A regional fisheries ecological footprint of Jakarta Bay (An analysis of carrying capacity based on primary production requirement)

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Abstract. This research aimed to analyze the sustainability of fisheries in the bay based on ecological footprint (EF) and bio-capacity (BC). The used methods were ecological footprint and biocapacity approaches based on primary production requirement (PPR). Data were derived by surveying main caught fish of small fishermen as a main basis of calculation and the trophic levels were determined by fish base data. The calculation of BC also followed the ecological footprint calculation pattern where its estimation was according to the water types. Results of this research exhibit that all water system types possess the value of EF is higher than the EC value. The average values of EF in tropical shelves (TS) and non-tropical shelves (non-TS), and C&C are 64708 km², 6474 km², and 8148 km², respectively. Whilst, the value of BC is around 2707 km² or only about 30% from all total waters of Jakarta Bay that is able to support fishing activities. Furthermore, the values of EF per-capita for TS and non-TS, C&C, and BC, are 6.04 km²/fisherman, 0.71 km²/fisherman, 0.42 km²/fisherman, and 0.21 km²/fisherman, respectively. These counting results signify that the values of ecological footprint (EF) are higher than the values of bio-capacity (BC). This result infers that fishing sustainability in Jakarta Bay has delivered a heavy burden.

1. Introduction
Jakarta is one of sixteen megacities in Asia [1], where most of those cities are located in coastal areas that drive environmental damages, air pollution, eutrophication, and fish source degradation¹. Jakarta Bay scratches between Kawang foreland in eastern and Pasir foreland in the western. It covers areas around 285 km², 33 km length of coastline, and 8.4 m of averaged water depth. Progress and development attempt Jakarta as a capital city of Indonesia is closely related to dynamics of social-cultural, social-economic, and politic. Jakarta Bay waters are territorials which their coastal areas are utilized for various activities such as voyages, ports, tourism, capture fisheries, settlements, industries, and trades, that will generate huge impacts on the water ecosystem. An ecological footprint was firstly introduced by William Rees in 1992. It is a measurement of how many lands and waters which are

¹ Blackburn et al. (2014).
The ecological footprint approach is intended to point out a dependence of human on their used environment and also to serve the natural resource for the next generation in the future. This footprint consists of four fundamental parameters such as population, land and sea, productivity (product/ha), and an indicator (ha/capita). These parameters will be a part of environmental carrying capacity equation in determining the resistance of natural resources and environment.

Pauly and Christensen [2] have introduced a calculation approach for assessing fishery sustainability in a certain ecosystem in which its main basis is a Primary Production Required (PPR) that is compared with a primary productivity level (PP) (kg.C/m²/year). The PPR concept rose from a fact that in order to an exploited species can be restocked, it has to possess a minimum organic energy stock. In simple, the energy comes from the sun that is captured by autotrophic species (phytoplankton for instance), passes to the secondary producer (for examples: zooplankton, suspension feeder), then come into the planktivorous species and it finally becomes a predator through a trophic network. In each step, only a small part of the energy that is consumed by (after metabolic charge), it is proceed into the individual growth or population growth (through gonad development). The used fraction for growing the individuals or population is called transfer efficiency. The transfer efficiency depends on many factors such as the required efforts for chasing foods, overcoming metabolisms, and organism assimilation efficiency of organic carbon from its food [3]. As a result, the PPR calculation requires knowledge about the trophic level of species and assumption relating to the efficiency of the trophic level. To count these factors, Pauly and Christensen [2] have estimated the PPR in supporting Wet Weight Catch (WWC) for species in certain trophic level by using the following formula.

\[
PPR = \frac{WWC}{WTC} \times \left(\frac{1}{TE}\right)^{(TL-1)}
\]  

(1)

This calculation is based on several factors such the conservative wet weight towards the conversion of weight total carbon (WTC) with ratio 1:9², estimated average trophic efficiency (TE) that is about 10%, and estimated trophic level (TL) which is based food composition. It should be bearing in mind that this technique will traverse food web complexity (for instance, competition to resources, recycling), and generate PPR value, through this function form, that is sensitive to TE and TL. Its general information is available in food composition of individual species, that the TL is able to be predicted exceeding an acceptable accuracy level. However, the TE value is more complex and should consider the complexity of food web interaction like species competition for resources or indirect effect, detrital carbon microbe recycling. There are some approaches to calculating fisheries ecological footprint or marine ecological footprint. Clark et al. [4] try to count fisheries footprint on a very wide scale and a long data series. Their approach is carried out by counting fisheries footprint through an ecological footprint consumption approach.

\[
EF_C = EF_p + (EF_t - EF_E)
\]  

(2)

The ecological footprint consumption (EFc) for a state is equal to an ecological footprint production (EFp) that is added with an ecological footprint trade or import and reduced with export. The EFp is estimated by summing the required total productive area in bolstering the organism collection sustainably. The created ecological footprint in export (EF_E) is higher than in import (EF_I) signifies that a certain country is an exporter of clean ecological resources [6]. Trade flows are able to be spotted as a realization of demand for biocapacity, which is traded on a global scale. Calculating of fisheries footprint consumption of species is higher in aquatic food webs, and needs more biological supports than estimating consumption [5]. Its measure is also appertained into an aquaculture production, including marine and land inputs that are utilized for aquaculture [6, 7].

Escalating of social, economic and environmental issues in Jakarta as one of the megacities in the world is an interesting puzzle to be grab currently. Economic benefits and environmental management are two aspects that should be driven carefully by the government in order to avoid friction in both terms regulation and social. Ecological footprint and biocapacity are the environmental assessment tools that

\[2\] Strathmann (1967).
are able to be used for estimating environmental aspects due to human activities, in this case, fishing activities in Jakarta Bay. This research aimed to analyze the values of ecological footprint and biocapacity in Jakarta Bay and their relation to small-scale fisheries activity.

2. Material and Methods

2.1. Method
The fishery is an important system happening in coastal areas, that is able to figure out an environmental carrying capacity. We collected data of fishing activities especially fish production for 17 years of the period in describing explicitly fishing production in Jakarta Bay. Based on provincial government data, total production of fishing in the bay is increased during the years, however, this total is compiled by all fish landings in Jakarta. The problem is how many total productions of capture fisheries actually coming from Jakarta itself? So far there is not any approach yet that has been conducted to estimate specifically numbers and types of fish which are originated from Jakarta Bay waters. By paying attention to the condition of Jakarta Bay which continues to experience a decline in environmental quality, it is able to be surmised that this condition can influence the sustainability of fish resource of the bay. Accordingly, this research tried to establish assumptions especially in classifying fisherman types of Jakarta which is related to types of fish and fishing gears in the bay.

2.2. Estimating ecological footprint
Analysis of coastal resource condition was begun by collecting and compiling data base according to economic-social data.

2.3. Ecological footprint
Collecting the ecological footprint data in this research used an analysis of primary production required (PPR) that was adopted from Pauly and Christensen [2] and de Leo et al. [8] with a little modification.
Table 1. The required data for analyzing ecological footprint.

| Main component          | Method of data collection | Data source                                                                 | Data type                      |
|-------------------------|---------------------------|----------------------------------------------------------------------------|--------------------------------|
| Social component of populations | Survey, Interview         | Statistics Indonesia                                                       | Primary and secondary data     |
| Fishing grounds          | Survey, Interview         | Fishermen and communities                                                  | Primer (First Hand data)       |
| Economical component    | Interview                 | Fishermen and communities                                                  | Primer (First Hand data)       |
| Fish production          | Survey, Interview         | Fishermen, Fish Auction, Sudin KPKP kantor walikota Jakut, Dinas Pertanian Kelautan dan ketahanan pangan DKI Jakarta | Primary and secondary data     |
| Catch Fish               | Survey, Interview         | Fishermen, Fish Auction, Sudin KPKP kantor walikota Jakut, Dinas Pertanian Kelautan dan ketahanan pangan DKI Jakarta | Primary data                   |

2.4. Data analysis
To measure a single unit system of ecological footprint, we utilized a more applicable equation based on Pauly and Christensen [2] and de Leo et al. [8], which is well known as a Marine Ecological Footprints (MEF):

\[
M_{EF_{a}} = \frac{PPR_{a}}{PP_{a}}
\]

where \( M_{EF_{a}} \) = Ecological Footprint for the aquatic system a \((\text{km}^{2}/\text{years})\) or transformed to Hectare, \( PPR_{a} = \) Primary Production Required for species a in aquatic system a \((\text{kg/year})\). \( PP_{a} = \) Primary Production for Aquatic System a \(\text{kgC/m}^{2}/\text{Year}\).

\[
PPR_{i} = C_{i} \times 10^{(TL-1)}
\]

where Primary Production, \( PPR_{i} \), which is required for \( i \) species \((\text{gC})\), \( C \) is a total catch of \( i \) species that is divided into 9 as conversion of atomic weight \( C \), \( TL \) is a trophic level of species \( i \) that gained from fishbase.org or other sources.

2.5. Bio-capacity for single land use type
Bio-capacity uses a modified equation of de Leo et al. [8]:

\[
Regional Fisheries Biocapacity (RFBC) = A \times YF \times EQF
\]

\( A \) is fishery zona in Jakarta \((\text{km}^{2})\); \( YF \) = factors of global performance in metric ton per km\(^2\), that is estimated as a total catch fish which is divided by total fishing grounds in a certain year; \((\text{Ton/km}^{2})\); An equivalence factor \((EQF)\) that is involved to transform a hectare of fishing area to be a global hectare standard. This variable is counted for each biomass that divides biomass average production of world average production. The \( EQF \) of Indonesia is about 0.35 [9]. When \( RFEF < RFBC \) means sustainable, and If \( RFEF > RFBC \) means unsustainable.

3. Results and Discussion

3.1. PRR Analysis and Regional Fisheries Ecological Footprint
In this current research, we conduct an analysis related to the ecological footprint of fisheries based on primary production required \((PPR)\). To simplify an analysis process, we defined our analysis scope only for Jakarta Bay. The number of catches and types of fish caught are assigned based on results of interviewing small-scale fishermen. In this case, assuming the fishermen catch fish in only surrounding Jakarta Bay. The result of interviewing the fishermen, some fish species are identified as main catches.
of them. A regional ecological footprint (RFEF) is a calculation approach of an area capability to support an aquatic biota life sustainably. In other words, this approach also exhibits the carrying capacity of a water ecosystem.

Table 2. Results of main catch of fishermen in Jakarta Bay.

| No. | Fish type       | Latin name                  | SP | TL  | SD | Global name                  |
|-----|----------------|----------------------------|----|-----|----|------------------------------|
| 1   | Swimming Crab   | Portunus pelagicus          | 2  | 3.43|    | Swimming Crabs               |
| 2   | Rabbit Fish     | Siganus javus               | 2  | 2.4 | 0.08| Streaked spinefoot           |
| 3   | Anchovy         | Stolephorus tri             | 2  | 3.3 | 0.4 | Spined anchovy               |
| 4   | Snapper         | Lutjanus bitaeniatatus      | 2  | 3.8 | 0.6 | Indonesian snapper           |
| 5   | Grouper         | Epinephelus malabaricus     | 2  | 4.2 | 0.61| Malabar Grouper              |
| 7   | Giant trevally  | Charax ignobilis            | 2  | 4.2 | 0.4 | Giant trevally               |
| 8   | Shrimp+Dry skin| Acetes sp                   | 2  | 3.11|    | Shrimp                       |
| 9   | Squid           | Loligo                      | 2  | 3.3 |    | Squid                        |
| 10  | Threadfin sea  | Arius arius                 | 2  | 3.5 | 0.37| Threadfin sea catfish        |
| 11  | Mullet fish     | Mugil cephalus              | 1  | 2.5 | 0.7 | Flathead grey mullet         |
| NO  | Jenis Ikan      | Nama Latin                  | SP | TL  | SD |                              |
| 1   | Sardinella     | Sardinella fibriata         | 1  | 2.7 | 0.3 | Fringescale sardinella       |
| 2   | Threadfin fish | Eleutheronema tetradyction   | 1  | 4.1 | 0.5 | Fourfinger threadfin          |
| 3   | Big eye scad    | Selar crumenophthalmus      | 1  | 3.8 | 0.2 | Big eye Scad                 |
| 4   | Mackeral        | Rastrelliger kanagurta      | 1  | 3.2 | 0.38| Indian mackerel              |
| 5   | Barracuda       | Sphyraena barracuda         | 1  | 4.5 | 0.6 | Great Barracuda              |
|     | Spanish         | Nannopterus acaraei         |    |     |    | Narrow-barred                |
| 6   | Mackeral        | Scomberomorus commerson     | 1  | 4.5 | 0.4 | Spanish mackerel             |
| 7   | Sword fish      | Trichiurus savala           |    |     |    | Savalai hairtail             |

The RFEF is widened from a research of Pauly and Christensen (1995) about Primary Production Required which gets a little modification on its primary productivity value. Pauly and Christensen [2] define a denominator of PPR (gC) a value of primer productivity (PP) (gC.m\(^{-2}\).y\(^{-1}\)) according to the water system. In this case, they divide water systems into some types such as the oceanic system, upwelling system, tropical shelves, non-tropical shelves, coastal and coral system, dan fresh water system. These six water systems possess a predetermined level of primary productivity namely 103, 973, 310,310, 890, 290, respectively. Until recently, an approach using the PP value is not yet widely used to estimate the carrying capacity of the aquatic environment. In the current research, the ecological footprint is categorized into three types of water systems through a different PP approach namely coastal & coral system, tropical shelves, and non-tropical shelves. Types of catch fish have been separated based on these three water systems which are listed in Table 2 above by referring to a determination of Pauly and Christensen [2]. Further, the PPR value of Jakarta Bay has an increasing trend, whilst the fish catch undergoes a downward trend, except catching in non-tropical shelves area which contains catches of shrimp + dry shrimp skin, swimming crab, and squids. According to Pauly and Christensen [2] that global fish catch is highly influenced by water productivity. Morato et al. [10] try to link between the fish biomass of orange roughly (Hoplostethus atlanticus) and primary productivity level change in surrounding seamounts ecosystem, and also to find out their connectivity to PPR (Primary Production Required). In structurally, Morato et al. [10] also estimate a biomass relationship of several fish species that live in border ecosystem of seamounts such as sharks, rays, billfishes, baleen whales, toothed whales, seabirds, tuna, skates, and turtles. The result in the second part of the modeling study has attempted to quantify more accurately by modeling the values of PPR in order to preserve a great aggression of fish in around underwater ecosystems. The study also has promoted a concept that an increase of local primary productivity is not able to maintain a great aggression of the sea fish. This is
due to there is not any possibility of seawater circulation to be preserved in around seamounts during several months that are required for productivity which works through a food network to a higher trophic level in around the seamount itself. Our research in Jakarta Bay signifies contrasting results where the values of PPR belong an increasing trend when in the same time the biomass of catch precisely has a downward trend even though the correlation between them is very small. A further analysis related to the ability of a certain ecosystem to ensure biomass sustainability of fish is taken through analyzing ecosystem biocapacity that is linked to ecological footprint value that is obtained from the PPR value which is divided with primary productivity values of certain water.

![Figure 2](image1.png)

Figure 2. A comparison of ecological footprint and biocapacity in Jakarta Bay in three areas based on Pauly dan Chirstensen [2] namely tropical shelves (a), non-tropical shelves (b) dan coastal and coral system (c).

Estimating of biocapacity (BC) is derived from counting results of all fish catch is divided with a total area of waters and then its result is multiplied with the coefficient of fish caught in the tropical area (0.35 source of GFN). The calculation of BC also follows ecological footprint estimation pattern where its calculation is based on types of water systems. Results of these estimations are delineated in the Fig 2. This figure points out that all types of water system possess higher ecological footprint values than their biocapacity values. The averaged values of tropical shelf (TS), non-TS, and C&CS, are 64,708 km²; 6,474 km²; and 8,148 km² respectively. While the BC value is in range of 2,707 km² or only 30% of total areas of Jakarta Bay waters that are able to support fishing activities. Moreover, the EF per capita is yielded by dividing the EF value with total fishermen in each year. The estimating result of the EF per capita for four different observed variables namely TS, C&CS, Non-TS, and BC, are 6.04 km²/fisherman, 0.71 km²/fisherman, 0.42 km²/fisherman, 0.21 km²/fisherman, respectively.

3.2. Discussion
Particularly, a high ecological footprint has become a special problem in tropical coastal ecosystems of megacities, including the city of Jakarta that is comprehensively marked and quantified by pressures which threaten the function and health of the environment in long term especially for areas around
Jakarta Bay (JB). Breckwoldt et al. [11] explain about the environmental pressure that is happening in Jakarta Bay with a number of possible feedback loops among various environmental stressors, marine resources, and human population in this bay and Keputauan Seribu can be noticed. The magnitude of anthropogenic pressure on the larger JB ecosystem is able to be clearly spotted. Cleary et al. [12] found that the distribution and abundance of several organisms associated with coral reefs are able to reflect the water condition which is very eutrophic and chronic exposure due to the number of disturbances originating from upper land use function changes. In terms of sampling location, the seashore areas are highly dominated by sand algae, debris and grass, less benthic organisms such as fish, sponge, Echinodermata, ascidia, mollusk and foraminifera, and macro algae which is marked by a disturbing physical-chemical condition of the water such as a high sea surface temperature, a low dissolved oxygen and chlorophyll concentration, and very low live coral cover. The environmental gradient along the Seribu Islands also predisposes the ratio of Sr/Ca in the coral core that is applied as a proxy for predicting sea surface temperature in the past. Cahyarini et al. [13] can evidence that the coral core derived from Jakarta Bay is highly influenced by air temperature and also urbanization, while the coral core derived from offshore of Jakarta Bay is mainly affected by sea surface temperature. In addition, during onset El Nino phase in past years (exemplified in 2015), the coral core of inshore signifies a warming condition, while the coral core of offshore indicates an opposite condition. These impacts on coral reefs will then leaven various fish resources that live in the ecosystem. Based on results of these research, we confirm that fish catch, especially for fish associated with coastal areas and coral reefs, possesses a declining pattern, and ecological footprint has exceeded the biocapacity of Jakarta Bay. Therefore, sustainable management patterns are necessitated to map the sustainability of fishery sectors in this bay, even less this bay is encountered with an intensity of massive coastal development currently. Based on the magnitude occurring pressures above, it is able to be figured out in the fishing catch of fishermen. There are several economically important fish species that their catches continue to be declined gradually. Fish caught by fishermen in Table 1 is a base of estimating regional fisheries of ecological footprint in Jakarta Bay. This matter is assumed by all small fishermen only catch fish in the bay as their main fishing ground.

There are 17 species of main fish catch in Jakarta Bay including squid and shrimp/dry skin shrimp. These data are similar to the main fish catch that has been explained by Baum et al. [14]. The fish production continues to increase gradually (Fig. 2), however, when this production is posited on water systems as seen in Fig 2a, its production is getting declined. In another side, the total production of fish on coastal and coral system is upgraded. It should be underlined that these increases only occur in total, however, when they are arranged according to fish species, the majority of the fish catch is decreased.

The data was taken from the fisheries authority of Jakarta, manifests that a drastic drop of red snapper that associates with coral reef so does the mullet fish (Mugil sp.) that associates with mangroves. While rabbitfish (Siganus sp.) possesses a stagnant trend. Declining several economically import fish species in Jakarta Bay is caused by lowering environmental quality as impacted by damaging some important ecosystems which substantiate the life of the living organism in the bay. Further, Baum et al. [14] describe that coral reef condition in this bay is damaged due to a high sedimentation and anthropogenic pollution that leads to a decrease in fish species. Maduppa et al. [15] also suppose that fish stock decline in this bay and Seribu Island in total exhibiting the biodiversity of coral fish in Seribu Island is strongly connected with the environmental conditions like turbidity and pollution level from Jakarta Bay towards the north of islands. The researches about links between coral reefs and diversity and density of fish have been carried out a lot [15]. But, an interesting case in the current research is a trend of rabbitfish (Siganus sp.) catch where it tends to be stagnant and even escalated (although it is not so high). According to Clearly [16], the disturbed fish species in coastal areas relatively has a fast-growing rate but short-lived than fish species which inhabits areas in still good water condition. These include finding species in inshore areas such as Canthigaster compressus, Cephalopholis boenak, Cheilodipterus quinquelineatus and Siganus canaliculatus. The finding species inshore areas commonly occur in all parts of Jakarta Bay. This indicates that these fish possess a wide distribution pattern and tolerate various environmental conditions. While in another hand, fish communities that live in middle or offshore have consisted of long-growing rate and slower growth such as Abudelfdif sexfasciatus and Hemiglyphidodon plagiometopon which are not traced in coastline areas. This reality is proven by during observing
swimming crabs (*Protunus* sp.). This commodity has a considerable fluctuation of catch. Fortunately, its trend is mounted during the last 17 years. Some research about this resource, the catch swimming crabs in Jakarta Bay denote carapace size and first mature gonads are relatively small than other areas. According to Hamid et al. [17], carapace sizes of swimming crab in the first mature gonads found in Lasongko Bay, Southeast Sulawesi, for male and female are 109.83 mm and 115.71 mm, respectively. Ernawati et al. [18] found that the size of fist mature gonad of swimming crab in Pati, Central Java, is in range of 107 mm.

### 4. Conclusion

This research infers that there is an increasing number of fishermen dramatically in Jakarta Bay that leads to decrease fish catch especially for species which inhibit coastline areas, coral reefs, and borders of the bay. While other non-fishery resources such as shrimp, squid, and swimming crab, possess a mounted trend during the last 17 years. Furthermore, in terms of estimating ecological footprint values for three different water systems signify that fishing activities in the bay have got beyond the biocapacity values. This condition reflects that fishing activities in this bay are in an unsustainable status.

### 5. Suggestion

By recognizing the complexity management of Jakarta Bay recently, we would like to express three inputs of advice through this research as described below.

1. Regarding especially utilization of coastal and marine resources, analysis of sustainable fisheries policy and trade-off management activities of Jakarta Bay in the future, is required;
2. A planning design of integrated fisheries management of Provincial Government DKI Jakarta is needed to organize fishing activities in total;
3. To appraise the establishment of integrated fishermen villages and water zonation regards the sea territorial conflicts have just begun in this bay.

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