Study of Ecosystems Condition in Karimun Jawa And Its Effect On Growth Rate Prediction Of Barramundi (Lates Calcarifer) Based On Average Temperature In 2010 – 2017

Avrionesti¹ and Mutiara Rachmat Putri²
¹ Marine Technology Cooperation Research Center (MTCRC), Cirebon, Indonesia
² Oceanography Research Group, Institut Teknologi Bandung, Bandung, Indonesia

E-mail: avrionesti@mterc.center

Abstract. Barramundi (Lates calcarifer) is one of main catches fish in the demersal category. Ecosystem condition is assessed to predict the growth rate of Barramundi. Therefore, the ecosystem condition is being modeled, includes nutrient, phytoplankton, zooplankton, and detritus (NPZD) and their interaction with Barramundi. The result shows that the growth rate of Barramundi is 4.07 gram/day with the fastest growth rate (latest) occurs if the seed is stocked in August (November) with growth rate 5.11 gram/day (3.1 gram/day). The slow growth rate of seeds stocked in November occurred because of crustaceans as the main diet of Barramundi in the early phase of the hatchery has a low abundance.

Keywords: NPZD, Barramundi, growth rate, and Fish interaction model

1. Introduction

1.1. Background

Barramundi or white snapper or asian seabass (Lates calcarifer) life throughout the Indo-Pacific region. Barramundi could live in a high salinity range, between 0 - 40 psu and temperatures between 20 - 33°C, it makes barramundi is relatively easy to adjust to the environment. In Indonesia Barramundi is one of the main catch fish for the demersal category. Based on fisheries statistics from the Ministry of Maritime Affairs and Fisheries, during 2004 - 2014 the number of Barramundi catches reached 7.76% in the national demersal fish category (+ 84,502.3 tons/yr). In terms of production, Barramundi production value reach 1.531 trillion rupiah per year [1]. This shows that Barramundi fish is one of the main catch fish and has a role in the national economy. At present, the Ministry of Maritime Affairs and Fisheries has planned the construction of offshore fish cages, one of which will be built in Karimun Jawa, Jepara, Central Java Province. The ecosystem condition needs to be assessed to predict the productivity of the cultivation by looking at the growth rate of Barramundi. Ecosystem modeling will be carried out which includes calculation of nutrients, phytoplankton, zooplankton, and detritus (NPZD).

Figure 1. Barramundi (Lates calcarifer) [2]
1.2. Aim and Research scope

The purpose of this study was to examine the effect of ecosystems condition on the growth prediction of Barramundi in planned offshore cage in Karimun Jawa waters. The study area is in the Karimun Jawa, Central Java. Selection of the study area on the plan for developing offshore fish cages by the Ministry of Maritime Affairs and Fisheries. The study period is 8 years, 2010-2017 and we use a 1-dimensional model ecosystem model from Fennel and Neumann, 2015 [3]. The bathymetry map of Karimun Jawa can be seen in Figure 2 obtained from GEBCO Digital Atlas [4]. It is assumed that there is no cannibalistic behavior between Barramundi in cages.

![Figure 2. Karimun Jawa Waters Map [4]](image)

2. Data and Method

2.1 Data

Input for the ecosystem model is daily temperature and nutrients data. In the ecosystem model built by Fennel and Neumann [3], they use are nitrate as nutrient. Daily temperature data obtained from Aqua MODIS satellite (coastwatch.pfeg.noaa.gov/erddap/index.html)[5]. Monthly nitrate data obtained from WOA 2013 (nodc.noaa.gov/OC5/woa13/woa13data.html) [6]. Daily nutrient values are assumed to be the same for one month. Other data used is chlorophyll-a data to verify model results of phytoplankton abundance. Daily chlorophyll data was obtained from Aqua MODIS[5].

2.2 Ecosystem Model

In this study, we modified an ecosystem model developed by Fennel and Neumann [3]. The ecosystem model takes two-way interactions between NPZD (Nutrient, Phytoplankton, Zooplankton, Detritus) and zooplanktontivor which divided into three levels of the food chain, crustaceans at the lowest level, teleost at the second level, and Barramundi as the highest predators in the food chain. In this ecosystem model, NPZD values are integrated from depths of 0 to 50 meters. The equation used is expressed in Equations (1) to (6) below:
\[
\frac{dN}{dt} = -M(N)P + l_{PN}P + l_{DN}D + l_{ZN}Z + Q_{\text{import}}^N + L_{PN} \tag{1}
\]
\[
\frac{dP}{dt} = M(N,t)P - l_{PN}P - g(P)Z - l_{PP}P \tag{2}
\]
\[
\frac{dZ}{dt} = g(P)Z - (l_{2D} + l_{ZN})Z - G_F \tag{3}
\]
\[
\frac{dD}{dt} = l_{2D}Z + l_{PP}P - (l_{DN} + l_{DD_{sed}})D + L_{FD} \tag{4}
\]
\[
\frac{dD_{sed}}{dt} = l_{DD_{sed}}D \tag{5}
\]
\[
M(N) = \frac{rN^2}{\alpha^2 + N^2} \tag{6}
\]

\(M(N)\) term is a Michaelis-Menten formula which states nutrient uptake. The effect of solar irradiation time represented by \(r\), while the terms \(G(P,t)\) in equations (2) and (3) express the zooplankton grazing rate. For cage simulations, the reproduction time is modified to the desired seeding time. The interactions used in equations (1) to (6) can be summarized by the scheme in Figure 3(a).

![Ecosystem Model Interaction Scheme](image1)

![Food Chain Schemes in Ecosystem Models](image2)

**Figure 3.** (a) Ecosystem Model Interaction Scheme (b) Food Chain Schemes in Ecosystem Models

Consumption by zooplanktontivor is denoted by \(G_F\). Zooplanktontivor in this model consists of crustaceans, teleost, and the five lowest classes of the barramundi (description of each zooplanktontivor class can be seen in
Table 2). The zooplanktontivor mass concentration depends on the rate of consumption of food-limited $g_i^Z(Z)$, where $x$ is biota and $i$ is referred biota class. The conversion factor, $f_{con}$, is used to transform the concentration of biomass in g/km$^3$ into a carbon unit, mmolC m$^{-3}$. The combination of the fish model and NPZD model $L_{FN}$. The recycle process of fish into detritus, $L_{FD}$, is a function of the excretion rate, $L_{ex}$, and mortality, $\mu_{ex}$. The food chain scheme and also the description of zooplanktontivor biota classes can be seen in Figure 3 and Table 1.

$$G_F = f_{con} \left[ \sum_{i=1}^{6} g_i^{kj}(Z)B_i^{te} + \sum_{i=1}^{7} g_i^{kr}(Z)B_i^{kr} + \sum_{i=1}^{7} g_i^{kp}(Z)B_i^{kp} \right]$$  \hspace{1cm} (7)

$$L_{FN} = f_{con} \left[ \sum_{i=1}^{6} L_{KR,N}B_i^{kr} + \sum_{i=1}^{7} L_{TEL,N}B_i^{te} + \sum_{i=1}^{7} L_{KP,N}B_i^{kp} \right]$$  \hspace{1cm} (8)

$$L_{FD} = f_{con} \left[ \sum_{i=1}^{6} (L_{KR,D} + \mu_{KR})B_i^{kr} + \sum_{i=1}^{7} (L_{TEL,D} + \mu_{TEL})B_i^{te} + \sum_{i=1}^{7} (L_{KP,D} + \mu_{KP})B_i^{kp} \right]$$  \hspace{1cm} (9)

2.3 Ecosystem Model

Daily growth rate (DGR) of barramundi fish is calculated using equation (10) [3]. Daily growth of fish depends on the grazing rate and loss rate. The grazing rate and loss depend on the optimum amount of diet that can be eaten by individuals (zooplankton limitation factor), sea temperature, and variations in annual grazing that are related to variations in the abundance of food supplies.

$$g_{\text{eff}} = g - L_N - L_D$$  \hspace{1cm} (10)

$$g = g^{max}G(Z)A(T)Q(t)$$  \hspace{1cm} (11)

$$L_N = 0.0625[g + 0.5A(T)Q(t)g^{max}]$$  \hspace{1cm} (12)

$$L_D = 0.0625g$$  \hspace{1cm} (13)

$$G(Z) = [1 - \exp(-L_Z)]$$  \hspace{1cm} (14)

$$A(T) = \theta(T_{ref} - T) \exp(aT) + \theta(T - T_{ref}) \exp(bT - cT^2)$$  \hspace{1cm} (15)

$$Q(t) = [\theta(t - d_o) - \theta(t - d_{365})] \frac{0.9}{d_{320}} (t - d_o)$$  \hspace{1cm} (16)

The density of the biota at the beginning of growth model simulation can be seen in Appendix 1 (Table 3). In order to approach the fish cage conditions, it is assumed that the barramundi at the beginning of the simulation is only the juvenile (class1 to 3). Whereas the concentration of adult snapper (class 4 to 7) is considered zero.

2.4 Simulation

The ecosystem model in this study calculate two-way interaction between NPZD and zooplanktivor with the assumption that the ecosystem is in a basin with a depth of 50 meters. This assumption is suitable with the Karimun Jawa water which has an average depth of 50 meters. This ecosystem model simulation was conducted from 2008 to 2017 with warming up for 1.5 years at the beginning of the simulation.

The effect of ecosystems on fish growth is examined in several scenarios. Simulations with input monthly temperature that have been averaged over 10 years are conducted to see how the general condition of the ecosystem influences the growth of the barramundi.

| Scenario | Zooplanktontivor | Temperature     |
|----------|-----------------|-----------------|
| 1        | No              | 2008-2017 monthly |
| 2        | Yes             | Average         |
3. Result

3.1 Condition of Karimun Java Waters Ecosystem Data

Verification of Chlorophyll-a with phytoplankton from the results of 1D ecosystem model simulation carried out in the form of anomaly values (Figure 4). Based on the verification results there is a 1-month gap, where the simulation results are slower than Aqua MODIS data. The chlorophyll concentration from simulation results have the range between 0.49 to 0.55 mmolN/m³, while the data from Aqua MODIS has values between 0.13 to 0.6 mmolN/m³. The correlation pattern between the two is 38.53% with RMSE 0.09 if the phase between the two is equalized. The maximum peak phytoplankton abundance based on data from Aqua MODIS occurs alternately between June or July. But on average, peak abundance occurred in June with a value of 3.28 mmolC/m³ and a minimum in November with an average value and 1.14 mmolC/m³.

![Figure 4](image.png)

Figure 4. Phytoplankton concentration anomaly between model results and Aqua MODIS [5]

To find out the condition during normal conditions, a simulation is performed with scenario 1. In conditions without zooplanktonivores, nutrient and phytoplankton concentrations tend to be constant in the range of 3.01 mmolC/m³ and 3.41 mmolC/m³ with seasonal fluctuations. The maximum value occurs in August and decrease at the end of the year. Unlike nutrients and phytoplankton, the concentration of detritus and zooplankton continues to increase. At the beginning of 2010, detritus concentration was valued at 15.95 mmolC/m³ and at the end of 2017 it was at 26.15 mmolC/m³. While the zooplankton concentration in early 2010 was mmolC/m³ and at the end of 2017 it was mmolC/m³. Increased zooplankton concentrations occur due to the absence of predators. Detritus and Zooplankton become steady in 2016 (Figure 5). In more detail, steady conditions can be seen in Figure 6.

![Figure 5](image.png)

Figure 5. Nutrient, Phytoplankton, Zooplankton, and Detritus Concentrations Based on Scenario 1
Scenario 2 is made to see the condition of the ecosystem with the offshore fish cages (Figure 7). In this scenario, the presence of zooplanktivor is included in the calculation. Unlike the previous scenario, all components of the NPZD experience seasonal fluctuations. The pattern of monthly concentrations of nutrients, zooplankton, and detritus have low value at the beginning of the year, reaching a maximum value in the middle of the year, then decrease at the end of the year. Phytoplankton have a low concentration pattern at the beginning of the year and reach a peak at the end of the year. This relates to two-way interactions between NPZD and zooplanktivors. In Figure 7 we can also see that zooplanktivor in general continues to increase. This happens because in this simulation, the harvested zooplanktivor is only barramundi while teleost and crustaceans are not harvested and will die naturally if experiencing hunger. However it can be seen that in the last 2 years and zooplanktivor concentration NPZD stabilized.

**Figure 6.** Concentrations of (a) Nutrients and Phytoplankton and (b) Zooplankton and Detritus in 2016 (steady state) Based on Scenario 1

**Figure 7.** Zooplanktivor and NPZD Concentration
Figure 8. Concentrations of Zooplanktontivvor, in 2016 (steady state) Based on Scenario 2

Figure 8 and 9 is a graph of zooplanktivvor and concentrations in steady state. The addition of zooplanktivvor into the ecosystem shifts the peak phytoplankton concentration, which originally occurred in August (Figure 5) to December-January. Compared to scenario 1, zooplankton and detritus concentrations in scenario 2 have lower values and their peak abundance also shift. The existence of zooplanktivvor changes ecosystem balance leads to ecosystem components adjustments.

Figure 9. Concentrations of (a) Nutrients and Phytoplankton and (b) Zooplankton and Detritus in 2016 (steady state) Based on Scenario 2

3.2 Fish Growth at Average Temperature

Growth of barramundi in the nursery phase (classes 1 to 3) according to scenario 2 has an average duration of 3 months. Growth of the class 4 to 7 fish who stocked in 2016 can be seen in Figure 10 and Figure 11. The fastest growth conditions are presented in Figure 10 and the slowest growth is presented in Figure 11 with each color on the graph showing different mass classes. When stocking seeds due in August, class 4 barramundi only takes 1 month to increase its body mass to 200 grams. Whereas in stocking seeds in November, class 4 snapper takes 3 months to increase its body mass to 200 grams.
Scenario 2 results show that the growth rate of the barramundi since it has been stocked (100 gr) until it is ready to harvest (800 gr) varies depending on the time of seeding. The average growth rate of the barramundi is 4.07 gr/day with the fastest rate occurring if stocking is done in August (5.11 gr/day). Whereas the slowest growth rate occurs when stocking is done in November (3.1 g/day).

The difference occurred due to variations in the availability of barramundi diet in the study area. Based on the simulation results we known that the concentration of crustaceans is higher than other diets, zooplankton and teleost (Figure 12). The newly stocked barramundi have main diet zooplankton and crustaceans. After reaching the weight of 400 gr, barramundi began eating teleost and leaving the zooplankton diet. Based on the description, the seeds which are stocked in August will grow along with the increasing concentration of diet. Whereas the seeds which are stocked in November, although at the beginning of the hatchery get abundant diet supply, but will experience a reduction in diet supply entering the weight of 400 gr which began in February.
4. Conclusion

Based on the results in the previous chapter, some conclusions can be drawn as:

1. Verification of the phytoplankton model with Aqua MODIS satellite data revealed one-month phase gap and a similarity pattern of 38.53%. The RMSE value between the two is 0.09.

2. The abiotic component of the ecosystem, such as temperature, has an indirect effect on the growth rate of the barramundi. While the biotic component, such as the availability of barramundi’s diet in the form of zooplankton, crustaceans, and teleost has a direct influence on the growth rate.

3. Seasonal variations of the Java Karimun waters ecosystem cause seasonal variations in the abundance of barramundi’s diet and affect the growth rate of the fish. The fastest growth rate of barramundi occurs when stocking held in August (5.11gr/day) and the slowest if stocking held in November (3.1gr/day). The average value of the growth rate of barramundi is 4.07 gr/day.
Appendix

Table 2. Description Class of Crustacea, Teleost, and Barramundi [3][7]

| Class | Weight (gr) | Barramundi | Teleost | Crustacea |
|-------|-------------|------------|---------|-----------|
| 1     | 2 ≤ weight < 10 | 2 ≤ weight < 7 | 1 ≤ weight < 5 |
| 2     | 10 ≤ weight < 35 | 7 ≤ weight < 10 | 5 ≤ weight < 7 |
| 3     | 35 ≤ weight < 100 | 10 ≤ weight < 30 | 7 ≤ weight < 15 |
| 4     | 100 ≤ weight < 200 | 30 ≤ weight < 60 | 15 ≤ weight < 20 |
| 5     | 200 ≤ weight < 400 | 60 ≤ weight < 150 | 20 ≤ weight < 35 |
| 6     | 400 ≤ weight < 800 | 150 ≤ weight < 240 |           |
| 7     | 800 ≤ weight < 1500 |           |         |           |

Table 3. Biota Density Description at Initial Condition [3]

| Class | Density (individu/km²) | Barramundi | Teleost | Crustacea |
|-------|-------------------------|------------|---------|-----------|
| 1     | 0,0008121               | 0,007367   | 0,007513 |
| 2     | 152,9089                | 0,00697    | 0,009189 |
| 3     | 22786,61                | 0,008675   | 6801206  |
| 4     | 0                       | 473117,7   | 0,009525 |
| 5     | 0                       | 615210,3   | 16927881 |
| 6     | 0                       | 1390200    |           |
| 7     | 0                       |           |         |           |

References

[1] Directorate General of Capture Fisheries, 2015
[2] Humphrey C., S. C. King, dan D. Klumpp, 2007. The use of biomarkers in barramundi (Lates calcarifer) to monitor contaminants in estuaries of Tropical North Queensland. Australian Institute of Marine Science
[3] Fennel W, dan T. Neumann. 2015. Introduction to the Modelling of Marine Ecosystem: Second Edition. Elsevier. ISBN: 978-0-444-63363-7
[4] IOC, IHO, dan BODC, 2003. Centenary Edition of the GEBCO Digital Atlas, published on CDROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization as part of the General Bathymetric Chart of the Oceans; British Oceanographic Data Centre, Liverpool.
[5] NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group, 2014. doi.org/10.5067/ORBVIEW-2/SEAWIFS_OC.2014.0.

[6] García, H. E., R. A. Locarnini, T. P. Boyer, J. I. Antonov, O. K. Baranova, M. M. Zweng, J. R. Reagan, D. R. Johnson, 2014. World Ocean Atlas 2013, Volume 4: Dissolve Inorganic Nutrients (phosphate, nitrate, silicate). S. Levitus, Ed., A. Mishonov Technical Ed.; NOAA Atlas NESDIS 76, 25 pp.

[7] Badrudin, B. Slamet, T. Keast, Dikrurahman, K. B. Kurniawan, S. Mulyono, Sarwono, Setiawan, R. S. Purwana, dan K. Widiada, 2015. Better Management Practices, Seri Panduan Perikanan Skala Kecil Budidaya Ikan Kakap Putih (Lates calcarifer, Bloch., 1790) di Karamba Jaring Apung dan Tambak: Edisi 1 Maret 2015, ISBN 978-979-1461-71-9. Tim Perikanan WWF-Indonesia.