The exploration of trophic structure modeling using mass balance Ecopath model of Tangerang coastal waters

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Abstract. Ecopath model approach was used to describe trophic interaction, energy flows and ecosystem condition of Tangerang coastal waters. This model consists of 42 ecological groups, of which 41 are living groups and one is a detritus group. Trophic levels of these groups vary between 1.0 (for primary producers and detritus) to 4.03 (for tetraodontidae). Groups with trophic levels 2≤TL<3 and 3≤TL<4 have a range of ecotropic efficiency from 0 to 0.9719 and 0 to 0.7520 respectively. The Mean transfer efficiency is 9.43% for phytoplankton and 3.39% for detritus. The Mixed trophic impact analysis indicates that phytoplankton have a positive impact on the majority of pelagic fish, while detritus has a positive impact on the majority of demersal fish. Leiognathidae have a negative impact on phytoplankton, zooplankton and several other groups. System omnivory index for this ecosystem is 0.151. System primary production/respiration (P/R) ratio of Tangerang coastal waters is 1.505. This coastal ecosystem is an immature ecosystem because it has degraded. Pedigree index for this model is 0.57. This model describes ecosystem condition affected by overfishing and anthropogenic activities. Therefore, through Ecopath model we provide some suggestions about the ecosystem-based fisheries management.

1. Introduction

Coastal areas are ecosystems of waters that have high productivity. These ecosystems are the nursery ground for various fish biotas with economic value [1]. Nowadays, the rapidly growing human population and various human activities such as industrial waste and household garbage can increase the nutrient inputs in the waters. In addition, fishing activities and changes of global climate are also the aspects influencing fisheries system in an ecosystem, such as changing productivity, biodiversity and interaction within the ecosystem [2,3,4].

Tangerang Regency has a coastal area directly bordering the Java Sea influenced by anthropogenic activities, including massive exploitation through construction, exceeding the ecological carrying capacity of the coastal area. The growing number of population during the period of 2003 to 2010 had caused uneven population distribution, coastal erosion and sedimentation. Damage at the coastal area due to abrasion in Tangerang coastal waters has reached 51%. This was caused by heavy coastal currents, weak water catchment, lack of mangrove where the potential of mangrove in Tangerang coastal waters has been declining in the last 10 years, and the remnants of illegal sea sand exploitation occurring 3-5 years ago. Waste from industries and households are also the causes of the damage of
natural resources at Tangerang coastal waters. There were around 100 industries in Tangerang Regency in 2010. Furthermore, fishing by using explosives, toxin and trawl has contributed to overfishing, proved by the shrinking number of fish catch landed at the fish landing site. This intensified exploitation is threatening the preservation of coastal resources [5].

Generally, management of fisheries is still conducted through single species or stock approach [2,6]. However, this is considered inadequate. So, ecosystem-based management is getting much attention in fisheries management and ecosystem health [6]. Management through the food chain approach becomes an attempt to comprehend ecosystem-based management. This is because each organism in an ecosystem is related to one another, forming trophic level [7]. Knowledge about food web interaction is an ecosystem-monitoring program, which is relevant to develop knowledge about the structure and functions of ecosystems [8,9].

In recent years, Ecopath with Esocim has been used as one of the tools for ecosystem-based management. Using this tool, the impact of fishing activities and climate changes can be identified. It can even evaluate the cumulative impacts of environmental and human activities in marine food webs [10]. Ecopath software was first introduced by Polovina [11] to provide a simple method related to standing stock and energy flows within an ecosystem. This software was subsequently developed, modified and widely applied to aquatic systems, both freshwater and seawater [12,13]. Ecopath with ecosim (EwE) is open source software consisting of three sub-models including Ecopath, Ecosim and Ecospace [12,14]. Currently, Ecotracer has become the 4th sub-model in the Ecopath with Ecosim software. At this moment, this study is only focused on the Ecopath model.

There has been no research employing tropical analysis conducted in Tangerang coastal waters. Studies on trophic analysis using Ecopath modeling approach in Indonesia, especially in coastal areas, have not yet been performed. This type of research was only done in Cirata Reservoir [15] and the Gulf of Ekas [16]. Therefore, this research is a new study related to coastal resource management using Ecopath model approach. The purpose of this research is to analyze the food web interaction of different functional groups and to describe the flow of energy in Tangerang coastal water using mass balance EwE version 6.

2. Methodology

2.1. Study Site

The research location was the Tangerang coastal waters (Figure 1). Tangerang coastal waters is a coast into which various rivers, including Cipasilian, Cimandiri, Cimauk, Cileuleus, Cirarab, Cisadane, Tanjung Burung and Teluk Jakarta flow. This shallow coastal ecosystem is influenced by various anthropogenic activities and is exploited by fishing. In addition, it has a gently sloping condition with a height ranging from 1 to 10 meters above the sea level. Our study area covers an inshore water body of 305.92 km² within an average water depth of 12.5 m.
2.2. Overview of Ecopath Model
Ecopath model is a static and descriptive model used to identify trophic interactions in aquatic systems in a given period [12,14]. Although this software is progressing and is constantly updated, the principles have not changed [17]. This model represents an ecosystem in which there is an interconnection between trophic groups based on biomass and is linked by mass transfers [11,12]. The Ecopath model refers to the principle of mass balance, which assumes that the production of any given prey is equal to the biomass consumed by the predators plus the biomass caught (e.g., in fisheries) plus any exports from the system (Eq.1)

\[ B_i(P_i) \times EE_i = Y_i + \sum B_j(Q_j) \times DC_{ij} + EX_i \]  

(1)

where \( B_i \) = biomass of prey group \( i \); \( P/B_i \) = production/biomass ratio of group \( i \); \( EE_i \) = ecotrophic efficiency; \( Y_i \) = yield (=fishery catch); \( B_j \) = biomass of predator group \( j \); \( Q/B_j \) = food consumption per unit biomass of \( j \), and \( DC_{ij} \) = fraction of \( i \) in the diet of \( j \). Input data was standardized, \( B \) as wet weight \((\text{ton km}^{-2})\) and \( P/B \) and \( Q/B \) rates per year for each component group. The ecotrophic efficiency (EE) has no unit.

The current version of Ecopath does not limit the number of ecological groups that should be in the model, but detritus group must exist. For each ecological group, \( B \), \( P/B \) and \( Q/B \) parameters must be inputted, but EE parameter is difficult to determine. So, it is estimated from other parameters through the software. A full description of Ecopath can be seen in Christensen and Pauly [12], Christensen and Pauly [18] and Pauly et al. [13].

2.3. Construction Model
2.3.1. Ecological grouping
Ecological groups were grouped based on species with similarity in size, population parameters, prey equality and predators [19]. Based on these assumptions, resources in Tangerang coastal waters were grouped into 42 ecological groups (table 1).
Data on basic parameters, diet composition and other information were obtained from primary data and literature study. If there were incomplete data, the complementary data were taken from an ecosystem having the same characteristics. In addition, Fishbase [20] was also used to supplement the inadequate data where possible. The data on annual landing obtained from Kronjo Fish Landing Site are presented in Table 1.

**Table 1.** Ecological groups and their annual landings in 2013.

| No | Group name           | Annual landing (ton/km²) |
|----|----------------------|--------------------------|
| 1  | Ambassidae           | -                        |
| 2  | Apogonidae           | -                        |
| 3  | Ariidae              | 0.008027                 |
| 4  | Caesionidae          | 0.002266                 |
| 5  | Carangidae           | 0.003063                 |
| 6  | Clupeidae            | 0.01161                  |
| 7  | Cynoglossidae        | -                        |
| 8  | Drepanidae           | -                        |
| 9  | Engraulidae          | 0.003236                 |
| 10 | Gobiidae             | -                        |
| 11 | Haemulidae           | -                        |
| 12 | Lactariidae          | -                        |
| 13 | Leiognathidae        | 0.017446                 |
| 14 | Lutjanidae           | 0.00106                  |
| 15 | Menidae              | -                        |
| 16 | Mugilidae            | 0.001799                 |
| 17 | Mullidae             | 0.008003                 |
| 18 | Nemipteridae         | 0.00598                  |
| 19 | Platyecephalidae     | 0.004696                 |
| 20 | Polynemidae          | 0.000866                 |
| 21 | Pristigasteridae     | -                        |
| 22 | Psettodidae          | 0.004321                 |
| 23 | Scatophagidae        | -                        |
| 24 | Sciaenidae           | 0.005111                 |
| 25 | Scombridae           | 0.001628                 |
| 26 | Serranidae           | 0.002291                 |
| 27 | Siganidae            | -                        |
| 28 | Sillaginidae         | -                        |
| 29 | Sphyraenidae         | 0.001722                 |
| 30 | Stromatidae          | -                        |
| 31 | Synodontidae         | -                        |
| 32 | Tetraodontidae       | -                        |
| 33 | Terapontidae         | -                        |
| 34 | Triachantidae        | -                        |
| 35 | Trichiuridae         | 0.001722                 |
2.3.2. Basic Parameters

2.3.2.1. Biomass

Average biomass of fish per families (t/km²) was estimated from swept area method [21]. Where B is biomass (ton/km²), Cw is caught in weight per hour, a is swept area and X₁ is the fraction of the biomass in the effective path swept by the trawl (0.5).

\[ B = \frac{C_w}{a X_1} \]  

(2)

Phytoplankton biomass value was estimated from chlorophyll a value. The mean chlorophyll a value in this study was 12.01 mg m⁻³ [22]. This value was converted into a square meter unit (12.01 mg m⁻²) by multiplying it with the euphotic depth (1 m). This value was subsequently converted to the wet weight of phytoplankton using conversion twice [23]. In the first conversion, chlorophyll a value was converted to carbon, where the ratio of carbon and chlorophyll a was 40:1. It was subsequently converted back into the wet weight where carbon was 10% of wet weight. So, the phytoplankton biomass of Tangerang Coastal waters is estimated to be 4.8052 ton/km².

Zooplankton biomass was calculated by looking at the biomass and abundance of zooplankton in Pari Island conducted by [24], which is assumed to have the same composition of zooplankton as in Tangerang coastal waters. By comparison method, through the data abundance of zooplankton [25], the biomass of zooplankton in Tangerang coastal waters is 0.0028 ton/km².

Detritus biomass was calculated as a function of primary production and euphotic depth based on the formula of [18]. Where D = detrital biomass (gC/m²); PP = primary production (in gCm⁻² year⁻¹); E = euphotic depth in meter (1.4 m)

\[ \log B_D = 0.954 \log P + 0.863 \log E - 2.41 \]  

(3)

2.3.2.2. Production/biomass (P/B) ratio

Fish production/biomass ratio (P/B) value is difficult to estimate directly. So, the value was assumed to be total mortality (Z) [13]. Total mortality value is the sum of fishing mortality (F) and natural mortality (M). Natural mortality value was obtained from Fishbase [20], while fishing mortality was obtained from the equation \( B = Y / F \) [26], where B is biomass of the biota, Y is yield, and F is fishing mortality. In addition, the P/B values of several groupswere obtained from literature studies such as [27], [19], [28], [16],[29], [30], [31], [32]and[6].

P/B value of phytoplankton was predicted from primary production [33]. Primary production value in Tangerang coastal waters is 941.54 gr C/m²/year. This value was subsequently converted to wet weight to be adjusted with phytoplankton biomass so that the primary production became 9415.43 gr/m²/year. The average biomass of phytoplankton is 4.8052 gr/m². So, the P/B phytoplankton value is 1959 per year. P/B value of Cephalopods was obtained from Indriyati (2005). Shrimps, crabs, and benthos values were obtained from Mohamed et al. (2008).
2.3.2.3. Relative food consumption (Q/B)

Q/B value for fish was estimated from the empirical relationship below (Palomaros and Pauly 1999) using FishBase database (Froese and Pauly, 2014):

\[
\log \frac{Q}{B} = 7.964 - 0.204 \log W_{\text{inf}} - 1.965T + 0.083A + 0.532h + 0.398d
\]

(W inf is the asymptotic weight, A is the ratio of the square of the height of caudal fin and its surface area, indicating metabolic activity. Values of h and d are variables indicating feeding category of fish species, namely herbivore (h = 1, d = 0), detritivore (h = 0, d = 1) or carnivore (h = 0, d = 0). T is the average annual habitat temperature for fish population [expressed as 1000/(Tc + 273.15)] where Tc is average annual sea surface temperature (31°C). The height measurement of caudal fin and its surface area was implemented in Macro Biology Laboratory, Department of Aquatic Resources Management, Bogor Agricultural University. Q/B values of some ecological groups were obtained from literature studies, while cephalopods and zooplankton values were obtained from Mohamed et al. [19]. Shrimps value was obtained from Ullah et al. [6] and benthos value was obtained from Indriyati [16].)

2.3.2.4. Diet composition of groups

Information on diet composition becomes an important information to understand the dynamics of ecosystems, given that food networks connect different ecological groups[34]. Diet composition of an ecological group was estimated through stomach content analysis [33]. In this study, the data on diet composition were obtained from primary data through stomach content analysis and some secondary data through literature studies such as Mohamed et al. [19], Hajisamae [35], Zahid [36] and Fishbase [20].

2.3.2.5. Ecotrophic efficiency (EE)

Ecotrophic efficiency (EE) is the proportion of a group used in the system[37] or a fraction of production of an ecological group consumed by another ecological group or caught by fishing activities. EE value is difficult to calculate directly. So, it was estimated by Ecopath software based on other parameters inputted. EE value ranges from 0-1[38].

2.4. Balancing the model

A model is said to be mass-balanced if the catches, consumption, biomass accumulation and export do not exceed the production of a group. This is in accordance with the Ecopath equation (Eq.1). A balanced model is characterized by an EE value not exceeding 1 [6]. EE value exceeding 1 means that demand for the group is very high [19]. Therefore, modification of diet composition and biomass (mean or maximum biomass) is conducted until a balanced model is achieved.

3. Result

3.1. Model validation

Ecotrophic efficiency (EE) value is a parameter used in the validation of the Ecopath model [38]. EE values in the Ecopath model in coastal Tangerang range from 0 to 0.9719. According to [6], EE value close to 0 means that the group is not consumed by another group in the system, whereas if the EE value is close to 1 then the group is highly consumed by predators (another group) or caught by fishing activities. Biota with tropical 2≤TL<3 and 3≤TL<4 levels have EE 0-0.9719 and 0-0.7520 respectively. Ecological groups that have high EE values include Leiognathidae, Ariidae, Carangidae, Scombridae, Trichiuridae, cephalopods, shrimps and detritus (table 2).
Table 2. Basic estimates obtained after the Ecopath model was mass-balanced.

| No | Groups               | Trophic level | B (ton/km²) | P/B (/year) | Q/B (/year) | EE  |
|----|----------------------|---------------|-------------|-------------|-------------|-----|
| 1  | Ambassidae           | 3.00          | 0.0177      | 2.88        | 57.90       | 0.0000 |
| 2  | Apogonidae           | 2.76          | 0.0047      | 2.14        | 27.90       | 0.0000 |
| 3  | Ariidae              | 2.98          | 0.0039      | 2.50        | 8.70        | 0.8233 |
| 4  | Caesionidae          | 3.00          | 0.0195      | 0.88        | 7.50        | 0.1321 |
| 5  | Carangidae           | 2.64          | 0.0172      | 3.47        | 14.97       | 0.9719 |
| 6  | Clupeidae            | 2.11          | 0.0060      | 10.37       | 34.82       | 0.5945 |
| 7  | Cynoglossidae        | 3.00          | 0.0067      | 1.20        | 11.00       | 0.0027 |
| 8  | Drepanidae           | 3.00          | 0.0028      | 0.47        | 7.50        | 0.0000 |
| 9  | Engraulidae          | 2.33          | 0.0437      | 5.77        | 56.90       | 0.5701 |
| 10 | Gobiidae             | 3.00          | 0.0048      | 4.17        | 37.00       | 0.0000 |
| 11 | Haemulidae           | 3.30          | 0.0056      | 1.32        | 6.40        | 0.0000 |
| 12 | Lactariidae          | 3.47          | 0.0103      | 1.64        | 22.90       | 0.0110 |
| 13 | Leiognathidae        | 2.50          | 0.4436      | 5.28        | 45.00       | 0.8951 |
| 14 | Lutjanidae           | 3.00          | 0.0030      | 1.57        | 6.90        | 0.2251 |
| 15 | Menidae              | 2.50          | 0.0043      | 1.00        | 11.40       | 0.0000 |
| 16 | Mugilidae            | 2.50          | 0.0707      | 1.57        | 32.80       | 0.0162 |
| 17 | Mullidae             | 3.00          | 0.0817      | 2.56        | 30.20       | 0.0405 |
| 18 | Nemipterida          | 2.94          | 0.0061      | 2.95        | 5.50        | 0.3199 |
| 19 | Platyecephalidae     | 3.18          | 0.00061     | 2.95        | 5.50        | 0.3199 |
| 20 | Polynemidae          | 3.09          | 0.0070      | 0.68        | 4.40        | 0.1820 |
| 21 | Pristigasterida      | 3.00          | 0.0301      | 0.96        | 17.10       | 0.0000 |
| 22 | Psettodidae          | 3.50          | 0.0972      | 3.94        | 9.10        | 0.0113 |
| 23 | Scatophagidae        | 2.61          | 0.0029      | 2.15        | 22.20       | 0.0000 |
| 24 | Scianidae            | 3.33          | 0.0146      | 8.36        | 12.33       | 0.6927 |
| 25 | Scombridae           | 2.14          | 0.0248      | 6.24        | 20.47       | 0.6190 |
| 26 | Serranidae           | 2.40          | 0.0014      | 3.80        | 9.00        | 0.4307 |
| 27 | Siginidae            | 2.00          | 0.0017      | 2.10        | 29.70       | 0.0000 |
| 28 | Sillaginidae         | 2.50          | 0.0013      | 2.10        | 32.60       | 0.0000 |
| 29 | Sphyraenidae         | 3.81          | 0.0287      | 0.73        | 11.00       | 0.0822 |
| 30 | Stromateidae         | 2.18          | 0.0378      | 1.27        | 6.00        | 0.0000 |
| 31 | Synodontidae         | 3.36          | 0.0021      | 0.94        | 11.60       | 0.1580 |
| 32 | Tetraodontidae       | 4.03          | 0.0354      | 0.91        | 49.90       | 0.0000 |
| 33 | Terapontidae         | 3.19          | 0.0176      | 1.69        | 10.75       | 0.0000 |
| 34 | Triachantidae        | 2.90          | 0.0040      | 0.42        | 8.40        | 0.0000 |
| 35 | Trichiuridae         | 3.52          | 0.0166      | 2.66        | 8.70        | 0.7520 |
| 36 | Cephalopods          | 3.01          | 0.0257      | 4.87        | 36.50       | 0.7679 |
| 37 | Crabs                | 3.21          | 0.4933      | 6.42        | 8.50        | 0.4818 |
| 38 | Shrimps              | 2.80          | 0.2733      | 6.68        | 19.20       | 0.8263 |
| 39 | Benthos              | 2.00          | 405.5554    | 6.57        | 27.40       | 0.0108 |
| 40 | Zooplankton          | 2.00          | 0.0028      | 119.70      | 300.00      | 0.8008 |
3.2. Trophic flows
Values of tropical ecological groups in Tangerang coastal waters range from 1.0 for primary producers and detritus to 4.03 for the top predator, that is Tetraodontidae. The grey circle indicates the amount of biomass, in which benthos has the highest among other groups. Other biotas that still have high biomass include Leiognathidae, crabs, and shrimps (figure 2).

3.3. Niche overlap
Overlap index was summarized to prey overlap and predator overlap[39,40]. Prey overlap is an index comparing preys with similar predators, whereas predator overlap is the similarity of two predators in consuming the same prey. This index compares each pair of ecological groups and the value ranges from 0-1[41]. In figure 3, the rectangular shape is an example of an ecological group that has a prey overlap value close to 1; the triangle shape has a predator overlap value close to 1, and the circle shape is an example of a group having a prey and predator overlap value close to 1. Biotas with prey overlap close to 1 are between Clupeidae (6) and Engraulidae (9), and Nemipteridae (6) and shrimp (38), whereas the group with predator overlap close to 1 are between Mullidae (17) and Synodontidae (31), and Sciaenidae (24) and Trichiuridae (35). The groups with prey and predator overlap close to 1 have the same preys and predators, which are between Cynoglossidae (7) and Mullidae, and Engraulidae (9) and Scombridae (25).

Figure 2. The flow diagram shows trophic flows in Tangerang coastal waters. The grey circles show biomass.

3.4. Transfer efficiency
Transfer efficiency is a fraction expressing total flows from a trophic level to another trophic level [37]. Based on Ecopath software, the grouping of the trophic level is generally more than 4, commonly called Lindeman spine [42]. For the ecosystem of Tangerang coastal waters, it consists of 8 trophic levels, where Ecopath presents the flow of each trophic level (Figure 4). Based on Table 3, the transfer
rate efficiency for TL II is 0.3%. For TL III and IV, the transfer efficiency are 11.6% and 12.4%, respectively. The average transfer efficiency is relatively low, 9.43% for phytoplankton and 3.39% for detritus, and the total transfer efficiency in Tangerang coastal waters is 3.42%.

Figure 3. Niche overlap in Tangerang coastal waters.

Figure 4. Trophic flows transmitted between discrete trophic levels in Tangerang coastal waters. TST: total system throughput; TL: trophic level; TE: transfer efficiency. Units: ton/km²/year.
Table 3. Flow (ton/km²/year) and transfer efficiency (%) for each trophic level of Tangerang coastal waters.

| Transfer efficiency (%) by trophic level | Source | TL I | TL II | TL III | TL IV | TL V | TL VI | TL VII | TL VIII |
|-----------------------------------------|--------|------|-------|--------|-------|------|-------|--------|---------|
| Producer                                |        | 11.3 | 6.4   | 11.7   | 5.1   |      |       |        |         |
| Detritus                                |        | 0.3  | 11.9  | 12.5   | 1.4   | 7.5  |       |        |         |
| All flows                               |        | 0.3  | 11.6  | 12.4   | 1.5   | 7.4  | 4.3   | 2.4    |         |

Proportion of total flow originating from detritus: 0.73
Transfer efficiency (calculated as geometric mean for TL II-IV)
From Primary Producer: 9.43%
From Detritus: 3.39%
Total: 3.42%

3.5. Mixed Trophic Impact

In Tangerang coastal waters, phytoplankton and detritus have a positive impact on most other groups (figure 5). The impact of phytoplankton is the highest for some pelagic fish like Stromateidae, Sillaginidae, Siganidae, Serranidae, Scombridae, Scatophagidae, Menidae, Engraulidae, Clupeidae, Carangidae, and Apogonidae. Detritus has a positive impact on some groups like shrimps, benthos, Nemipteridae, Mugilidae, and Cynoglossidae. Leiognathidae have a negative impact on some groups and themselves, showing competition for the same food resources within and between the groups. Gears also negatively impact many groups. Trawl negatively impacts some of the economic groups such as Sphyraenidae, Serranidae, Psettodidae, Polynemidae, Platyccephalidae, Mullidae, Mugilidae, Lutjanidae, Caesionidae, and Ariidae. Therefore, increasing fishery activities in Tangerang coastal waters ecosystem would have a more influential negative impact on fish groups, particularly on the economic groups.

Through MTI analysis, the Ecopath model provides information related to key species. Ecological groups included in key species are the groups playing important roles in the ecosystem. The key species are represented by plot point approaching or greater than 0.43 (figure 6). The key species groups in Tangerang coastal waters are Leiognathidae, Sphyraenidae, Cephalopods, and Phytoplankton.

Figure 5. Mixed trophic impacts of the ecological groups of Tangerang coastal waters. Positive impacts are shown above the baseline in light columns, while negative impacts are shown below the baseline in dark columns.
3.6. Total System Statistics

Total system statistic of Tangerang coastal waters is shown in Table 4. Total system statistic consists of total system throughput, which is the sum of all existing flows in the system. The flows consist of consumption, exports, respiration and flows into detritus. Total system throughput estimated for Tangerang coastal waters is 34851 ton/km$^2$/year. The value of the mean trophic level of the catch for Tangerang coastal waters is 2.778 and its gross efficiency is 0.00001.

The maturity of the ecosystem is described by the value of primary production/respiration (P/R) ratio [44]. P/R ratio of Tangerang coastal waters is 1.505. The value of net system production (or yield) for this ecosystem is 3156.84 ton/km$^2$/year while the PP/B value for the present model is 22.825. The system biomass/throughput ratio is 0.012 ton/km$^2$/year. Finn’s cycling index and Finn’s mean path length are 24.85% and 3.702% respectively. Pedigree index for this model is 0.57. The current version of Ecopath model provides the Shannon diversity index, and the value of the diversity index in Tangerang coastal waters is 0.107.

Table 4. Total system statistic of Tangerang coastal waters (The language of the table below is genuinely from the software results).

| Parameter                     | Value     | Units    |
|-------------------------------|-----------|----------|
| Sum of all consumption        | 11164.510 | t/km$^2$/year |
| Sum of all exports            | 3157.473  | t/km$^2$/year |
| Sum of all respiratory flows  | 6256.581  | t/km$^2$/year |
| Sum of all flows into detritus| 14272.390 | t/km$^2$/year |
| Total system throughput       | 34850.960 | t/km$^2$/year |
| Sum of all production         | 12088.440 | t/km$^2$/year |
Mean trophic level of the catch 2.778
Gross efficiency (catch/net p.p.) 0.00001
Calculated total net primary production 9413.416 t/km²/year
Total primary production/total respiration 1.505
Net system production 3156.835 t/km²/year
Total primary production/total biomass 22.825
Total biomass/total throughput 0.012 t/km²/year
Total biomass (excluding detritus) 412.426 t/km²/year
Total catch 0.088 t/km²/year
Connectance Index 0.072
System Omnivory Index 0.15
Throughput cycled (including detritus) 8659.56 t/km²/year
Ascendancy 53.2
Overhead 46.8
Finn's cycling index 24.85 % of total throughput
Finn's mean path length 3.702
Ecopath pedigree index 0.57
Shannon diversity index 0.107

3.7. Model Comparison
The comparison of Ecopath model with other marine and coastal ecosystems as follows (table 5).

| Ecosystem                                      | TST   | TPP   | TPP/TR | GE    | NSP   | CI    | OI    | FCI   | FML  | PI   |
|------------------------------------------------|-------|-------|--------|-------|-------|-------|-------|-------|------|------|
| Laguna Alvarado, Mexico [45]                   | 2683  | 1291  | 1.30   | >0.001| 303.5 | 0.27  | 0.3   | -     | -    | -    |
| Karnataka Arabian Sea [19]                     | 11522.00 | 4095 | 1.283  | 0.0016| 904   | 0.382 | 0.299 | 6.03  | 2.81 | 0.52 |
| Northern Hangzhou Bay [46]                     | 19323 | 6785.80 | 2.56 | -     | 4139.15 | 0.31  | 0.35  | 25    | 2.174 | 0.61 |
| The Bay of Bengal [6]                          | 2628.00 | 1017.363 | 1.351 | 0.0015| 264.235 | 0.42 | 0.224 | 10    | 2.58 | -    |
| Jimo Coastal Ecosystem [43]                    | 5112.73 | 1993.60 | 3.78  | -     | 1466.05 | 0.40 | 0.36  | 4.92  | 2.57 | 0.48 |
| Tropical coastal estuarine ecosystem around Bight of Benin, Nigeria [2] | 34385.762 | - | 6.325  | -     | 12598.790 | 0.327 | 0.288 | 1.7   | 2.298 | 0.36 |
| Red Sea [47]                                   | 7335  | 2996  | 2.25   | 0.000085| 1665.03 | 0.31 | 0.24  | -     | -    | -    |
| Tangerang coastal waters(Present study)        | 34850.960 | 9413.416 | 1.505  | 0.00001 | 3156.835 | 0.072 | 0.15  | 24.85 | 3.702 | 0.57 |
3.8. Discussion

Leiognathidae have a high ecotrophic efficiency value. So, it must be predated by other groups because their abundance and biomass in Tangerang coastal waters are so high. Whereas, Ariidae, Carangidae, Scombridae, Trichiuridae, Cephalopods, and shrimps, in addition to being affected by predators, are also affected by fishing. According to Kepmen KP 45 [48], fish resources in coastal area around the Java Sea are overexploited. EE value of the detritus describes the incoming stream that becomes the detritus and that comes out of detritus. The EE value of detritus in Tangerang coastal waters is less than 1, indicating that a stream that becomes detritus is higher than the stream coming out (Table 2).

Many coastal biota groups in Tangerang coastal waters are found in 2≤TL<3 and 3≤TL<4 trophic level. Indriyati [16] stated that the more groups in the same trophic level mean that there is a competition in getting food sources. Biota having a trophic level of ≥4 is only one group, which is Tetraodontidae (Figure 2). Biotas that are predators or carnivorous fish such as Scombridae, Carangidae and Trichiuridae have low trophic level values, meaning that the food network in Tangerang coastal waters has a short food web. This indicates the low ecological efficiency of the ecosystem.

The low value of trophic levels is inseparable from anthropogenic activities and fishing activities in these ecosystems. High anthropogenic activities around Tangerang coastal waters cause a decline in water quality and affect biota in the ecosystem. It is indicated by the size of biota that tends to be small so that the biomass is also low. This contaminated condition can cause fish to experience environmental stress, which may cause the decrease in population. This becomes an indication of low fish biomass in Tangerang coastal waters. According to Zahid et al. [49], biological richness in an ecosystem reflects the health of the environment.

In addition to anthropogenic activities, other factors affecting trophic levels are fishing activities. Fishing activities can alter the abundance and spatial distribution of fish, especially piscivores or carnivores. This has an important impact on the interaction of species and trophic structures [50,51]. Loss of carnivorous fish has an impact on the entire ecosystem [52]. According to Pauly [53], the decline in the number of carnivorous or predatory fish in water indicates the occurrence of fishing down the food web. Fishing down the food web is a condition where predatory fish are depleted and fishing activities target small fish that have low trophic levels.

Overlap value close to one means higher level of similarity in food and predators, which includes similarity in consuming prey (predator overlap) and the similarity of predators (prey overlap). The similarity is influenced by habitat similarities, such as between Clupeidae and Engraulidae groups and between Engraulidae and Scombridae. which are pelagic fish, Nemipteridae and shrimps, and between Mullidae and Synodontidae, which are demersal biota. Sciaenidae fish which are demersal fish have predator overlap with Trichiuridae, which are pelagic fish. This can happen because Tangerang coastal waters are shallow waters. So, it becomes an indication of both groups in having the same food niches (Figure 3).

A group that becomes a prey has a positive impact on its predator, while a predatory group has a negative impact on its prey. Based on MTI analysis (Figure 7), phytoplankton and detritus have positive impacts on most groups. Phytoplankton affect most groups that are phytoplankton predators such as pelagic fish, whereas detritus has a positive impact on biota groups dominated by demersal biota. Leiognathidae have negative effects on phytoplankton and zooplankton because phytoplankton and zooplankton are part of their prey. Leiognathidae also negatively affect some biotas, even themselves, due to the existence of competition in getting food sources. Trawler fishing equipment negatively affects the biomass of several groups, especially economic biotas, due to the ongoing fishing activities that cause the stock of biota to decrease.
Based on Table 3, the transfer rate efficiency for TL II is 0.3%. This value is very low compared to the typical value for coastal areas, which is 15% [54], or ranging between 10-20% [55,56]. This result is similar to that of Ullah et al. [6] in Bay of Bengal which is 0.5% but different from Su [43]’s research in Jimo coastal ecosystem, which is 27.4%. The low transfer efficiency on TL II in Tangerang coastal waters is caused by the absence of predators and the high respiration flow of TL II as shown in Lindeman spine (Figure 3). The TL III and IV efficiency transfer is in the range of 10-20% for coastal zones [55,56]. These results are comparable to Su [43] in Jimo coastal ecosystem but it is different from Bay of Bengal which has higher transition efficiencies for trophic III and IV than the standard range due to high exports of fishery yields and the presence of major dominating fish groups with higher EE value around trophic level III [6].

Based on total system statistics of the Ecopath model (Table 4), Tangerang coastal waters have a high total system throughput value. This is consistent with tropical coastal ecosystems in general which tend to have high turnover rates [19]. The mean trophic level of catch in Tangerang coastal waters is low, indicated by the lack of predatory species on Tangerang coastal waters and the domination by species that have low tropical levels. This can be proved by the low biomass of predatory fish in Tangerang coastal waters. In addition, low energy efficiency value makes the food chain of Tangerang coastal waters short. According to Ullah et al. [6], mean trophic level of the catch describes the overall level of exploitation in the food web in an ecosystem and how it impacts predators and preys. The gross efficiency value in Tangerang coastal waters is only 0.00001. This is because, in general, the total catch in this ecosystem has a very small value, which is 0.088 ton/km²/year. Predatory fish have already been overfished. So, their biomass tends to be low.

The Ecopath model also presents several parameters related to ecosystem maturity described by Odum [44]. The first parameter is primary production/respiration (P/R) ratio system. A mature ecosystem has P/R value equal to 1 which means that there is an ecosystem balance between production and respiration (44). Research results in Tangerang coastal waters show a value of >1 which means that Tangerang coastal waters are immature ecosystem. According to Fetahi and Mengistou [34], this could be caused by the effect of human activities including fishing and the declining water quality due to pollution, water diversion, etc.

Net system production (or yield) is reduction in total primary production and total respiration. Net system production will be large for systems that are still in the process of maturation and close to zero for mature systems [19]. The net system production value of Tangerang coastal waters is 3156.835-ton km⁻²-year⁻¹ which indicates that the ecosystem is immature.

The ratio between primary production and biomass also reflects the maturity of the ecosystem. According to Ullah et al. [6], immature ecosystems tend to have greater production value than respiration. This causes the accumulation of biomass so that it impacts the PP/B value. The PP/B value for this model is 22.825. The next parameter that describes ecosystem maturity is the ratio of total biomass to total system throughput. According to Christensen [14], total biomass/total system throughput value is proportional to the maturity of the ecosystem, of which the value will be low in the ecosystem that is still undergoing the maturation process. For this model, the ratio of total biomass and total system throughput is 0.012 per year. This means that the total biomass existing in Tangerang coastal waters is smaller than the total system throughput.

Total biomass is the sum of all biomass including detritus 412.426 ton km⁻². This result is greater than that in the Arabian Sea, which is 136 ton km⁻² [19], in the Bay of Bengal 69.241 ton km⁻² (Ullah et al., 2012), and in Indian Vellar Estuary 250.397 ton km⁻² [57]. This is due to the high biomass of benthos obtained. According to Meilana [58], the content of organic materials such as high total organic carbon in the coast of Tangerang becomes an indication of the high biomass of benthos in the ecosystem.

System omnivory index is the average omnivory index of all consumers. This index measures the complexity of eating interactions distributed among trophic levels [19]. System omnivory index value in this study is 0.151. Overall, the majority of biota groups in Tangerang coastal waters are specialist in choosing food.
Finn’s cycling index (FCI) is the proportion of flow in a system that is recycled compared with total system throughput while Finn’s mean path length (FML) describes the average number of ecological groups flowing from entry to exit from the system (Xu et al., 2011). The low FCI and FML in this model mean that the proportion of matter recycled through the detrital pathway is still low. This signifies an immature ecosystem.

Ascendency is the key index that characterizes the rate of development and maturity of the system [59], while overhead describes the existing reserve energy in the system [60]. The relative values of ascendancy and overhead in Tangerang coastal waters are 53.2% and 46%. This ascendancy value is greater than that in the Bay of Bengal which is only 38.7%, but its overhead is smaller than BOB which reaches 61% [6]. Overall, these results indicate the level of maturity and stability of ecosystems. These results indicate that Tangerang coastal waters have energy reserves to be resistant or resilient to perturbations.

The output obtained from the Ecopath model in Tangerang coastal waters was compared with some other coastal and marine waters (Table 5). The total system throughput (TST) value of Tangerang coastal waters is the highest among other ecosystems; the second highest is the tropical coastal estuarine ecosystem around the Bight of Benin, Nigeria. The gross efficiency value of coastal Tangerang is the lowest among other ecosystems. TPP/TR value describes the maturity of the ecosystem. The TPP/TR value of Tangerang coastal waters is moderate compared to other ecosystems but exceeding 1 which means that it is an immature system. According to Su [43], this condition means that many nutrients are not used in the system. So, the ecosystem is said to be immature. This is related to the large number of nutrient inputs in Tangerang coastal waters derived from human activities as well as industry. Connectance index (CI) and omnivory index (OI) values show the internal state of ecosystem complexity. A mature ecosystem tends to have CI and OI values close to 1 [43]. The CI and OI of Tangerang coastal waters have moderate values compared to other ecosystems, but these values are still low. The low value of the omnivory index is due to the low diversity of feeding interactions within the ecosystem. Finn’s cycling index (FCI) and Finn’s mean path length (FML) also describe the maturity condition of an ecosystem. This is related to the proportion of nutrient materials or flow through the food chain. According to Christensen and Walters [61], high FCI value will be followed by high FML value. Tangerang coastal waters have the second highest FCI value after Northern Hangzhou Bay and its FML value is the highest among other ecosystems. This means that Tangerang coastal waters have higher and more energy as well as material flow compared to other ecosystems. The results of Ecopath model research in Tangerang coastal waters have a relatively high pedigree index value compared to other studies. Based on the data from Morisette et al. [62], 150 Ecopath research survey models in the world have pedigree index ranging 0.16-0.68. The pedigree index value of Ecopath model of Tangerang coastal waters is in the range of these values. This means that the data sources in this study are quite accurate and reliable. So, based on Christensen et al. (2000), this model is acceptable.

3.9. Management Recommendations

This Ecopath model can be used to evaluate the impacts of fishing and environmental changes. It can be employed as a management strategy which has been proven to be a useful tool for the development of policies for tropical fisheries catchment and multispecies fisheries management (Ullah et al., 2012). The management of Tangerang coastal waters should pay attention to the aspects of capture fisheries and coastal biology. Tangerang coastal waters have generally collapsed in terms of fishery resources. Predatory fish have been decreasing in number, biomass and size. This is due to the high catching activities that cause the existing biota to be overfished. Based on the trophic model obtained, fishery resources that can still be utilized and optimized include Leiognathidae, Nemipteridae fish, crabs and swimming crabs, and shrimp, especially Leiognathidae fish which are very abundant in nature and their utilization is not optimal. Based on the information by fishermen, Leiognathidae are only used for duck feed. These fish have low economic value because the price is only around Rp. 2000. Actually, the fish can be processed into various processed foods that have high economic value.
In addition, Tangerang coastal waters are still classified as an ecosystem that is still at development stage. So, it is more vulnerable to disturbance, both by natural and anthropogenic activities. The pollutants from various industries and garbage along the coast can impact on the existing biota. Biota will experience environmental stresses so that more energy is used to adapt to environmental conditions than for growth. Therefore, it is necessary to monitor and evaluate pollutants entering the waters. Further, related institutions need to regulate/manage industrial waste and garbage that have been causing pollution in the ecosystem.

4. Conclusion
This model is able to describe trophic interaction, energy flows and ecosystem conditions that have been affected by fishing and anthropogenic activities. This model has an important role related to the availability of ecological data on Tangerang coastal waters ecosystem. It also serves as a basis for new data which can subsequently be used to develop models, especially Ecosim, Ecospace, and Ecotracer models. The research on Tangerang coastal waters ecosystem is expected to contribute to the policy making by the stakeholders.

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