Stock assessment and potency of sustainable yield of glass eel (Anguilla spp.) in Cimandiri River Estuary, West Java

Triyanto1,3*, R Afandi2, M M Kamal2 and G S Haryani3
1 Graduate School of Marine and Coastal Resources Management, Bogor Agricultural University (IPB), Bogor, West Java, Indonesia 16880
2 Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Bogor Agricultural University (IPB), Bogor, West Java, Indonesia 16880
3 Research Center for Limnology, Indonesian Institute of Sciences (LIPI), Bogor, West Java, Indonesia 16911

*Corresponding author
Email: triyanto@limnologi.lipi.go.id

Abstract. The demand for glass eel (Anguilla spp.) as a source of seeds for aquaculture activities depended on natural catches continue to increase. It has caused glass eel fishing activities to increase and potentially affect the biological condition and sustainability of fishing activities. The study aims to assess the potential stock, maximum sustainable yield (MSY) and the level of utilization of glass eel in the Cimandiri river estuary, West Java. The data were obtained from data on fisherman catches in the period 2014-2018. Potential stock calculation using the CPUE method is based on the Leslie model. Calculation of MSY based on the surplus production model from Schaefer. Utilization rates are determined based on the percentage of actual catch to the total allowable catch (TAC). The results of the study obtained an estimated glass eel potential stock of 4,575 kg. The maximum sustainable yield (MSY) was 991.20 kg.years\(^{-1}\) and the effort (f\(_{MSY}\)) was 1050 trip.years\(^{-1}\). The average of glass eel production was 725.55 kg.years\(^{-1}\) and fishing effort 1031 trip.years\(^{-1}\). The TAC which set at 80% from the MSY was 792.96 kg.years\(^{-1}\). The average of the utilization rate of glass eel reached 91.50%. Utilization rates exceeding the TAC value occurred in 2014 and 2017. Management of glass eel fisheries is needed through limiting fishing efforts and the number of catches.

1. Introduction
Eel (Anguilla spp.) is a catadromous fish, which is a fish that migrates into sea waters to spawn [1, 2]. Eel larvae live in the sea shaped like a broadleaf, transparent, and known as leptocephalus [3]. Leptocephalus lives as plankton carried by ocean currents near the coast [4]. Leptocephalus undergoes a metamorphosis that turns into a transparent eel and is called a glass eel. Glass eel will be returned to freshwater through river estuary to further grow and develop to mature size in freshwater habitats such as rivers and lakes. The overall eel life cycle is divided into three phases, namely the ocean phase, estuarine phase and river phase [5, 6].

Eel is one of the fisheries commodities that has economic value and has a high nutritional content. Eel is one of the famous Indonesian fishery exports. Eel exports are mainly aimed at countries such as Japan, Hongkong, South Korea, China, and Taiwan. Eel demand on the international market reaches...
300 thousand tons per year. Of the total demand, Japanese demand for the Kabayakiunagi is 150 thousand tons per year. The domestic demand reaches three tons per month only for the Jakarta area, not other regions yet [7]. The need for glass eel for cultivation in Japan extents 220,000 tons a year [8].

The development of the eel fisheries sector in Indonesia has promising opportunities. Indonesia's potential for the development of eel cultivation is quite large [9]. Indonesia has abundant larval potential, the availability of extensively cultivated land, feed raw materials available in large quantities, and supported by appropriate climatic conditions. The need for glass eel for cultivation needs continues to increase. Based on the Ministry of Marine and Fisheries Affairs Regulation No. 19/Men/2012 eel at a size of ≤150 gram is prohibited from being exported. This can be an opportunity for the development of national eel cultivation activities.

Cimandiri River is located in Sukabumi Regency. The river discharges into the Pelabuhan Ratu Bay, West Java. Cimandiri River is known as one of the centers for catching glass eel [10, 11, 12, 13]. Catching glass eel in the Cimandiri River has become one of the local people's livelihoods. The economic value of glass eel makes the commodity of the main target of capture. Glass eel catches in the Cimandiri River estuary have now been reported to have decreased [14, 15]. The decline in catches of glass eel might be triggered by many things. According to some studies, the decline in eel populations in nature could be occurred due to over exploitation, pollution, habitat destruction and a decrease in the quality and quantity of freshwater, estuary, and coastal habitats [16, 17, 18].

Glass eel caught was used for eel aquaculture purposes at several aquaculture companies such as in the areas of Sukabumi, Kerawang, Bogor, Bandung, Jogjakarta, Cirebon, and Banyuwangi. Glass eel needs continue to increase. This happened because of the growing eel cultivation technology and high demand for eel commodities. Research on the stock and sustainable potential of glass eel is currently not much done. This study aims to assess the stock and sustainable potential of glass eels in the Cimandiri River estuary. The results of this study are expected to provide predictive information on the availability of stocks and the sustainable potential of glass eel as a scientific reference in the sustainable management of glass eel resources.

2. Methods

2.1. Location, research time, and data source
The study was conducted in the Cimandiri River estuary, Sukabumi West Java (figure 1). Glass eel catch data were obtained based on data collection from glass eel collectors. Available data are in the form of catch production and data on the fishing effort of glass eel in 2014-2018.

2.2. Data analysis
2.2.1. Stock assessment of glass eel
Estimation of glass eel stock done is based on the CPUE (Catch per Unit Effort) based on the Leslie model [19]. The data used are commercial fisheries data, in the form of catch production data, fishing effort and data of catch per unit effort (CPUE). The basic assumption in using the model is that the stock studied is a population or stock caught is assumed to have the same chance of being caught [19; 20]. The model is formulated as follows:

The formulation of the Leslie model equation [19] is as follows:

\[ \frac{Ct}{ft} = qNt \text{ or } CPUE_t = qN_t \]  
(1)

\[ N_t = No - Kl \]  
(2)

\[ CPUE_t = qNo - qKt \text{ It is a form of linear equation } Y = a + bx \]

\[ K_t = C_1 + C_2 + C_3 + \ldots \ldots + 1/2C_t \text{ (1/2}C_t = \text{correction factor)} \]

From the initial linear population or stock equation form, it can be assumed based on the following calculation:
\[ N_{\infty} = \text{intercept} \ (qN_{\infty}) \text{ divided by slope (q)} \]
\[ N_{\infty} = \frac{qN_{\infty}}{q} \]  \hspace{1cm} (3)

Where \( C_t \) is the catch of glass eel at \( t \) unit time; \( f_t \) is an effort at \( t \) unit of time; \( q \) is the capture coefficient; \( N_{\infty} \) is the estimated population/stock; \( K_t \) is the cumulative of the total catch.

**Figure 1.** Research location at the Cimandiri River estuary (Map Source: Google Earth, May 2018).

2.2.2. Analysis of Maximum Sustainable Yield (MSY)

The calculation of sustainable catch potential is based on calculating the value of MSY (Maximum Sustainable Yield). The analysis was carried out based on the surplus production model [21]. MSY calculations based on the Schaefer model are as follows:

\[ \frac{C_t}{f_t} = a - b f_t \]  \hspace{1cm} (4)

This linear relationship is used to calculate the MSY by determining the first derivative of:

\[ \frac{\partial C_t}{\partial f_t} = a - 2 bf_t = 0 \]  \hspace{1cm} (5)

So that the fMSY is obtained:

\[ f_{MSY} = \frac{a}{2b} \text{ and to get the value of MSY is:} \]  \hspace{1cm} (6)

\[ MSY = \frac{a^2}{4b} \]  \hspace{1cm} (7)

Where \( MSY \) is the maximum sustainable yield; \( fMSY \) is a sustainable fishing effort; \( a \) and \( b \) are regression constants; \( C_t \) is the catch; and \( f_t \) is a fishing effort.

2.2.3. Utilization Rate analysis

Utilization rate is calculated by comparing the number of glass eel catches in a certain period with the MSY value. The utilization rate (UR) can be calculated based on the formulation as follows [22]:

\[ UR = \frac{C_t}{TAC} \times 100% \]  \hspace{1cm} (8)
Where $UR$ is the utilization rate of glass eel; $Ci$ is the number of catches in the $i$-year. TAC is the total allowable catch, which is 80% of MSY.

3. Results

3.1. Condition of glass eel fisheries in Cimandiri River Estuary

Fishing glass eel in the Cimandiri River estuary is a small-scale fishery activity. The availability of data that includes fishing activities in the form of total catches and the number of fishing effort have not been well recorded yet. In this study, the data of glass eel catches were obtained based on data collection from CV Indo Bahari (Mr. Ce Engkan). CV Indo Bahari is the main collector of glass eel in Cimandiri. Data on glass eel catches were successfully collected based on records from 2014 to 2018. The recorded catches of glass eel can be seen in Figure 2 and Figure 3. According to the data collection conducted by CV Indo Bahari, the glass eel catches manages to absorb almost 90% of the catches of glass eel fishermen from the Cimandiri River estuary.

![Figure 2. Glass eel catches and fishing effort at the Cimandiri River estuary in 2014-2018.](image)

![Figure 3. Catches of glass eel per month at the Cimandiri River estuary in 2014-2018.](image)
Glass eel catches fluctuate each year with the highest catch in 2014 of 1,202.61 kg, and the lowest in 2016 of 140.29 kg. In 2015, 2017 and 2018 glass eel catches were 745.79 kg, 945.53 kg and 593.53 kg, respectively. Since 2014-2018 the glass eel catches showed a decreasing trend of 50.65%. The fishing effort is calculated based on the accumulation of the number of fishermen who catch each day during one fishing year. The number of fishing effort trends to increase. In 2014 the number of fishing effort was 897 trips, in 2015 it was 684 trips, in 2016 it was 397 trips, in 2017 it was 910 trips and in 2018 it was 1631 trips. Trend of fishing effort increased by 81.82%.

Glass eel catches per month in 2014-2018 was also fluctuated. In 2014 there were two catches peaks, namely in April and October. In 2015 there were two catch peaks, namely in April and November. In 2016 the glass eel catch started in August with the peak catches in December. In 2017 there were two catch peaks, namely in March and June. In 2018 there was one peak of catch that was in June. When viewed from the average catch per month there are two peak catches, namely in April and October.

3.2. Glass eel stock
Glass eel stock is estimated based on the calculation by the Leslie method [19], the regression equation formed between the relationship of catch productivity (CPUE) with cumulative catch is $y = 1.372 - 0.0003x$ with an $R^2$ of 0.66 (figure 4). From the same equation, the value of $a = 1.372$ and $b = 0.0003$ is obtained so that the glass eel stock is estimated to be 4,575 kg.

![Figure 4](image.png)  
**Figure 4.** Graph of the relationship of the cumulative catch with the catch per unit effort (CPUE) of glass eel.

3.3. Maximum Sustainable Yield (MSY) and Effort at Maximum Sustainable Yield ($F_{MSY}$)
The value of sustainable catch (MSY) from the calculation results is 991.20 kg.years$^{-1}$ with the value of sustainable fishing effort ($F_{MSY}$) is 1,050 trip.years$^{-1}$. The actual condition of the glass eel catches in the period 2014-2018 was an average of 725.55 kg with an actual fishing effort of 1,031 trip.years$^{-1}$ (figure 5).

3.4. Total Allowable Catch (TAC) and Utilization Rate
The total allowable catch (TAC) of glass eel is set at 80% of the MSY value. The TAC is 792.96 kg.years$^{-1}$. The glass eel utilization rate is obtained based on the percentage of the actual catch value against the TAC value. The results of the calculation of the level of glass eel utilization per year can be seen in Table 1. The utilization rate of glass eel that show more than 100% indicate the utilization of resources has exceeded the sustainable potential. Utilization that exceeds the potential for sustainable use occurred in 2014 and 2017. When viewed from existing data the level of glass eel utilization is carried out maximally when the existing stock is high. Overall, the level of glass eel utilization from
the Cimandiri River estuary in the period 2014-2018 reached 91.50% or as close to the limit of sustainable potential.

![Graph showing the relationship between catch production, fishing effort, and estimated MSY of glass eel.](image)

**Figure 5.** The relationship between catch production, fishing effort and the estimated MSY of glass eel.

| Year | Catch of Glass eel (kg) | Fishing Effort (trip) | TAC (kg.years⁻¹) | Utilization Rate (%) |
|------|-------------------------|-----------------------|------------------|----------------------|
| 2014 | 1202.61                 | 897                   | 792.96           | **151.66**           |
| 2015 | 745.79                  | 684                   | 792.96           | 94.05                |
| 2016 | 140.29                  | 397                   | 792.96           | 17.69                |
| 2017 | 945.53                  | 910                   | 792.96           | **119.24**           |
| 2018 | 593.53                  | 1631                  | 792.96           | 74.85                |
| **Average** | 725.55                 | 904                   | -                | **91.50**            |

**Table 1.** Utilization rate of glass eel in the Cimandiri River estuary.

4. Discussion

Glass eel (*Anguilla* spp.) is a fish resource in the larval stage that has economic value. In the management of eel fisheries resources, the success of adult eel migrates to the sea to spawn and the process of recruitment of glass eel to freshwater to grow into adults becomes very important. The glass eel stock will depend on the adult eel which successfully regenerates the reproductive process. The most important role in the recruitment process is the availability of adult stock (spawning stock biomass), because the availability of safe brood stock can guarantee the continuity of the process of entry of young fish into the fisheries area [21].

The process of eel recruitment that enters estuarine waters is determined by internal and external factors. Internal factors are determined by the success of the number of adult eel to reproduce. While external factors are determined by environmental factors. From many studies mentioned glass eel migration to freshwater is influenced by temperature, salinity, turbidity, river currents, tidal cycles, and moon phases [3; 4].

Glass eel resources are used for the cultivation of eel. Along with the increasing demand for eel commodities, the need for glass eel for cultivation also increased. The need for glass eel for
Reducing fishing activities for fishermen can reduce the welfare of these fishermen. This needs to be anticipated by providing other business alternatives so that fishermen income can be maintained. Alternative fishing activities can be shifted into aquaculture activities. The captured glass eel is partly be anticipated by providing other business alternatives so that fishing efforts can be sustained. Management that can be done is to reduce fishing activities and limit the catch to increase by 81.82%. An increase in fishing effort is a common occurrence of a resource that is exploited and of economic value. As a result of the increased fishing effort, it is thought to have caused glass eel catches to decline as well.

The highest glass eel catches took place in 2014, amounting to 1,202.61 kg with a fishing effort of 897 trips. The lowest glass eel catch occurred in 2016, amounting to 140.29 kg with a fishing effort of 397 trips. The highest fishing effort occurred in 2018, totaling 1,631 trips, but the high fishing effort occurred did not produce high catch, because the catch in 2018 was only 593.53 kg. The difference in glass eel catches is thought to be influenced by the process of eel reproduction in the oceans and the recruitment process of eel larvae that enter estuarine waters. In 2016 the glass eel recruitment process did not take place every month. In 2016 glass eel was only available in August-December, whereas in 2014-2015 and 2017-2018 the recruitment process took place every month.

In the period 2014-2015 and 2017-2018, the capture of glass eel took place every month. The highest glass eel catches took place in March-April and October-November. The peak of the catch is related to the glass eel recruitment process and the time of eel spawning. The first recruitment peak took place in April. It is suspected that the glass eel entering the Cimandiri River estuary waters originated from the initial spawning period during the start of the rainy season, namely in December-February. The second peak of recruitment that took place in October-November comes from the spawning period at the end of the rainy season, namely June-July. The pattern of glass eel recruitment in the Cimandiri River estuary has similarities with glass eel migration in the Progo River, Yogyakarta. The migration of glass eel into the estuary waters of the Progo River takes place during the rainy season and the peak of migration occurs at the end of the rainy season, namely in April-May [23].

The estimated stock of glass eel resources available in the 2014-2018 period reached 4.6 tons. Calculation of stock estimation is very important in the needs of the management and utilization of a fishery resource [21]. In managing migratory fish resources such as eel, stock management is very important. To maintain the sustainability of eel fish resources, it is necessary to save the remaining stock so that glass eels that enter the estuary waters can grow and develop into adult eels (silver eel). Furthermore, the silver eel will migrate back to the sea to be able to reproduce so that the survival of glass eel resources can also be sustained.

In fisheries management needs, there are limitations to the utilization of captured fish resources, namely the total allowed catches (TAC). TAC calculation is based on the calculation of the value of MSY (Maximum Sustainable Yield). The estimated results of the MSY glass eel calculation are 991.20 kg.years\(^{-1}\) with a sustainable catch effort of 1,050 tripe.years\(^{-1}\). TAC allowed for glass eel capture is 792.96 kg.years\(^{-1}\). The actual condition of the glass eel catches in the period 2014-2018 was 725.55 kg with an actual catch attempt of 1,031 tripe.years\(^{-1}\). From this calculation, it is known that the glass eel capture activities in 2014 and 2017 have exceeded the TAC and in 2018 the fishing effort carried out has exceeded the sustainable fishing effort.

Glass eel fishing activities in the Cimandiri River estuary are approaching overfishing. The last few years the catch and the level of fishing effort of glass have exceeded the management value of MSY (biologic overfishing). The catch condition is more biologically due to fishing that has exceeded the maximum sustainable yield. Biological overfishing can cause fish resource stocks to decrease dramatically, further causing fisheries activities to cease. The management of glass eel capture in the Cimandiri River estuary needs to be regulated wisely so that the sustainability of glass eel resources can be sustained. Management that can be done is to reduce fishing activities and limit the catch according to the TAC value.

Reducing fishing activities for fishermen can reduce the welfare of these fishermen. This needs to be anticipated by providing other business alternatives so that fishermen income can be maintained. Alternative fishing activities can be shifted into aquaculture activities. The captured glass eel is partly...
kept to be raised to a certain size that can be sold to farmers. This aquaculture activity can provide alternative work for fishermen. Technically the rearing glass eel for aquaculture activities needs to be supported by the local government so that there is technical guidance to the cultivating fishermen. In the implementation of glass eel, cultural activities can be undertaken in groups coordinated by the collectors. Members of fishermen generally have limited capital and infrastructure. The role of the collectors who are the driving factors for fishing glass eels is very important in this alternative activity. An eel aquaculture company whose seed needs come from the Cimandiri River estuary must also play a role by participating in glass eel cultivation activities. Segmentation of the size of eel culture needs to be made so that there are commodity opportunities based on the size that can be cultivated at the fishermen level.

The effort to manage glass eel resources at the Cimandiri River estuary has begun to be carried out by the government of Sukabumi Regency with the issuance of the regulation of the Sukabumi District No 25/2018. The regulation mentioned the need for management of eel catching so as not to become extinct. Efforts to recover eel populations have also been carried out by conducting a restocking program to release fingerling eel and adult eel. This program is carried out by eel cultivation companies and local governments. Since 2014-2016, 85,600 fingerling of an eels size of 5-10 g/individual has been released to the Cimandiri River and tributaries by PT IROHA. This eel cultivation company is located in Banyuwangi, East Java, most of its glass eel needs are obtained from the Cimandiri River. In 2017 PT Labas releases the adult eel as much as 200 kg with a size of 1-2 kg/individual. PT Labas is an eel cultivation company in Bogor, this company also gets most of the glass eel from the Cimandiri River estuary. Eel release activities to protect the population and the availability of eels in nature are expected to be one of the efforts in maintaining the conservation of eel resources in the Cimandiri River. Illegal release activities to protect eel seed populations in nature are still being initiated by aquaculture companies. Henceforth, this program needs to be included in the management rules applied in the process of licensing aquaculture activities. Cultivation companies must set aside part of their cultivation to be released in the waters where glass eel is obtained.

5. Conclusions
The stock of glass eel resources in the Cimandiri River is estimated at approximately 4,575 kg. Sustainable catches are estimated at 991.20 kg.years⁻¹ with the sustainable fishing effort of 1,050 trip.years⁻¹. The total allowable catch (TAC) is estimated at 792.96 kg.years⁻¹. The actual condition of catching glass eel in the Cimandiri River reaches 725.55 kg.years⁻¹ with a fishing effort of 1,031 trip.years⁻¹. The level of glass eel resource utilization is 91.50% or has approached the TAC value. Glass eel resource management needs to get attention by reducing catching efforts and catches so that the capture and preservation activities of glass eel resources can be sustained.

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