

Population dynamic and exploitation rate of glass eels (*Anguilla* spp.) in Cimandiri River estuary, West Java, Indonesia

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Abstract. This study on population dynamics and the exploitation rate of glass eel (*Anguilla* spp.) in Cimandiri River estuary was carried out from December 2017 to November 2018. The objective of the study was to analyze the population dynamics and the exploitation rate of glass eels. Population dynamic analysis consisted of growth parameter analysis, mortality rate and exploitation rate of glass eels, being computed by using the FiSAT II software. The results showed that the glass eel population consisted of a one size group. The average total length of glass eels was 52.4 mm, with an average weight of 126 mg. The growth rate (K) and asymptotic length (L_{∞}) of glass eels were 0.50 years⁻¹ and 70.8 mm, respectively. The natural mortality rate (M) was 0.89 years⁻¹, the fishing mortality rate (F) was 3.05 years⁻¹, and the total mortality (Z) was 3.94 years⁻¹. The estimated value of the exploitation rate (E) was 0.77 years⁻¹. The glass eel exploitation rate has exceeded its optimum value ($E > 0.5$). Glass eel capture management is needed to limit the number and period of capture, so that the sustainability of eel resources can be maintained.

Key Words: *Anguilla bicolor*, eel, fishing mortality, growth parameters, natural mortality.

Introduction. The eel (*Anguilla* spp.) is a catadromous fish that migrates to sea for spawning (Tesch 1977; Tesch 2003). According to Tesch (1977) and Rousseau et al (2014) the life cycle of eels consists of four stages: leptocephalus, glass eel, yellow eel, and silver eel. Leptocephali are the eel larvae with a leaf-like shape and transparent body. According to Bru et al (2009), the leptocephali live as plankton carried by ocean currents moving to the coastal areas. Leptocephali undergo metamorphosis and turn into glass eels (Tabeta & Mochioka 2003). Glass eel is a transparent larval phase that migrates to freshwater through river estuaries to grow and develop into adult size.

Cimandiri River flows to the Palabuhanratu Bay, Sukabumi, West Java, and it is known as one of the centers of glass eel fishing (Sriati 2003; Fahmi & Himawati 2010; Hakim et al 2015). Glass eel capture in the Cimandiri River has been carried out for a long time. Glass eels have become the main target of fishing and one of the livelihoods for the local community. The glass eels are the main seed source in eel farming activities. The production of glass eel catches from the Cimandiri River in 2017-2018 is estimated at 1-1.5 tons (personal communication from Mr. Ce Engkan - glass eel trader).

Some studies reported that there are three species of eel found in the Cimandiri River: *Anguilla bicolor*, *Anguilla marmorata* and *Anguilla nebulosa*. The most dominant species is *A. bicolor* (Sriati 1998; Setiawan et al 2003; Fahmi & Himawati 2010; Hakim et al 2015). Studies on the population dynamics of glass eels in Indonesia have not been widely explored. To date, most studies are limited to the morphology and taxonomy of species (Sugeha et al 2001; Fahmi & Himawati 2010; Hakim et al 2015; Sugeha & Genisa 2015), distribution and species composition (Sriati 2003; Budiharjo 2010).

Currently, eel populations in the world are declining. Overexploitation of eels in their natural habitat, water pollution, habitat damage, and a decrease in the quality and

quantity of freshwater, estuarine and coastal habitats are factors contributing to the decrease of eel populations in the world (Aprahamian & Walker 2008; Lokman et al 2015; Jacoby et al 2015). In Indonesia, the issue of declining eel populations has been reported in various research, such as in Poso, Central Sulawesi (Krismono & Kartamihardja 2012), and in Cimandiri, Sukabumi (Sriati 1998).

Cimandiri River estuary is a small-scale fishery, characterized by a lack of fishing data, yield capture data, and the number of fishermen regarding glass eel capture. The eel catch data is not well recorded or managed, which brings difficulty in the management effort. According to Gulland (1983), an understanding of exploited fish population dynamics is essential, so that the maximum benefits and an effective fishery management can be achieved. Moreover, the study of glass eel population dynamics is important for the sustainable management of eel resources. The purpose of this study is to estimate glass eel population parameters as instruments in eel resources assessment. The assessment of the population parameters was conducted to evaluate the mortality and exploitation rate of glass eels in the Cimandiri River estuary. The results of this study could be used as scientific base information for the management of glass eel fishery resources.

Material and Method

Sampling method. The study was carried out in Cimandiri River estuary, Sukabumi, West Java (Figure 1), from December 2017 to November 2018. Glass eel samples were collected at night, during the new moon, at 6 locations distributed around the estuary waters.

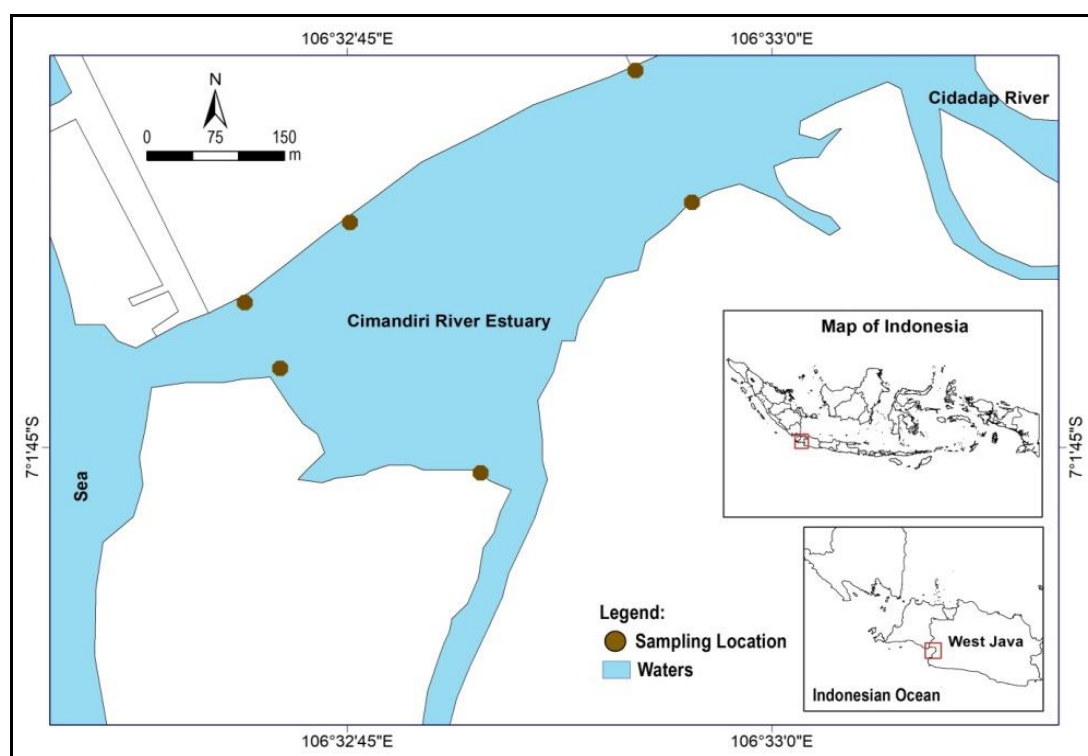


Figure 1. Research location in Cimandiri River estuary, West Java, Indonesia.

Glass eels were collected by fishing at night for approximately 2 hours, from 19.00 to 21.00, while waters were at high tide. Sampling was carried out using a triangular shaped hand net with a dimension of 1.5 m in length, 1.5 m in width, and a 0.2 cm mesh size. Glass eel capture was done by littering the water in the opposite direction of the water flow, on the shore of the river estuary, at a depth of 0.5-1 m. The captured glass

eels were counted and measured to determine the total length by a precision of ± 1 mm. They were weighed with a digital scale with 0.01 g accuracy.

Data analysis. The glass eel length group analysis was carried out by analyzing the length frequency data, using the Bhattacharya method (Sparre & Venema 1998). Calculations were carried out using the FiSAT II software (Gayanilo et al 2005). Length groups are obtained by separating length frequency data into groups with a certain average length and standard deviation. The data used in determining the length frequency distribution is the total length of the glass eels.

The length group analysis was conducted to determine the changes in population size based on changes or shifts in the distribution of length groups. Glass eel length frequency is calculated by making class intervals. The number and interval of the classes were calculated determined by the following formula (Sturges 1926):

$$SK = 1 + 3.322 \log_{10}N$$

$$JK = (P_{\max} - P_{\min})/SK$$

Where: SK is the length class interval; N is number of samples; JK is number of class; P_{\max} is the maximum total length of glass eels; and P_{\min} is the minimum total length of glass eels.

The estimations of growth parameters include estimating the growth rate (K), asymptotic length (L_{∞}), and theoretical age when the fish length is zero (t_0). Estimation of growth parameters (K and L_{∞}) were calculated using the FiSAT II software (Gayanilo et al 2005) with the ELEFAN I method (Electronic Length Frequency Analysis). The growth parameter values were used to calculate t_0 by following Pauly's empirical equation (Pauly 1980a; Sparre & Venema 1998). The equation is as follows:

$$\log_{10}(-t_0) = -0.3922 - 0.2752 (\log_{10}L_{\infty}) - 1.038 (\log_{10}K)$$

The recruitment pattern was estimated by using the FiSAT II software (Gayanilo et al 2005) in the recruitment pattern subprogram. Calculations were performed using information on growth parameters, namely L_{∞} , K and t_0 . The calculation results will provide an overview of recruitment patterns from length frequencies based on the peak of recruitment in one year.

According to Sparre & Venema (1998), mortality parameters consist of natural mortality (M), fishing mortality (F), and total mortality (Z). Z is estimated by a linear curve based on length data. Estimation of M is calculated by following the Pauly equation (Pauly M Equation) with additional data on the average annual water temperature (T) in the research location. The annual average temperature in the waters of the Cimandiri River estuary was 27.6°C. The calculations were made using the FiSAT II software (Gayanilo et al 2005). The equation is as follows (Pauly 1980b):

$$\log_{10}M = -0.0066 - 0.279 \log_{10}L_{\infty} + 0.6543 \log_{10}K + 0.4634 \log_{10}T$$

Estimation of Z was obtained by the length-converted catch curve method on the FiSAT II software (Gayanilo et al 2005). After Z and M are known, F and the exploitation rate (E) can be determined based on the Pauly equation (1980b), as follows:

$$F = Z - M; E = F/Z$$

According to Pauly (1980b), $E > 0.5$ indicates a high exploitation rate, $E = 0.5$ indicates optimum exploitation rate (E_{opt}), and $E < 0.5$ indicates a low exploitation rate.

Results and Discussion

Length and weight group distribution. The number of samples obtained during the study was 1088 glass eels. The glass eels have a total length between 40-65 mm, and a

body weight ranging from 30 to 230 mg (Figure 2). Most glass eels had a total length between 52.5 and 55.5 mm, with a weight between 120 and 140 mg. The average distribution of glass eels in every month is presented in Figure 3. The average total lengths of glass eels in every month range from 50.7 to 53.7 mm, with a monthly average of 52.4 mm. The average total lengths of glass eel in February (53.3 mm), April (53.7 mm) and September (53.3 mm) were higher than those in other months. The smallest average total lengths of glass eels were found in July (50.7 mm) and May (50.9 mm). The weight of the glass eels ranges from 30 to 230 mg, with a monthly average of 126 mg. The average weights of glass eels in September (167 mg) and February (149 mg) were higher than in the other months. The smallest average weights were found in May (68 mg) and July (98 mg).

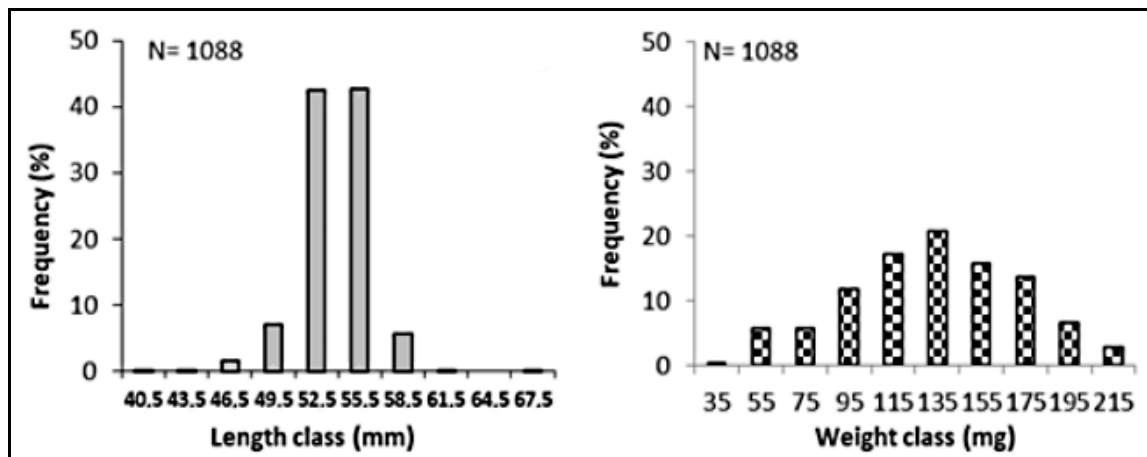


Figure 2. Length and weight frequency distribution of glass eels (*Anguilla* spp.) in Cimandiri River estuary, from December 2017 to November 2018.

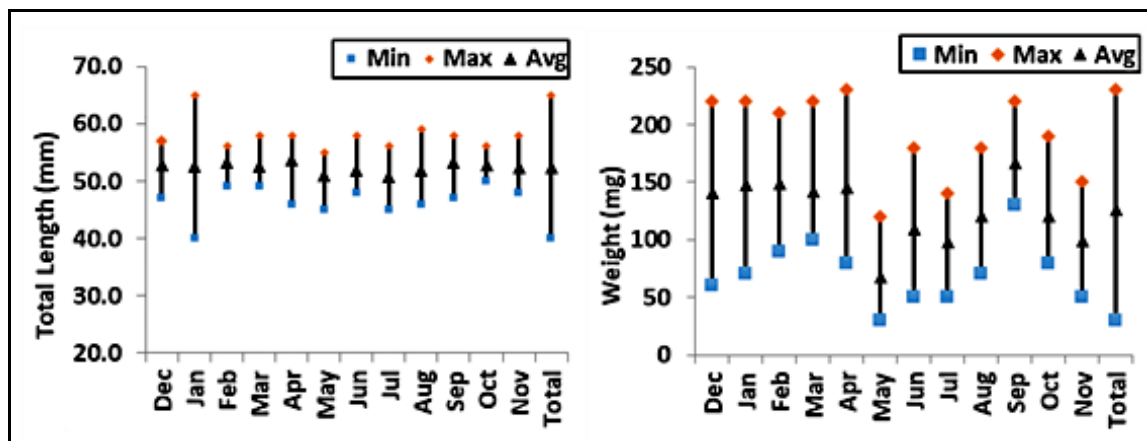


Figure 3. Total length and weight of glass eels (*Anguilla* spp.) in Cimandiri River estuary, from December 2017 to November 2018.

The variation in the total length and weight of the glass eels is supposed to be related to the differences in spawning time, duration of migration and quality of broodstock during reproduction. The results of total length frequency by the Bhattacharya method showed that the distribution of the total length of glass eels follows a normal distribution with one group of sizes (Figure 4). The size group had an average total length of 52.8 ± 2.7 mm, with an estimated population of 1087 individuals ($r^2=0.93$). From this grouping, it is known that the glass eels entering the Cimandiri River estuary every month have the same age group, and are assumed to be from the same spawning period.

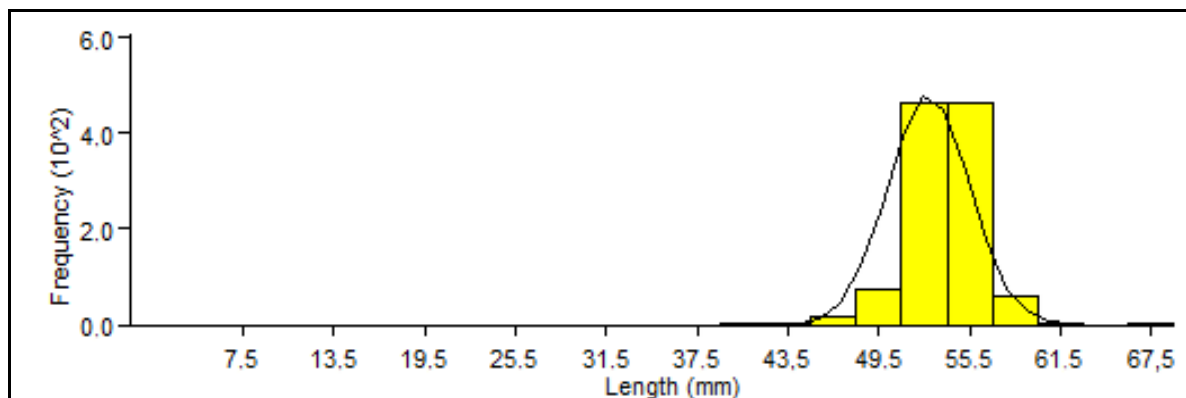


Figure 4. Length distribution of glass eels (*Anguilla* spp.) using the Bhattacharya method (FiSAT II) showing a normal distribution in a one size group.

The population structure of the glass eels that entered the Cimandiri River estuary consisted of a one-size group (one cohort). According to Sparre & Venema (1998), a cohort is a group of fish that has the same age and comes from the same stock. The length of the glass eels in this study is relatively the same as in some previous studies. Setiawan et al 2003 reported a total length of 52.7 ± 2.1 mm for glass eels (*A. bicolor*). Sriati (2003) observed a total length of glass eels in Cimandiri River with the highest values between 51.57 and 53.27 mm in a one-size cohort. Glass eels (*A. bicolor*) from the Cibaliung River in Banten have a total length of 53.01 ± 1.75 mm (Sugeha & Genisa 2015). Sugeha et al (2001) reported that glass eels from the Poigar River estuary, North Sulawesi, have a total length from 42 to 57 mm (*A. marmorata*), 40 to 55 mm (*A. celebensis*), and 43 to 54 mm (*A. bicolor pacifica*). The total length of glass eels (*A. marmorata*) caught in the estuary of Palu River, Central Sulawesi, ranged from 41 to 50 mm (Ndobe 2010). According to Setiawan et al (2003), the total length of tropical glass eels seems to be lower than that of some temperate species, including the European eel, *A. anguilla* (68 mm), and Japanese eel, *A. japonica* (57 mm). The length differences between the temperate and tropical eels is due to the low growth rate of tropical eels during the stage of leptocephalus, resulting in smaller glass eels at the time of recruitment (Arai et al 1999). The statement was confirmed by Marui et al (2001). The differences are likely to be related to the duration of larval development, in which the development of eel larvae in the four-season habitat is longer than that of the tropical eels.

Growth parameters. The growth parameters of the glass eels presented a K value of 0.50 years^{-1} and a L_{∞} value of 70.8 mm. The t_0 value was -0.037. The glass eel growth equation formed based on von Bertalanffy's model is presented in Figure 5. Based on the growth model, it is known that the age of glass eels caught in the waters of the Cimandiri River estuary was 1.6-5 days (in the glass eel life stage). Glass eels will reach asymptotic length at approximately 12 days. Glass eels enter the waters of the Cimandiri River estuary when the new moon period starts, from 25th to 30th of every month. According to fishermen, glass eel capture effectively occurs for 5-7 days in the period of the new moon, each month.

The growth of glass eels entering the Cimandiri River is relatively faster compared to that of adult eels. The same results were noted for *A. marmorata*, in Malunda River, West Sulawesi, which had a K value of 0.2 years^{-1} (Amir et al 2009). Moreover, the study of Tzeng et al (2000) in Japan, China, and Taiwan, reported that the K of *A. japonica* ranged from 0.15 to 0.28 years^{-1} . Rapid growth generally occurs in young organisms because, at that time, the growth has an exponential phase. The growth rate of glass eels is faster compared to that of adult eels because larvae are in the stage of active growth. According to Sparre & Venema (1998), the value of K is a curvature parameter that determines how quickly the fish reaches its asymptotic length. K values can be used to predict environmental conditions and food availability that affect fish growth in a

location. Based on Effendie (1997), the availability of food is a factor that determines population density, growth, reproduction, and population dynamics and the condition of fish in the waters.

The von Bertalanffy growth curve (Figure 5) shows that the age of glass eels inhabiting Cimandiri River estuary was approximately 3 days and would reach asymptotic length at the age of 12 days. Setiawan et al (2003) mentioned that based on the reading of the otolith circumference structure, the average age of glass eels that enter Cimandiri River estuary was 7.9 days (*A. marmorata* and *A. bicolor*), and 2.4 days (*A. nebulosa*).

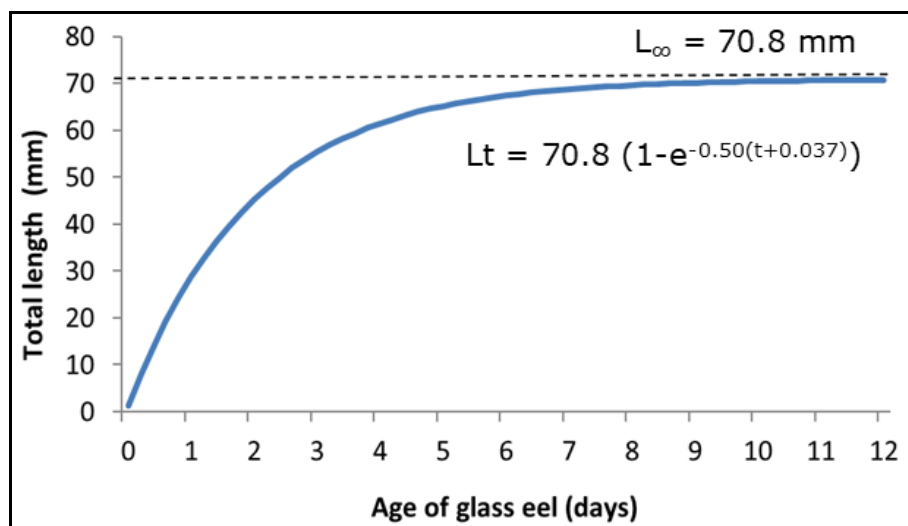


Figure 5. Growth curve and von Bertalanffy equation for glass eels (*Anguilla* spp.) in Cimandiri River estuary.

Recruitment pattern. The recruitment pattern of glass eels entering Cimandiri River estuary showed two peaks in one year. The first peak of recruitment took place in April, with a recruitment percentage of 17.1%. The second peak of recruitment was in August, with 13.17%. The pattern of glass eel recruitment in the waters of the Cimandiri River estuary is presented in Figure 6.

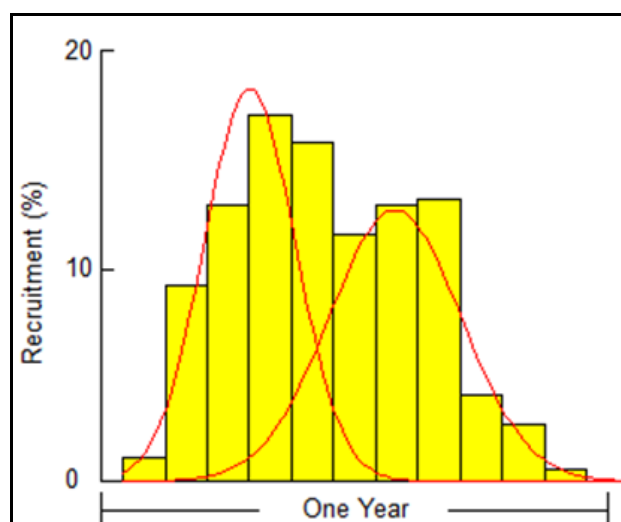


Figure 6. The recruitment pattern of glass eels (*Anguilla* spp.) in Cimandiri River estuary, from December 2017 to November 2018.

The recruitment pattern of glass eels is related to the spawning time. The first peak of recruitment took place in April. Allegedly, the glass eels that enter Cimandiri River

estuary originate from the initial spawning period at the start of the rainy season, which is in December-February. The second peak of recruitment took place in August, and the glass eels from this month originate from the spawning period at the end of the rainy season (April-June). According to Setiawan et al (2003), the spawning time of eels in the Indian Ocean lasts throughout the year, with spawning peaks occurring in May and December for *Anguilla bicolor bicolor*, October for *Anguilla marmorata*, and May for *Anguilla nebulosa*. The recruitment pattern of glass eels in the Cimandiri River estuary has similarities with the migration of glass eels in Progo River, Yogyakarta, Central Java. According to Budiharjo (2010), the migration of glass eels in the Progo River estuary takes place during the rainy season and reaches its peak at the end of the rainy season, in April-May.

Mortality and exploitation rate. The results of the analysis showed that the M value was 0.89 years⁻¹, the F value was 3.05 years⁻¹, and the Z value was 3.94 years⁻¹. The M value of glass eels is higher than the F value. The M value of glass eels in the waters of the Cimandiri River estuary is more influenced by capture factors. Based on the correlation formed between F and Z, it is known that the E value for glass eels was 0.77 years⁻¹, with $r^2=0.93$ (Figure 7). According to the criteria of Pauly (1980b), the exploitation rate of glass eels has exceeded its optimum value.

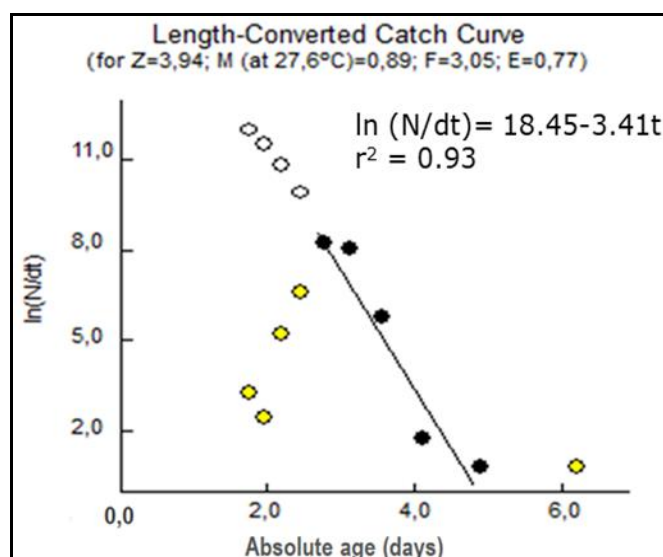


Figure 7. Estimation of total mortality of glass eels (*Anguilla* spp.) in Cimandiri River estuary using length converted catch curve analysis. Z - total mortality; M - natural mortality; F - fishing mortality; E - exploitation rate; 27.6°C - average water temperature in the research location; N - the number of fish in a given length class; t - the mean age of the fish.

Studies on the M value in the glass eel phase are still limited, so the comparison of M value in other locations is based on studies of eels generally in the adult size. The M and F value of *A. marmorata* in Lasolo and Lalindu rivers, Southeast Sulawesi were 0.66 years⁻¹ and 1.24 years⁻¹, respectively (Pangerang et al 2018). Amir et al (2009) reported that the M and F value of *A. marmorata* in Malunda waters, West Sulawesi, were 0.366 years⁻¹ and 0.978 years⁻¹, respectively. Dekker (2000) reported that the M value of glass eels (*A. anguilla*) in Europe was 0.14 years⁻¹, with a F value varying from 1.06 to 3.15 years⁻¹.

The E value of glass eels has exceeded the optimum exploitation value. According to Pauly (1980b), the optimum exploitation rate occurs at a value of $E \approx 0.5$ or in conditions of $F = M$. This condition describes the overexploited status of glass eel in the Cimandiri River estuary. If the glass eel fishing activity in Cimandiri River continues, it can threaten the population of eels. To achieve the optimum catch results, it is

recommended to reduce fishing efforts by approximately 54%. The reduction in fishing activity can be done by limiting fishing time or limiting the number of catches. Efforts to limit fishing activity have been carried out by glass eel fishermen in the Cimandiri River estuary. They agreed not to catch glass eel on Friday nights every month in the fishing season. High exploitation rate was also discovered in some studies in the Malunda River of West Sulawesi, and the Lasolo and Lalindu River of Southeast Sulawesi. The E value of eels in the Malunda River was 0.728 years⁻¹ (Amir et al 2009), and in the Lasolo River and Lalindu, E value was 0.65 years⁻¹ (Pangerang et al 2018). High exploitation rate occurs because eel is an economically valuable fishery resource and an export commodity.

The glass eel capture management in Cimandiri River needs to get more attention, considering that the eel farming activities are highly depended on the wild glass eels. There should be a regulation to limit the number of glass eel catches according to the eel farm requirements. Haryono & Wahyudewantoro (2016) suggested that for limiting the fishing activities of glass eels, it is necessary to collect data on the number of fish farmers and their business capacity, so that the total glass eel requirement per year can be estimated. Other strategies to increase the sustainability of eel resources in the wild are to maintain glass eels and reproductive migration ways, so that the recruitment process is not disrupted, limit the number of catches for preventing overexploitation, use glass eels efficiently in aquaculture activities, and improve the aquaculture technology to attain a high survival rate of the glass eel in the farm (Affandi 2005).

Conclusions. The population structure of glass eels entering the Cimandiri River estuary consists of one age group and is dominated by an average total length of 52.4 mm. The growth rate of glass eels is 0.50 years⁻¹, and the asymptotic length of glass eels reaches 70.8 mm. The glass eel recruitment pattern has 2 peaks in one year, in April (17.10%) and August (13.17%). The glass eel mortality rate at the Cimandiri River estuary is influenced more by fishing mortality compared to its natural mortality. The level of glass eel utilization has exceeded its optimum exploitation value. There is a need for management to regulate the capture of glass eels, so that the sustainability of eel resources can be achieved.

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