Research Article

Species Composition and Inshore Migration of the Tropical Glass Eels (*Anguilla* spp.) Recruiting to the Jali River, Purworejo Regency

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ABSTRACT

Purworejo Regency is located in the south coast of Java where rivers flow into the Indian Ocean. The Jali River in Purworejo becomes a migration route for eels where juvenile eels (glass eels) move from the ocean to freshwater passing through the estuary. During migration, glass eels will make efforts to survive, one of which is to manage their osmotic pressure (osmolarity). With regards to those, a study on the upstream migration of glass eels in Jali River was carried out. Glass eels samplings were conducted using hand-held lift nets at the new moon phase, from 20:00 pm to 4:00 am. Sampling stations included the estuary, a branch river, and below the dam. The osmolarity of both glass eels and media (river water) were measured. Furthermore, the chemical and physical parameters of the waters as the natural habitat for glass eels were also measured. Glass eel samples were then identified to species level. The results showed that glass eels entering the Jali River consisted of *Anguilla bicolor bicolor* and *Anguilla nebulosa nebulosa* with the former being the most common. Total length of glass eels ranged between 44.10 to 69.70 mm with total weights 0.08 to 0.54 g. Glass eel migration has a close relation with surface current and tide. The osmotic work level (OWL) of glass eels approaches 0.34 mOsm/l H_2O which is close to iso-osmotic. This happened at salinity 0 $^o/_{oo}$ so that the glass eels migrate to fresh water which has a lower salinity to achieve iso-osmotic condition.

INTRODUCTION

Eels (*Anguilla* spp.) have unique characteristics in a way that they adapt to multiple water conditions including fresh water, estuary and sea. Anguillid eels are catadromous species; they spawn at ocean, then the larvae migrate to rivers, and reach adulthood in fresh waters. By the time of spawning, the eels swim downstream and return to the ocean (Muthmainnah et al. 2016). The life cycle of eels consists of five stages, namely *leptocephalus, glass eel, elver, yellow eel* and *silver eel* (McKinnon 2006; Milosevic et al. 2022). Leptocephalus is a larval stage with its planktonic behaviour in open sea. This larva then metamorphoses into

glass eel (juvenile stage) which actively migrate to estuary (Tabeta & Mochioka 2003; Cresci 2020; Wichelen et al. 2022).

The migration of eels was influenced by environmental and physiological factors (Edeline et al. 2006). During migration, eels make efforts to enhance their survival, one of which involves regulating their osmotic pressure (osmolarity). The migrating eels have a wide tolerance for changes in salinity. Migration in fish is usually caused by physiological response to both internal and external inputs received. Migration is an important part of the fish life cycle for the continuity of the regeneration process (Lucas et al. 2001; Cao et al. 2021).

Distribution of eels in Indonesia starts from the coast of Sumatra, the south coast of Java, Bali, NTB, NTT, east coast of Kalimantan, Sulawesi waters, Maluku to Papua (Fahmi 2015). About 19 species of *Anguilla* have been reported worldwide (Arai 2020), two-thirds of eel species inhabit Indonesian waters (Sugeha et al. 2008a). However, there are three species were present in Java Islands, e.g. *A. bicolor bicolor*, *A. nebulosa nebulosa* and *A. marmorata* according to research in Palabuhanratu, Sukabumi (Hakim et al. 2015); Progo River, Yogyakarta (Budiharjo 2010); Segara Anakan, Cilacap (Sukardi et al. 2022).

In Java Island, the estuary of Jali River in Purworejo Regency is one of the migration routes for juvenile eel (glass eel). Geographically, this estuary is located on the south coast of Java, right next to the Indian Ocean. The estuary becomes a migration route for tropical eel species that exist in the waters of the Indian Ocean. Little is known about glass eels recruiting in Purworejo rivers.

The migrating glass eels are usually caught by local fishermen in the Jali River below the dam using hand-held lift nets. Therefore, most glass eels do not have the opportunity to grow up and reach gonadal maturity (silver eel stage) which hamper the addition process of new individuals to the population (recruitment). The removal of most glass eels will accelerate the decline of eel population in Jali River. Until now, to meet the high market demand, eels have been supplied from the catch of glass eels in open waters. The availability of this fish in the market depends on the success of the fishing in nature. Information about the life of tropical eels including the migration is needed for the basis of conservation and management efforts (Aoyama et al. 2014; Righton et al. 2021). Therefore, this study was conducted to investigate the migrating glass eels in the Jali River, consisting of biodiversity (identification of glass eel species entering the estuary of Jali River and their sizes), ecology aspect (abundance and distribution in Jali River and the influence of environmental factors to the abundance), as well as physiological aspect (the osmotic work level).

MATERIALS AND METHODS
Study Area
Glass eels were sampled in three stations shown in Table 1 and Figure 1. The sampling stations were chosen with the following considerations. Station 1 (ST 1) is the estuary which becomes the entrance for eel juveniles to fresh waters. After glass eels enter the Jali River, they migrate upstream. Glass eels migrate by swimming close to the banks of the river. Therefore, to know the distribution of glass eels, samplings should also be conducted in the river branches. At a distance of 3.5 km from the river mouth, Jali River branches into Kali Lereng. Therefore, this branch was set as sampling station 2 (ST 2) so that it can be found whether or not some glass eels migrate to the branch. At a distance of 7.5 km from the river mouth, there is a dam building. Samples of glass eels were taken

Table 1. The locations of sampling stations for glass eels.

Location	Coordinate		Distance from the river mouth	Information
	Latitude	Longitude		
Station 1	S7° 51' 11.73	E109° 54' 37.76"	0 km	River mouth
Station 2	S7º 49'25.53"	E109º 55'10.39"	3.5 km	A branch of Jali River
Station 3	S7º 47'30.38"	E109º 55'13.21"	7.5 km	Below the dam

below the dam, namely Station 3 (ST 3). In each sampling station (ST 1, ST 2 and ST 3), the physical and chemical parameters of waters were measured. This was to see the influence of the environmental factors to the abundance of migrating glass eels.
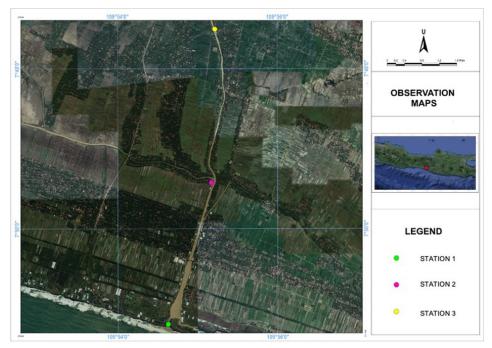

Figure 1. The locations of sampling stations for glass eels in Jali River, Purworejo Regency.

Procedures

Glass eels recruiting to the Jali River were sampled monthly from November 2015 to January 2016, in total of 9 times at 3 stations. As the migration season of glass eels in not year-round in Jali River, this research conducted in the three months of rainy season. The water discharge of Jali River was periodic and influenced by rainfall. The estuary of Jali River was closed by sand dunes during the dry season and followed by its opening in the rainy season. The information from local fisherman is also needed to conduct this field research. Fish collections were performed using hand-held lift nets of size 1 x 1 m (square shape with the area 1 m²) with the mesh size of the net 1 mm². Glass eels were caught during one night from 20.00 to 04.00 Western Indonesian Time of the new moon phase. The time interval between two consecutive samplings was 2 hours. The transect size was 2 m length and 1 m wide, following the bank of the estuary. The bulk of fish captured were divided into two groups, one for species identification and another one for analysis of osmotic work levels. Fish samples for species identification were put into plastic containers filled with oxygen and brought to the laboratory alive. Meanwhile, the ones for osmotic level analysis were put in a freezer. The physical and chemical parameters of water measured included salinity (º/ₒₒ), temperature (ºC), pH, dissolved oxygen (ppm), river current velocity (m/s) and turbidity (NTU). At the time the eel samples were collected,

the water sample was also taken which was used to measure the osmolarity of the media (habitat) of eel juveniles. The measurement used Automatic Micro-Osmometer Roebling. Daily rainfall and sea tide data needed as supporting data were obtained from the Meteorological, Climatological, and Geophysical Agency (BMKG) of Central Java Province.

Data Analysis
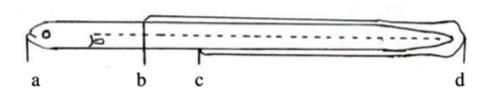#### Species identification
Identification of glass eels to species levels used morphological criteria and caudal pigmentation. Moreover, morphological characters including external morphology with morphometric measurements (ano-dorsal length) and internal morphology by counting the ano-dorsal vertebrae. In addition, the caudal pigmentation patterns which appear during the glass eel pigmentation process, were also used for species identification. To prepare the samples for species identification, live glass eels were put into clove oil solution (0.001%) for 30 seconds for anesthesia. Each glass eel was placed on an object glass for observation under the stereo microscope. To analyse the morphology, some morphometrics including dorsal fin length (L_D), anal fin length (L_A) and total length (L_T) were measured (Figure 2). The results of morphometric measurements were then analysed using an equation which could be used to recognize the species (Tabeta et al. 1976; Elie 1982; Reveillac et al. 2009; Leander et al. 2012).

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

A particular range of A/D% indicates a particular eel species. The value of A/D% was compared with the description of morphological characteristics of each species shown in Table 2.

Internal morphological analysis was carried out by counting the number of ano-dorsal vertebrae. The vertebrae counted were those right between the dorsal and anal fin tips (Ege 1939). If there was a symmetrical vertebrae to the tip of the dorsal fin, anal fin or both, then that vertebrae was not counted, as can be seen in Figure 2 (Ndobe 2010). The number of ano-dorsal vertebrae was then analysed by looking at the table of morphological characteristics (Table 2).

Figure 2. Analysis of external and internal morphology. Morphometric measurements: a-d total length (L_T), b-d dorsal fin length (L_D), c-d anal fin length (L_A). Counting of vertebrae: b-c ano-dorsal vertebrae (Ndobe 2010).

Table 2. Identification of glass eels based on external and internal morphology.

No	The species were found in the Java Island waters	A/D (%)	Number of ano-dorsal vertebras (vertebrae)	Initial positions of dorsal and ventral fins
1	*A. bicolor bicolor*	0.8	1 − 2	DFS
2.	*A. nebulosa nebulosa*	9.0	6 − 13	DFL
3.	*A. marmorata*	16.3	14 - 18	DFL

Note: DFL = *dorsal fin long*; DFS = *dorsal fin short*.

Length and weight frequencies of glass eel
Measurements of length (cm) and weight (gram) were conducted to all eel juveniles caught. The resulted data were analysed using frequency histogram. To find the average total length and body weight for each species in each month, the mean and standard deviation were computed using the following (Rice 2007; Wackerly et al. 2008):

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \quad \text{and} \quad Sd = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}}$$

Description:
Sd   = Standard deviation (each species)
X_i = Length or weight of each individual
n   = Total number of individuals
$\bar{X}$ = The mean length or weight each month

Osmotic
Osmotic work level (OWL, mOsm/l H_2O) was obtained by measuring the osmotic pressure (osmolarity) of the environment (media/river water) and osmolarity of glass eels using *Automatic Micro-Osmometer Roebling*. To measure the osmolarity of glass eels, the glass eel was put in a microtube. OWL (mOsm/l H_2O) was then computed using the following formula (Anggoro & Nakamura 1996; Anggoro 2000; Anggoro et al. 2018):

OWL = ⌈P.Osm eel − P.Osm media⌉

Description:
OWL   = Osmotic work level (mOsm/l H_2O)
P.Osm eel   = Osmotic pressure of glass eel (mOsm/l H_2O)
P.Osm media   = Osmotic pressure of river water (mOsm/l H_2O)
⌈ ⌉   = Absolute value
Note:
OWL > 0, means hyperosmotic osmoregulation pattern
OWL = 0, means iso-osmotic osmoregulation pattern
OWL < 0, means hypoosmotic osmoregulation pattern

The relationship between environmental factors and abundance of migrating glass eels
Multiple linear regression analysis was implemented to determine the relationship between various water physical and chemical parameters and the abundance of migrating glass eels. The physical and chemical parameters considered included temperature, pH, DO, current, salinity, turbidity, rainfall and tides. However, prior to regression analysis, these candidate independent variables were subjected to multicollinearity test to diagnose the inter-relations between two or more independent variables. In addition, the correlation level between independent and dependent variables for each significant covariate was computed using Pearson correlation analysis.

RESULTS AND DISCUSSION
Species Diversity
Glass eels that entered Jali River consisted of two species of eel juveniles, namely *Anguilla bicolor bicolor* and *A. nebulosa nebulosa*. This finding was confirmed after identifying 169 individuals of glass eels (Table 3). Morphological characters differed among glass eel species shown in Table 4, the mean ± standard deviation total length of 153 *A. bicolor bicolor* was 56,17 ± 4,48, and 50,40 ± 4,78 in 16 *A. nebulosa nebulosa*. Meanwhile, the difference of ano-dorsal length and the caudal pigmentation patterns of

Table 3. The species of glass eels migrating through Jali River.

Station	Month	The number sampled	*A. bicolor bicolor*	*A. nebulosa nebulosa*
1 (Estuary)	Nov	6	6	-
	Dec	4	4	-
	Jan	0	-	-
2 (River branch)	Nov	2	2	-
	Dec	11	11	-
	Jan	0	-	-
3 (Below dam)	Nov	83	77	6
	Dec	9	7	2
	Jan	54	46	8
Total		169	153	16

Table 4. Morphological characters of glass eels collected from Jali River.

Species	Weight (g)	Total length (mm)	Dorsal fin length (mm)	Anal fin Length (mm)	Ano-dorsal Length (mm)	A/D%	Ano-dorsal vertebrae
A. bicolor bicolor	0,17 ± 0,09	56,17 ± 4,48	34,84 ± 3,42	34,33 ± 3,38	0,51 ± 0,24	0,90 ± 0,41	1,45 ± 0,65
A. nebulosa nebulosa	0,12 ± 0,03	50,40 ± 4,78	33,98 ± 2,17	29,73 ± 2,06	4,25 ± 0,41	8,44 ± 0,43	7,00 ± 0,76

two glass eels species: *Anguilla bicolor bicolor* and *A. nebulosa nebulosa* in Figure 3.
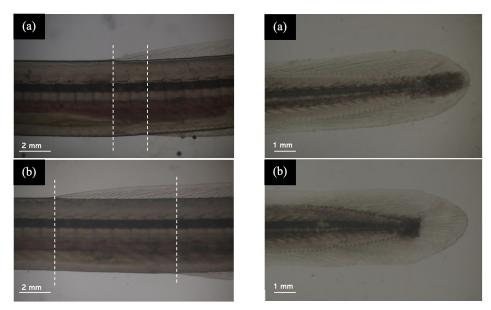

Figure 3. The distance between the dorsal and anal fin, as well as caudal pigmentation of the species (a) *Anguilla bicolor bicolor*, (b) *Anguilla nebulosa nebulosa*.

The percentages of glass eels of *A. bicolor bicolor* entering the Jali River over three consecutive months were 93, 92, and 85%, respectively, while those of *A. nebulosa nebulosa* were 7, 8, and 15%, respectively. The composition of glass eels found at all sampling stations is summarized in Figure 4. *A. bicolor bicolor* emerged as the most prevalent species. The species composition in the Jali River exhibited similarities with those of the Cimandiri River in Sukabumi (Fahmi et al. 2010; Annida et al. 2021; Triyanto et al. 2021) and the Progo River in Yogyakarta (Budiharjo 2010). In these locations, the species observed included *A. bicolor bicolor, A. marmorata, and A. nebulosa nebulosa*. Although this study exclusively encountered two distinct species, specifically *A. bicolor bicolor* and *A. nebulosa nebulosa*, migrating into the Jali River, Purworejo Regency. The spe-

cies A. *bicolor bicolor* is indeed a species commonly found in the waters of Java Island that are directly connected to the Indian Ocean (Annida et al. 2021), in significant numbers. On the other hand, *A. nebulosa nebulosa* is a type often found in the waters of Indian Ocean: East Africa to Sumatera, and its presence in the Jali River is believed to be due to the phenomenon of counter-currents in the eastern part of the Indian Ocean, known as the "Wyrkty Jet" or "equatorial jet," which transports the larvae of this species to the waters of Java Island.
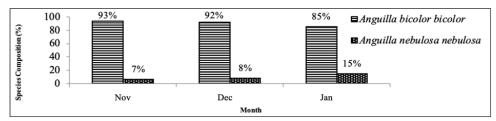

Figure 4. Species composition of glass eels entering the Jali River.

The presence of tropical anguillid eels within Indonesian waters indicated a diverse array of nine distinct species and subspecies inhabiting the region. These encompass *A. celebesensis, A. marmorata, A. borneensis, A. interioris, A. obscura, A. bicolor bicolor, A. bicolor pacifica, A. nebulosa nebulosa*, and *A. megastoma* (Sugeha et al. 2008a; Sugeha et al. 2008b). The central Indonesian waters demonstrated the highest level of diversity, where five species were found including four long-finned eel species (*A. marmorata, A. celebesensis, A. borneensis, A. interioris)* and one short-finned eel species (*A. bicolor pacifica*). Meanwhile, the waters of western Indonesia are predominantly inhabited by two species (*A. nebulosa nebulosa* and *A. bicolor bicolor*), and the waters of eastern Indonesia comprise *A. obscura* and *A. megastoma* (Sugeha et al. 2008a; Sugeha & Suharti 2009). This study found two species *A. nebulosa nebulosa* and *A. bicolor bicolor*, in the Jali River, Purworejo Regency, located in western Indonesia, consistent with the previous studies.

According to Minegisihi et al. (2012), *A. bicolor* consists of two subspecies, namely *A. bicolor bicolor* in the Indian Ocean (this study) and *A. pacifica* that is distributed in Pacific Ocean. However, previous molecular studied showed there are four distinct populations of this species, namely the ones in North Pacific, South Pacific, Indian Ocean and Mariana. Glass eels in Jali river are part of the population in the Indian Ocean. Both species of eel, namely *A. bicolor* are of interest because of its distribution and abundance in the center of economic position and these species are also known to have a relatively wide geographical distribution (more than 18,000 km east-west) (Fahmi et al. 2012). The IUCN listed five commercially exploited eel species in Indonesia in its Red List, including *A. bicolor* and *A. nebulosa nebulosa* classified as Near Threatened ; therefore, close monitoring of intensive exploitation of this eel is necessary (Nijman 2015; Righton et al. 2021).

Length and weights of glass eels in the Jali River
A total of 169 glass eels with a minimum length of 44.1 mm and a maximum length of 69.7 mm were collected during the study (Fig. 5). There seems to be differences in size distributions of glass eels for different months (November, December and January). In November, the length ranged from 48.0 to 60.0 mm, with a mean and median 54.36 and 54.0 mm, respectively. In December, the smallest glass eel found was 44.1 mm TL, and the largest was 66.4 mm, with a mean and median 5.1 and 53.8 mm, respectively. In January, the smallest glass eel found was 46.7 mm
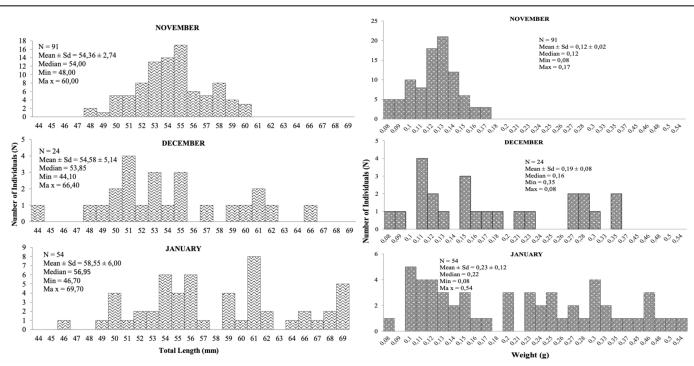
Figure 5. Frequencies of total lengths (left) and weights (right) of glass eels based on sampling time.
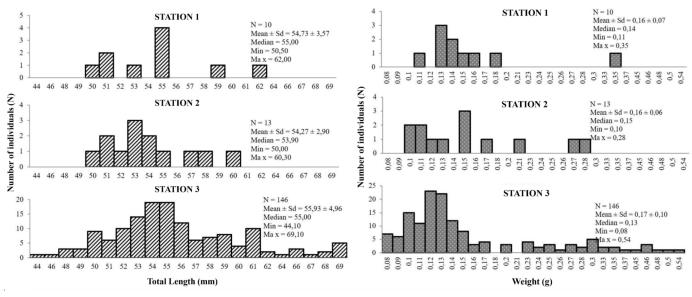

Figure 6. Frequencies of total lengths (left) and weights (right) of glass eels based on sampling stations.

and the largest was 69.7 mm, with a mean and median 6.0 and 56.9 mm, respectively. The weights of glass eels found during the study were 0.08 − 0.54 g. In November to January, the glass eels weight ranges were 0.08 -0.17, 0.08-0.35 and 0.08-0.54 g, respectively.

The size distribution of glass eels found in this study was similar with other studies. Sriati (2003) reported total lengths of glass eels in the Cimandiri River ranging from 51.57 to 53.27 mm. Glass eels of species *A. marmorata* caught in the Palu River estuary, Central Sulawesi, ranged in length from 41 to 50 mm (Ndobe 2010). According to Setiawan et al. (2003), the total length of tropical glass eels appears to be lower than that of some temperate species, such as the European eel *A. anguilla* (68 mm), and Japanese eel *A. japonica* (57 mm).

According to the findings of this study, glass eels in November have a smaller size range than December and January. At the same time, glass eel with the highest size was found in January (69.7 mm and 0.54

g). This observation aligns with the results reported by Triyanto et al. (2020). January showed the highest variations in glass eel lengths and weights. These variations are probably influenced by factors such as differences in spawning time, migration duration, and broodstock quality during reproduction, as previously suggested by Triyanto et al. (2020). In addition, the variations in eel length can be attributed to the slow growth rate of eels during the leptocephalus stage, leading to smaller glass eels during recruitment, as suggested by Arai et al. (1999) and confirmed by Marui et al. (2001). The differences also likely related to the duration of larval development, as emphasised by Triyanto et al. (2020).

The distribution of length and weight of eels varied considerably among sites (Fig. 6). In station 1 (estuary), length ranged from 50.5 to 62.0 mm and weight from 0.11 to 0.35 g; Station 2 (river branch) has a length of 50.0–60.3 mm and weight of 0.1-0.28 g, and Station 3 (below the dam) $44.1 - 69.1$ mm and 0.08-0.54 g. The glass eels at station 3 had longer bodies than the ones at Station 1 and 2. This study found a pattern of increasing body length of eel with the increase of distance from the sea. Kume et al. (2020) also found the similar pattern on Japanese eels. This suggests that recruitment to the upper sections of the river begins at a larger size, mainly as a consequence of the presence of the weir. The weir restricts upstream migration. In addition, at the time of sampling below the dam (Station 3), in December and January there were young eels that already had perfect pigmentation. The length of the young eel (elver) caught during the study in the Jali River ranged from $71-231$ mm with the body weight ranged between $0.53-15.70$ g. Kwak et al. (2019) reported that eels can spread within a river at the glass and elver stages, and then they will stay there until the onset of maturation when they move out to the sea.

The relationship between environmental factors and abundance of glass eels

The number of migrating glass eels caught in relation to sampling time was shown in Figure 7. Measurements of environmental parameters during this study resulted in the data shown in Table 5. The daily rainfall and sea tide data from Meteorological, Climatological, and Geophysical Agency were shown in Table 6.
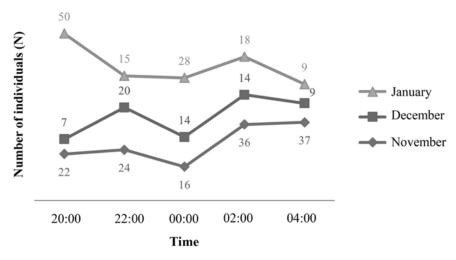

Figure 7. Daily migration of glass eels.

Multicollinearity test showed that variables temperature, pH, DO, salinity, and rainfall are multicollinear. Therefore, of all eight environ-

Table 5. The measurement results of water physical and chemical parameters in Jali River.

Month	Station	Temp. (°C)	pH	DO (mg/l)	Current(m/s)	Salinity (°/oo)	Turbidity (NTU)
Nov	ST 1	28.44	6.49	7.59	(-)0.25 - (-)0.50	36 – 20	1.23
	ST 2	30.10	7.14	6.34	(+)0.10 - (+)0.25	0	2.68
	ST 3	30.16	7.08	6.40	(-)0.01 - (+)0.03	1 - 0	1.69
Dec	ST 1	28.70	6.98	7.23	(-)0.30 - (+)0.50	16 - 0	78.59
	ST 2	26.12	7.46	7.15	(-)0.10 - (-)0.33	5	352.08
	ST 3	28.46	7.21	8.68	(+)0.33 - (+)0.50	0	45.90
Jan	ST 1	28.68	7.62	7.77	(-)0.50 - (-)1.50	34 – 12	10.47
	ST 2	30.05	7.11	5.79	(+)0.10 - (+)0.20	0	27.56
	ST 3	29.00	7.93	7.45	(-)0.01 - (+)0.08	0	20.75

Note:
Positive current (+): The direction of the current was from upstream to downstream
Negative current (-): The direction of the current was from downstream to upstream

Table 6. The rainfall and tide data.

Month	Rainfall (millimetre/day)	The number of rainy days	Tide (m)
November	6 − 47	6	0.3 - 1
December	3 − 115	14	0.3 − 0.9
January	2 − 52	9	0.4 − 2.1

Source: (Meteorological, Climatological, and Geophysical Agency 2015, 2016)

mental parameters, only turbidity, current and tide were used as independent variables in the multiple linear regression. Furthermore, variable turbidity was eventually removed because it was not found to have a significant effect on the dependent variable. Therefore, the resulting relationship between environmental parameters (current and tide) and the abundance of migrating glass eels is as follow:

$$Y = 2.507 − 34.921 \, X_1 + 18.173 \, X_2$$

Description:

Y = Dependent variable (the number of glass eels)
X_1 = Independent variable (current)
X_2 = Independent variable (tide)

Linear regression analysis showed that the daily migration of glass eels is closely related to both current and tide $R^2 = 0.56$. The regression coefficient associated with current has a t-value of -4.463, while the one associated with tide has a t-value of 3.784. The p-values for both t-values are <0.05, implying that both coefficients are significantly greater than 0. These indicate significant effects of both independent variables to the abundance of migrating eel juveniles. From the values of regression coefficients, it is clear that the relationship between juvenile abundance and current is negatively correlated (r = -0.585), while with tide is positively correlated (r = 0.508).

Current and tide are two variables affecting the abundance of migrating eel juveniles in Jali River. The eel juveniles caught, migrated through the estuary in November to January at the start of the rainy season. The lowest abundance was in December. Heavy rainfall in December around 3-115 mm/day with 14 rainy days caused strong current in Jali River. The velocity of the current in the estuary affected the time the eel juveniles entered the estuary. Glass eels would enter the river which had only moderate waves and current. This occured when there was no rain, as heavy rain resulted in a significant in water discharge and strong currents.

The sampling of glass eels in the estuary of Jali River were done at night during the new moon. The migration peaked when the seawater was rising (high tide) during which a substantial amount of seawater flows into the estuary. In that condition, eel juveniles migrated by making use of the tidal currents. They passively rode on the moving water pushed into the estuary in order to streamline the energy use (Tesch 2003; Zompola et al. 2008; Cresci et al. 2020).

Osmotic work level (OWL)

Osmotic work level (OWL) represents the difference between the osmolarity of glass eels and the media (water) (Anggoro 2000). Results of OWL analysis from various salinities of the media show that water with salinity 0 $^o/_{oo}$ led to the lowest OWL, with the mean 0.34 mOsm/l H_2O. Meanwhile, water with salinity 27 $^o/_{oo}$ led to the highest OWL, i.e. 327.86 mOsm/l H_2O (Table 7). The relationship between OWL and salinity was presented in Figure 8. The measurement of osmolarity of eel juveniles, its media as well as OWL resulted in values shown in Table 7.
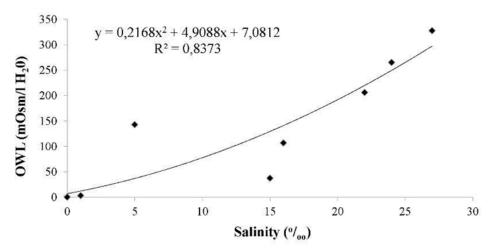

Figure 8. The relationship between salinity and osmotic work level (OWL).

The regression analysis showed that the relationship between salinity and OWL satisfies the following equation:

$$Y = 0.216x^2 + 4.908x + 7.081$$

Description:
Y = Osmotic work level
X = Salinity

The estuary (ST 1) had a wider range of salinity than those in other sampling stations. The salinity in the estuary ranged from 0 to 34 $^o/_{oo}$

Table 7. Data on salinity of media, mean osmolarity of media and glass eels as well as the osmotic work level (OWL) (mOsm/l H_2O).

Salinity ($^o/_{oo}$)	Osmolarity of media (mOsm/l H_2O)	Osmolarity of eel juvenile (mOsm/l H_2O)	Osmotic work level (mOsm/l H_2O)
0	2.92	3.26	0.34
1	29.19	26.05	3.13
5	145.915	3.14	142.77
15	437.72	400.35	37.37
16	466.91	360.00	106.91
22	641.97	436.02	205.95
24	700.32	435.01	265.32
27	787.90	460.04	327.86

where the high salinity occurred when the seawater flew into and the low salinity occurred during low tide when the water of the river flew to the sea. The osmolarities of the media (water as the habitat for eel juvenile) in three sampling stations ranged between 2.92 - 787.90 mOsm/l H_2O. Meanwhile, the osmolarity of eel juveniles in the same three sampling locations ranged between 3.14 - 460.04 mOsm/l H_2O.

Osmotic work levels (OWL) resulted from the differences of osmolarities of the media and eel juveniles were between 0.34 - 327.86 mOsm/l H_2O. The OWL 0.34 mOsm/l H_2O was the closest to iso-osmotic condition and occurred at salinity 0 $^o/_{oo}$. Therefore, to reach iso-osmotic condition, eel juveniles need to migrate to freshwater which has lower salinities than the sea. According to Anggoro (1992) and Anggoro et al. (2018), salinity is a very important environmental parameter for aquatic organisms, especially in maintaining the osmotic balance between the protoplasm of the organism and its environment.

Glass eels have an osmoconformer pattern, that is its osmotic pressure adjusts to the water they inhabit. Therefore, when the salinity increases, the osmotic pressure of glass eels increases too. In contrast, eels at elver stage live and develop in freshwater and have an osmoregulator pattern, i.e. the osmotic pressure of the elvers is not affected by the water salinity. Based on salinity data and the calculation of OWL, some glass eels migrating to Jali River were in the transition from osmoconformer to osmoregulator. Those glass eels were close to the elver stage which has a perfect pigmentation already.

CONCLUSIONS

Eel juveniles entering and migrating through to Jali River consist of *A. bicolor bicolor* and *A. nebulosa nebulosa*. Species *A. bicolor bicolor* was the most abundant. The migration of eel juveniles is closely related to current and tide. Eel juveniles enter the river with a low salinity to pursue an osmotic work level close to zero, hence reaching an iso-osmotic condition. Considering that glass eels are a crucial phase in the eel life cycle, catching them should take into account the sustainability of these glass eels. In the future, management strategy using e.g. catch quota of glass eels should be implemented in Jali River. Therefore, further study should aim to identify the abundance of glass eels migrating in Jali River to enable the formulating of this quota.

AUTHOR CONTRIBUTION

A.I. designed the research, collected, analysed data and wrote manuscript, P.S.I. analysed data and wrote manuscript, F.Y.Y analysed data and wrote manuscript, W.K. analysed data and wrote manuscript, S.Ai. analysed data and wrote manuscript, S.A. designed, supervised the research and wrote manuscript, S.W.S. designed, supervised the research and wrote manuscript.

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CONFLICT OF INTEREST

The authors declare no competing interests.

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