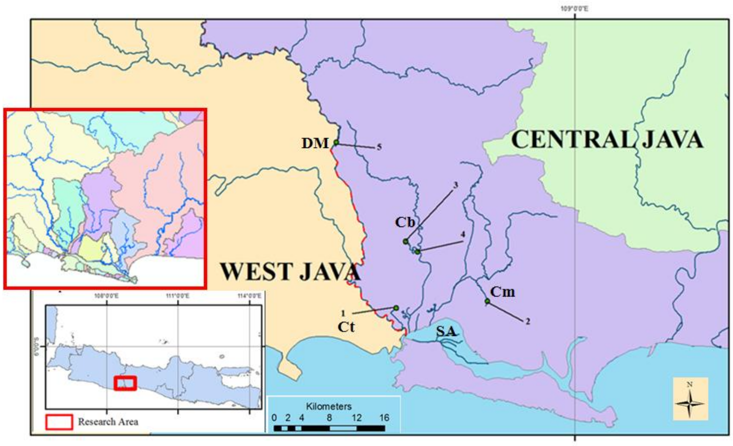

Fig. 1. The rivers with estuaries along Segoro Anakan (SA) are marked, and water quality sampling sites are located at the specific tributaries of the Cintandui River (Ct), Cibeureum River (Cb), and Cimeneng River (Cm). The numbered locations are as follows: 1. Patimuan eel collector I or catchment area I (a tributary of the Citandui River), 2. Kawunganten/ Bantarsari eel collector II or catchment area II (Grugu/Beling creek), 3 & 4. Kedungreja collector III and catchment area III (a tributary of Cibeureum), and 5. DAM Manganti (DM) in Sidareja District (Table 1). The red outline depicts the watershed of the rivers, and the different colors indicate various land divisions. **(Taufiq-Spj *et al*., 2023)**

Data on eel production

Monthly data on eel production in each riverine estuary location were recorded using payment information regarding the sizes and weights collected by collectors I, II, and III. The fishermen employed similar fishing gear, specifically PVC traps, which had previously used bamboo traps with bait inside. Each collector maintained records of payment receipts and the monthly eel production in kilograms. Data from eel collectors were gathered from 2017 to 2018, with limited data collected in 2020 and early 2021 due to the COVID-19 pandemic. However, during the dry and wet seasons of 2022 and 2023, five eel collectors continued to collect eels. The collected data from these collectors were categorized into size classes (Table 2), including consumption, fingerlings, big pencil, small pencil, elver, and glass eel sizes **(Taufiq-Spj *et al*., 2023)**. To determine the number of fish (tails) found, the weight of the caught fish in kilograms was divided by the mean value in grams of the respective size class range.

Additional data on eel production were obtained from fisheries bycatch in both sea and inland common waters from 2017 to 2022, as reported by the Fisheries Office in Cilacap for 2022 and 2023 (unpublished data).

Data analysis

The monthly production data from July 2017 to June 2018 were categorized into two seasons: May to October was considered the dry season, and November to April was considered the wet season, serving as monthly season indicators for the study area. Monthly eel catches by the three collectors were analyzed as seasonal production and compared based on percentage values. Thus, there were six months classified as dry and the remaining six months as wet seasons, making a total of 18 months for each season (across three collectors). The total production from the three collectors was divided into the two seasonal groups as described above, and the comparison was conducted using Levene's test for variance equality, followed by a T-test for equality of means.

To ensure the sustainability of their population, the mean of the yearly total eel catches (eel tails) and eel fecundity serve as fundamental assumptions in calculating the number of fish that must be released back into the natural environment. The statistical data from the fisheries office were transformed into the mean composition values of fish tail numbers collected by collectors (Tables 4, 5). The mean of all class sizes by weight (i.e. 86g) of eels caught was assumed to exhibit a similar pattern from year to year. The approximation of tropical eel fecundity (mean value: 2.5×10^6/ kg of body weight) is based on studies conducted by **Debowska *et al*. (2015)** and **Abdul-Kadir *et al*. (2017)**. It is hoped that silver eels can migrate to the spawning ground (1%) safely, especially during recruitment (1 of 1%). Therefore, the additional risk factor for migration safety is 0.01%. Another factor to be considered is potential growth, specifically the specific growth rate during one year of catch seasons, based on the study of **Taufiq-Spj *et al*. (2020)**, which was 0.7% per day. This value was originally derived from a logarithmic equation, and for one year, potential growth needs to be converted exponentially. As a result, the value (mean of all eel sizes caught) should be multiplied by 12.871 per year. This formula can be expressed as:

$$\mathbf{ER = Tc \times Pg \times (fc \times rf)^{-1}}$$

Where, **ER**= Eel replacement (release back); **Tc=** The total caught/lost; **Pg=** Potential growth for 365 days (12.871); **fc=** Eel fecundity, and **rf=** Risk factor (set at 0.0001).

RESULTS

1. Eel catchment sites and riverine identification

The study area encompasses the Citandui, Cimeneng, and Cibeureum Rivers, situated in the Patimuan, Bantarsari, and Kedungreja Sub-Districts of Cilacap Regency, within the Central Java province, respectively. These rivers share a common downstream location at the Segoro Anakan estuary (Table 1 & Fig. 1). Five specific points or loci were identified as potential sources of Java eel, all having similar latitudes and longitudes (-07º latitude and 108º longitude). The distance from the coastline to these points varied between 5.8 and 25.4km. The five locations exhibited a range of pH values, measuring between 7.12 & 7.67 during the wet season and 7.55 to 8.95 during the dry season. While temperatures and dissolved oxygen levels remained relatively consistent between wet and dry seasons, salinity showed slight variations due to differences in latitudes (Table 1).

Table 1. The areas where eels are caught and the identities of the riverine locations, including coordinates, distance from the coastline, and mean water quality values collected during both wet and dry seasons, correspond to the estuaries along Segoro Anakan in Cilacap

Locus	Subdistricts	Coordinates	River	D from CL	Season	pH	t ºC	DO	S ‰
1	Patimuan	07º 38' 38.40" S 108º 47' 21.72" E	Citandui (tributary)	**5.8 km**	Wet Dry	7.12 7.57	27.43 27.62	3.83 2.94	15.63 28.25
2	Grugu/ Kawunganten	07º 35' 09.25" S 108º 53' 49.49" E	Grugu/Beling (Death creek)	**12.7 km**	Wet Dry	7.26 7.55	26.56 27.63	3.65 2.67	12.32 28.15
3	Kedungreja Kaliwungu Vil.	07º 33' 56.16" S 108º 48' 02.12" E	Ciberem (Village creek)	**15.1 km**	Wet Dry	7.67 8.95	26.82 29.7	4.46 3.95	0.45 5.65
4	Kedungreja	07º 34' 40.71" S 108º 48' 51.98" E	Cibeureum (tributary)	**10.6 km**	Wet Dry	7.24 7.95	26.53 29.7	4.36 3.95	2.43 7.65
5	Kedungreja Bojongsari Vil.	07º 26' 55.28" S 108º 43' 06.91" E	Citandui Manganti dam	**25.4 km**	Wet Dry	7.16 8.67	26.72 28.0	4.1 3.6	0.32 0.52

Notes: S= South, E= East, D= Distance, CL= Coastal line, pH= Hydrogen ion concentration, t= Temperature, DO=Dissolved oxygen, S= Salinity.

Fish production by size and weight

The majority of eels discovered in Patimuan, Bantarsari, and Kedungreja are of the *Anguilla bicolor bicolor* species, with only a limited presence of *A. marmorata*. The second species was primarily observed during the wet season, particularly in Kedungreja along the Cibeureum River. The sizes of eels found remain relatively consistent during both the wet and dry seasons. Fingerling sizes, with weights ranging from 50 to 150 grams per tail, accounted for the largest production at 49.9%, equivalent to 2,398.3 kilograms. This was followed by consumption sizes at 33.3% (1,603.4 kilograms), big pencil sizes at 16.8% (806.2 kilograms), and small pencil sizes at 0.1% (2.8 kilograms per year) (Table 2).

Table 2. Eel production categorized by class sizes and weight were collected from CA I, CA II, and CA III in Patimuan, Kawunganten/Grugu, and Kedungreja Districts of Cilacap Regency, respectively, spanning from July 2017 to June 2018

Month	Class size by weight (kg) of eel from CA I						Weight (kg/month)		
	>150g (cons)	50- 150g (fing)	15- 50g (bp)	5- 15g (sp)	1- 5g (elv)	< 1g (GE)	CA. I	CA. II	CA. III
July	0	10	7.5	0	0	0	17.5	5	10
August	0	16.8	0	0	0	0	16.8	15	20
Sept	30	20	10	0	0	0	60	10	20
Oct	58	86	30	0.5	0	0	174.5	50	150
Nov	160	240	80.3	0.5	0	0	480.8	110	317
Dec	253.2	380	127.1	0.3	0	0	760.6	255.2	506.7
Jan	252	378	126.4	0.35	0	0	756.75	264	502
Feb	230.3	350	117.4	0.3	0	0	698	245	460
March	231.9	348	116.4	0.32	0	0	696.62	230	460
April	163	247.5	82.7	0.23	0	0	493.43	172.1	325.2
May	210	315	105.4	0.25	0	0	630.65	221.36	418.35
June	15	7	3	0	0	0	25	0	20
Σ	1,603.4	2,398.3	806.2	2,8	-	-	4,810.7	1,577.7	3,209.3

Notes: cons= Consumption, fing= Fingerling, bp= Big pencil, sp= Small pencil, elv= Elver, GE= Glass eel, Coll= Collector.

2. Eel production during wet and dry seasons

Eel production among collectors has a similar pattern during wet and dry seasons, where the wet season has the biggest production than dry season (Table 3). Based on the research result, these two seasons are found to be significantly different ($\alpha < 0.05$) both for individual collector (I, II, III) and the alliance of them. The biggest mean production of eel was attained by collector I (647.70 kg/month), followed by collector III and II during the wet season (Table 3). Nevertheless, the number of eels caught from a collector I during dry and wet seasons is the biggest in big pencil, and followed by fingerling, consumption and small pencil sizes. The consumption size used is 300gr as the biggest weight, and the mean value is 225g per eel individual. In addition, the smallest number of eel caught was in June (67 eels), and the biggest was in December (1,125 eels), as indicated in Table (4).

Table 3. Mean of seasonal production of eel during wet and dry seasons from three collectors at Cilacap estuary during 2017- 2018

Collector	Season	n	Mean (kg)	± SD (kg)
CA - I	Wet season	6	647.70	127.45
	Dry season	6	154.08	241.06
CA -II	Wet season	6	212.72	59.96
	Dry season	6	50.23	85.69
CA -III	Wet season	6	428.48	85.56
	Dry season	6	106.39	161.80
Produc-tion (Σ)	Wet season	18	429.63	203.42
	Dry season	18	103.57	169.89

Notes: CA= Catch area, n= The number of samples (months), SD= Standard deviation.

Table 4. Number of fish (eels) caught (individuals) during wet and dry seasons (using mean value of weight ranges) from catch area I at Citandui River of Cilacap estuary during 2017- 2018

Month	Monthly number of fish caught by weight class sizes						Total (Individual fish caught)
	cons. (> 150) g/ind	fing. (50-150) g/ind	bp (15-50) g/ind	Sp (5-15) g/ind	Elv (1-5) g/ind	GE (< 1) g/ind	
July	0	100	231	0	0	0	331
August	0	168	0	0	0	0	168
Sept	133	200	308	0	0	0	641
Oct	258	860	923	50	0	0	2,091
Nov	711	2,400	2,471	50	0	0	5,632
Dec	1,125	3,800	3,911	30	0	0	8,866
Jan	1,120	3,780	3,889	35	0	0	8,824
Feb	1,024	3,500	3,612	30	0	0	8,166
March	1.031	3,480	3,582	32	0	0	8,124
April	724	2,475	2,545	23	0	0	5,767
May	933	3,150	3,243	25	0	0	7,351
June	67	70	92	0	0	0	229
Σ	**7,126**	**23,983**	**24,806**	**275**	**0**	**0**	**56,190**

Note: cons= Consumption, fing= Fingerling, bp= Big pencil, sp= Small pencil, elv= Elver, GE= Glass eel.

3. Annual eel production

In Cilacap, Java eel production was found to dominate between 2017 and 2022 in comparison with giant mottled eel. However, there is an apparent year-on-year decline in the overall eel production. As a responsible commitment by fishermen to conserve eel resources, the calculation for the number of eels to be released back into nature resulted in 5.1% of the total individuals caught in a year (Table 5).

Table 5. Inland waters fisheries production by catch (ton) of two species of eel and estimated number of fish caught at Cilacap district from 2017– 2022

No.	Local/ international/ scientific name	Production by year (ton)					
		2017	**2018**	**2019**	**2020**	**2021**	**2022**
1	Pelus/ giant motled eel/ *Anguilla marmorata*	1,81	123,71	37,18	7,64	43,78	55,50
2	Sidat/ java eel/ *A.bicolor bicolor*	99,31	45,99	20,70	58,57	17,79	26,15
	Sum of production (ton)	**101,12**	**169,70**	**57,88**	**66,21**	**61,57**	**81,65**
3	Estimated number of fish	1.181.136	1.982.188	676.070	773.369	719.171	953.716
4	Eel release back responsibility	60.811	102.053	34.808	39.817	37.027	49.102
5	% Release back to the nature	5,1%	5,1%	5,1%	5,1%	5,1%	5,1%

DISCUSSION

Eel catchment areas and riverine location

There are seven rivers with estuaries along the Segoro Anakan lagoon, containing seawater in the northern side of Nusakambangan Island. These rivers include Citandui, Cibeureum, Citotok, Cimeneng, Cikonde, Sapuregel, and Donan River **(Taufiq-Spj *et al*., 2023)**. The first four rivers have estuarine areas close to each other, known locally as the Majingklak estuarine. The Citotok River, the third river, has a significantly smaller stream area than the other six rivers, and as a result, it plays a limited role in ecological properties, particularly in the migration of catadromous species. According to some fishermen, it is quite rare to find glass eel or elver in this small stream area (Citotok River) during either dry or wet seasons.

The Citandui River boasts the largest river stream area or watershed, spanning two regencies in Central Java (Cilacap and Brebes) and three regencies in West Java (Banjar, Ciamis, and Tasikmalaya). Notably, the Citandui River features a substantial dam called Manganti, located in the Kedungreja sub-district of Cilacap regency. Unfortunately, the structure and construction of the Manganti weir lack a fishway, hindering diadromous species' migration and vice versa **(Taufiq-Spj *et al*., 2023)**. Additionally, there is a flushing canal with a slope of approximately 35 to 40º, leaving open the possibility for a few fish to swim upstream**.**

The values of pH, temperature, and salinity are lower during the wet season compared to the dry season, while dissolved oxygen levels show an opposite trend. This can be attributed to the normal pH content, lower temperature, and reduced salinity of rainwater, which is prevalent during the wet season. Rainwater streams also help to increase oxygen levels by expanding the water's surface. Additionally, salinity tends to be higher in regions closer to higher latitudes or the coastline. Patimuan and Bantarsari sub-districts exhibit relatively similar salinity values despite differences in their distance from the coastline. This similarity is likely due to their similar elevations, evident from the close latitudes (07º 38' 38.40" S and 07º 35' 09.25" S), which result in a similar influence on seawater tides.

Moreover, between the 18 and 20th centuries, sedimentation occurred, leading to the separation of the three stream areas of these rivers **(Taufiq-Spj *et al*., 2023)**. Nevertheless, the data on water quality (pH, temperature in degrees Celsius, dissolved oxygen, and salinity in per mil) still fall within the range suitable for eel requirements. **Lukas *et al*. (2017)** also noted that salinity and calcium affect eel osmoregulation. Under optimal conditions of salinity and calcium, the energy required for osmoregulation is minimized, allowing for more available energy for growth. Consequently, the ideal environmental conditions for eels vary depending on their life stage.

Fish production by size and weight

The difficulty in locating *A. marmorata* in the lower estuaries, such as Citandui and Cimeneng, may stem from this species' preference for lower salinity levels compared to *A. bicolor bicolor*. Spatially, giant mottled eels are predominantly found in the upstream areas rather than the lower estuaries **(Taufiq-Spj *et al*., 2023)**. The research by **Rahmad *et al*. (2018)** postulated that *A. marmorata* exhibits better growth and survival rates in lower salinity environments. Consequently, the fish caught are not differentiated by species (especially for smaller sizes), and all of them are presumed to be *A. bicolor bicolor*. The consistency in size groups, as determined by weight, appears to correlate with the number of fish counted. The highest percentage of fish caught is typically in the fingerling size category (51.5%), followed by consumption sizes (31.3%), big pencil sizes (17.2%), and the lowest proportion is found in small pencil sizes (0.1%). Fingerling-sized eels are found throughout the year, while big pencil sizes are present in most months.

Variations in eel production sizes are primarily associated with the populations found. **Binder *et al*. (2011**) noted that the timing of migration typically occurs on a seasonal scale although some species exhibit coordinated daily movements, such as vertical or tidal migrations. Concerning this phenomenon, the two sizes mentioned above (fingerling and big pencil) typically inhabit areas close to lakes or upstream locations and later develop into silver eels, even though **Wiryanto *et al*. (2017)** reported the presence of fingerlings of *A. bicolor* in the mangrove area of Purworejo. However, the catch areas are situated at distances ranging from 5.8 to 15.1km from the coastal line, and some are located at Segoro Anakan at the river mouth. This signifies migratory activity, and for some, this movement represents a specialized form of foraging **(Binder *et al*., 2011)**. Another reason for this phenomenon occurring is when the upstream lacks a stable source of food due to an unstable rainwater catchment area in the forest or the presence of a large dam (e.g., Manganti).

The peak eel production in Cilacap (Central Java) estuary occurs from December to January. The peak production season can vary depending on the location, eel sizes, or species. **Pangerang *et al*. (2018)** mentioned that the peak production of *A. marmorata* in Southeast Sulawesi appears to be in May to June for silver eels and February to April for yellow eels. These patterns can be linked to the eels' migration periods, where the fitness of individuals benefits from moving to alternate habitats. Consequently, many fish species have evolved a life history that involves coordinated movement from one habitat to another. This synchronized directed movement of part or all of a population between distinct habitats is termed 'migration' **(Binder *et al*., 2011)**.

The largest consumption sizes found are typically between 250 to 300 grams for eels, which still retain their yellowish colors. Additionally, it is exceedingly rare for fishermen to encounter silver eels of *A. bicolor bicolor,* particularly those exceeding 1000 grams in size **(Rahmawati *et al*., 2022)**. This suggests that silver eels are likely to swim directly to the ocean for mating and spawning migrations, making them challenging to catch. Another possibility is that the eels become potamodromous organisms, where they become trapped in lakes or riverine areas with dams (e.g., Citandui with the Manganti dam, and they move along the lake or riverine systems. Regarding the first possibility, **Binder *et al*. (2011)** noted that long-distance migrations are energetically demanding, and feeding during such migrations is infrequent. This is due to the constraints imposed by feeding on migration, including foraging time and reduced metabolic capacity available for migratory activity when energy is reallocated for foraging and digestion. As a result, most species heavily rely on energy reserves accumulated in the months leading up to migration.

Eel production and abundance in wet and dry seasons

The monthly mean production of eels in three parts of the Cilacap estuary is 429.63kg during the wet season and 103.57kg in the dry season. The significant difference ($\alpha < 0.05$) between these caught seasons is attributed to the natural behavior of *Anguilla* sp., which is apparently attracted to freshwater streams and is related to their feeding sources. In contrast, there is a paradox when comparing anadromous and catadromous species. Anadromous species migrates to the ocean for growth, while catadromous species does the opposite **(Taufiq-Spj *et al*., 2022, 2023; Waldman & Quinn, 2022)**.

However, **Gross *et al*. (1988)** stated that saline water is more productive in temperate latitudes than in tropical areas, but conversely, freshwater is more productive in tropical than in temperate waters. Thus, anadromous species (i.e., salmonids) are more dominant in temperate waters, while catadromous species (i.e., anguillids) are more abundant in tropical waters. This is supported by **Tomiyama and Hibya (1977)** and **Tomiyama *et al*. (1979)**, who noted that the zone classification and geographical distribution of anguillidae show that tropical *Anguilla* sp. have twelve species, while only six are found in temperate latitudes. The tropical species with long fins include *A. reinhardti, A. marmorata, A. celebensis, A. megastoma, A. ancentralis, A. borneensis, A. nebulosa nebulosa, A. mossambica*; while *A. bicolor bicolor, A. bicolor pacifica, A. obscura* are short-finned eels. In temperate waters, there are *A. anguilla, A. rostrata, A. japonica* as long-finned eels, and *A. dieffenbachi, A. australis australis, A. australis* schmidt as short-finned ones. Furthermore, **Leander *et al*. (2012)** reported another species of tropical long-finned eel, *A. luzonensis/A. huangi*, found along the Hsiukuluan River in Taiwan.

Deviation in captured productions is very high among collectors, especially during dry seasons. This deviation is presumably due to the absence of eels in certain weight classes during June, July, and August. These size variations are primarily due to the eels' reduced activity during the dry season when they have fewer hunting opportunities. Eels, being predators, may occasionally exhibit cannibalism. Due to this feeding behavior, they may become less social and prefer to stay in their pit holes even before reaching the yellow and grey eel stages. Anguillids are complex species with cryptic behavior, a long body shape, the ability to excrete mucus, and excellent maneuvering abilities, making eels challenging to catch **(Prchalova *et al*., 2013)**. Additionally, **Able *et al*. (2015**) faced similar challenges in collecting glass eels and elvers, with the number collected varying among inlets, thorough fares, and tributaries during 2011 and 2012, partly due to different collecting techniques, collection timing, and effort levels.

Furthermore, using local PVC trap nets for capturing eels seems to align with the eels' natural preference to hide during both wet and dry seasons. Hence, deviation and errors during capture efforts are merely a reflection of eels' natural behavior during the wet season, and the decreased number of fish during the dry season can be attributed to the eels' reduced activity during that time.

The caught eels range in size from small pencil-sized individuals to consumption-sized ones. While silver eels are rarely caught by fishermen, they find many consumption-sized eels (33.3% of the caught fish). This complies with the Indonesian government regulations, specifically through the Ministry of Marine Affairs and Fisheries, numbers PER 18/MEN/2009 and 19/MEN/2012, which prohibits the export of eel seed under 150 grams. The use of static devices, such as PVC traps, is responsible for these production levels. Fishermen in Southeast Sulawesi use electric devices, long lines, and fish traps, which allow them to catch silver eels of the *A. marmorata* species with lengths ranging from 68.35 to 153.93cm. The largest length recorded is 163cm, with an approximate infinity length of 185.86cm **(Pangerang *et al*., 2018)**. **Arai (2014)** reported even larger sizes, with *A. marmorata* reaching up to 200cm in length and 21kg in weight. Given these facts, the silver eels from Cilacap estuaries are likely to continue their migration and reproduction in deep sea water. Consequently, the proportion of eels caught at Cilacap estuary is expected to remain within safe size ranges for sustainable reproduction.

Annual eel production

From 2017 to 2022, *Anguilla bicolor bicolor* appears to have dominated the yearly eel production in the common public waters of Cilacap compared to *A. marmorata.* This phenomenon is presumably due to the fact that giant mottled eels require more time to mature into silver eels. However, various developments in the river basin areas, such as weirs for agricultural irrigation and dams for hydroelectric power, have led to eels becoming trapped (landlocked) and unable to migrate for spawning. Another contributing factor is the destruction of the forest environment, which serves as a water catchment area, leading to insufficient water supply to facilitate eel migration both upstream and downstream **(Taufiq-Spj *et al.*, 2023)**.

The migration loop cycle of anguillid eels allows them to return to their spawning grounds and growth areas **(Taufiq-Spj *et al.*, 2022, 2023)**. Consequently, the risks encountered during their journey, whether inland or in the ocean, must be taken into account. The Manganti weir of Citandui serves as an obstacle to the migration of elvers and silver eels. Meanwhile, the estuary of the "Segoro Anakan" lagoon at the mouth of the Citandui River serves as a transit place for glass eels before continuing their upstream migration and silver eels' journey to the ocean. The condition of this lagoon is very turbid during the rainy season **(Taufiq-Spj *et al.*, 2023)**; however, the glass eels are attracted to the freshwater, which enables them to continue their migration.

As part of the inland fisheries project in Cilacap conducted by FAO Indonesia, the practice of releasing eels back into nature needs to be included on the global agenda, with a minimum of 5.1% of the total number of eels caught being responsibly released. In this regard, **Lyach (2022)** reported that the European countries have agreed that eels of *A. anguilla* caught at sizes less than 12cm must be saved and released for restocking. However, the eel sizes caught by Cilacap fishers, are typically between 30 and 60cm in length, and they use environmentally friendly devices. This ensures a higher survival rate when they are released for restocking. The responsibility for governing the responsible catch can be managed by the fisheries office of the local government.

CONCLUSION

Two species of eel, *Anguilla bicolor bicolor* and *A. marmorata,* are caught in the inland common public waters of Cilacap Regency, Central Java. Among these, the first species, *A. bicolor bicolor*, dominates inland fisheries production bycatch. These eels are typically in the fingerling sizes of 50- 150 grams per tail and are often trapped using traditional bamboo devices, especially along lower estuaries.

Various obstacles impact eel migrations in both directions. These include low river flow during the dry season and high sedimentation in the river basin to estuary during the wet season. Additionally, river weirs, high-wall dams, unstructured infrastructure of irrigation channels without fishways and ladders, and polluted river basins pose challenges for the migration of glass eel and elver upstream and silver eel downstream. Consequently, eel production in Cilacap showed a declining trend from 2017 to 2022.

To ensure the sustainability of eel resources, it is essential to release 5.1% of the caught eels back into their natural habitat.

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