The management of marine protected area of Raja Ampat Regency, West Papua Province through bioeconomic model approach

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Abstract. Raja Ampat Regency in West Papua Province, Republic of Indonesia has abundant natural fishery resources. Marine Protected Area (MPA) has been established in marine areas of Raja Ampat Regency. To manage MPA better, measureable parameters and clear indicators are required. The decision on the indicators can be conducted by bioeconomic model approach. The results of research show that the establishment of MPA will increase harvest level and revenue. But “bigger is better” could not be adopted for the development of MPA. The optimal MPA size will contribute to increasing yields and revenue and can reduce the level of effort.

Keywords: bioeconomic, MPA, Raja Ampat

1. Introduction

Raja Ampat Regency is a maritime regency with around 85% of marine waters and 80% of its people work as fishermen. Marine Protected Area (MPA) development has long been carried out and consists of Regional Marine Conservation Areas (RMCA) and Marine Wildlife Reserves (MWR), which cover more than 1 million Ha [1,2]. In accordance with Government Regulation No. 60 of 2007 concerning Fish Resource Conservation, the MPA is a protected marine waters area, managed by a zoning system, to achieve sustainable management of fish resources and the environment. But as an instrument to ensure sustainable fisheries, the Raja Ampat Regency MPA needs to be managed appropriately so that it is beneficial to the welfare of the community.

Raja Ampat Regency Marine Protected Area, with its ecosystem condition dominated by natural small island groups, requires measurable management efforts with clear indicators. Such approach needs to take into account various variables. These variables are not simple variables, rather the very complex ones. This complexity can be approached by bioeconomic modelling that simplifies such complex variables. The focus of the analysis in this study was on capture fisheries targeting reef fish or demersal fish. This research, with the bioeconomic modelling approach, was carried out to analyze the performance of the fisheries baseline in the MPA scenario. Performance indicators were
measured through the calculation of inputs and outputs, as well as optimal economic benefits with the existence of MPAs.

2. Materials and Methods

2.1 Research time
The research was carried out from September 2008 to September 2009. The research was carried out in the small islands cluster which was used as the basis for Raja Ampat MPA development as shown in figure 1.

![Figure 1. Boxes of Pink Color, the Area of Raja Ampat MPAs, in West Papua Province, Republic of Indonesia, source: https://indopacificimages.com/indonesia/diving-indonesia-the-marine-protected-areas-mpas-of-raja-ampat/](image)

The MPA Raja Ampat sites were selected because the area is fairly extensive and considered as newly established, i.e. on 12 May 2007 [2]. The development of the Raja Ampat Regency MPA is at its early stage, so its management plan and other management tools are not yet available. Besides, the condition of marine and fisheries resources is still good, with relatively high biodiversity. The Raja Ampat Regency MPA represents a system for MPAs development under the guidance of the Ministry of Marine Affairs and Fisheries, whose main purpose is to ensure sustainable fisheries management.

2.2 Data collection method
This research was limited only to bioeconomic analysis concerning fisheries resources and the interaction between capture fisheries and MPAs. The study covered 6 (six) villages in the South Waigeo District, namely in Yanbekwan Village, Sawingrai Village, Yen Buba Village, Kapisawur Village, Saporkren Village, and Saonek Village. Secondary data on fisheries focus on reef fish or demersal fish landed by boat at the Sorong Fishing Port.
Data collection was carried out with purposive sampling approach. Interviews were carried out for respondents consisting of fishermen, community leaders, fisheries business managers, tourism managers, MPA managers, local governments and tourists. The primary data include:

1) Operational costs for fishing, consisting of the cost of fuel oil (diesel), oil, ice blocks/packs, consumption costs (food and other expenses) during fishing and also bait to use fishing;
2) Maintenance cost of fishing vessels;
3) Fish price data and income per trip;
4) Perception of respondents (fishermen, MPA managers, community leaders and local governments) on the existence of MPAs at the research location;
5) Aquaculture, marine tourism, utilization of coral reefs, mangroves and seagrass; and
6) Social, economic and cultural conditions of the community in the research location.

The secondary data included time series data on landings of reef fish and inputs used (effort), price per unit output (fish price per kg per period), consumer price index (consumer price index) and other supporting data. These secondary data were obtained from the service/agency/institution research related to fisheries management and research at the research location. The service/agency/institution were the Bureau of Statistics Service, Marine and Fisheries Office, the Environmental Service, the Forestry Service, Local Agency for Development and Planning, Fishing Ports, Fish Auction Centers, local and central NGOs, and other related institutions.

2.3 Data analysis methods
Economic analysis of MPA areas can be performed with a bioeconomic approach by using a logistic fish growth function model. This approach was adopted for reef fish/demersal capture fisheries, assuming the biomass growth function in the conservation area followed the logistic function [3, 4]:

$$\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right)$$

(1)

Where $r =$ intrinsic growth rate;
$x =$ biomass;
$K =$ carrying capacity.

The capture function is assumed to be Cobb-Douglass:

$$h = qxE$$

(2)

Where $h =$ capture production;
$q =$ ability to capture;
$E =$ efforts

So, in the conditions applied by the MPA, the capture function will change into:

$$h = (1 - \gamma)qxE$$

(3)

where $\gamma =$ percentage of MPA area.

With the equation (3), the stock dynamics in equation (1) will change into:

$$\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right) - (1 - \gamma)qxE$$

(4)
Assuming the conditions in equilibrium, the solution of equation (4) will produce variable \( x \) as a function of biophysical and variable parameters \( E \). The results of this solution if substituted in equation (3) will produce the yield effort equation that contains the MPA parameters, as follows [3, 4]:

\[
q E K \left( 1 - \frac{(1 - \gamma)}{r} q E \right) = (5)
\]

Meanwhile, the economic rent generated from the arrests in the above sustainable conditions is:

\[
p = p q E K \left( 1 - \frac{(1 - \gamma)}{r} q E \right) - c E = (6)
\]

Where \( p \) = fish price per kg;
\( c \) = cost per unit effort (effort).

To find out the optimal level of effort, the above rent is derived from the following efforts:

\[
E^* = \frac{\partial \pi}{\partial E} = p q K - 2 p q K \left( \frac{(1 - \gamma)}{r} q \right) E - c = 0 \quad (7)
\]

so, it is produced:

\[
E^* = \frac{\left( p q K - c \right) r}{2 p q K \left( 1 - \gamma \right)} \quad (8)
\]

The MPA bioeconomic model is carried out in several MPA size scenarios, namely 10%, 20%, 30%, 40%, 50%, and 60% relative to the total area of fishing. In this model, economic parameters which are price and cost are assumed to be constant, while the demand function is assumed to be perfectly inelastic.

3. Results and Discussion

Spill-over effect in protected areas is expected, that excessive fish stocks in the protected areas will flow outside where fishers can utilize it in a sustainable way without reducing the growth capacity inside the protected areas [3]. The establishment of the MPAs is expected to promote sustainability of fisheries resources in Raja Ampat (Government Regulation No. 60 of 2007 concerning Fish Resource Conservation).

Management of reef fish resources as demersal fish in conditions with MPAs, with an MPA area of 0.1 (10%) relative to the total area of fishing resulted in the effort amount of 38.07 trips per week. Then the amount of catch obtained was 6.3 tons per week, with resource rent as much as Rp36.52 million rupiah per week. Compared to 0.2 MPA area (20%), it was known that the effort was 36.84 trips per week and the rent value obtained was smaller, that was Rp30.39 million rupiah per week. Likewise, with an MPA area up to 0.6 (60%), the amount of effort decreased to 25.77 trips per week, with a rent of Rp7.39 million rupiah per week. Table 1 shows result of bioeconomic.
Table 1. Results of bioeconomic analysis without MPAs and with deep MPAs management of reef fish resources or demersal in Raja Ampat Regency.

| \( \sigma \) Area of MPA (simulation to area of MPA from total areas in \%) | \( h \) without MPA (ton per week) | \( h \) MPA (ton per week) | \( E \) without MPA (trip per week) | \( E \) MPA (trip per week) | \( \pi \) without MPA (million rupiah per week) | \( \pi \) MPA (million rupiah per week) |
|---|---|---|---|---|---|---|
| 10 | 3.50 | 6.30 | 52.43 | 38.07 | 8.03 | 36.52 |
| 20 | 3.50 | 6.23 | 52.43 | 36.84 | 8.03 | 30.39 |
| 30 | 3.50 | 6.12 | 52.43 | 35.26 | 8.03 | 24.34 |
| 40 | 3.50 | 5.95 | 52.43 | 33.15 | 8.03 | 18.43 |
| 50 | 3.50 | 5.68 | 52.43 | 30.20 | 8.03 | 12.72 |
| 60 | 3.50 | 5.17 | 52.43 | 25.77 | 8.03 | 7.39 |

Source: processed data

Level of fishing effort in the MPA area of 0.1 (10\%) was much higher than the area of 0.2 (20\%) which was 38.07 trips per week, while for the area of 0.2 (20\%) as much as 36.84 trips per week. At a high level of effort, it will also cause high production, which in turn will have implications for the high rent received by fishermen. In table 1 above, it can be seen that the rent continues to decrease along with the decrease in production levels and the amount of effort, even though the area of MPA continues to increase. Then figure 2, figure 3 and figure 4 show a comparison between the actual production, actual effort, and rent in the management of reef fish as demersal fish with the influence of MPAs in Raja Ampat Regency.

![Production Development (h) Without MPAs (actual) and With MPAs, with an MPA Area of 10-60\% of the Total Capture Fisheries Area, h Actual; h MPA.](image)

MPAs have provided meaningful benefits, in the form of increased fisheries production by 59.22\% of fisheries production before the existence of MPAs (figure 2). MPAs has increased abundance by 2 (two) times, while fish biomass and biodiversity have increased 3 (three) times [3]. This increase in abundance and biomass also results in an increase in fisheries production (number of catches and catch ratio per unit effort or CPUE). There is a strong evidence that protecting the area from fishing could increase the amount, size and biomass of this type of fisheries resources exploited. MPAs are
often said to only applicable to coral reef ecosystems. But in reality, this method has been successfully applied to various ecosystems in the marine environment, from tropical and sub-tropical conditions. MPAs can be said to be a sustainable global fisheries resources management tool [5].

The actual level of production with the existence of MPAs was greater than the actual production without MPAs (figure 2). However, the actual production with the existence of MPAs continued to decline along with the increase of size of the MPA area. This condition was influenced by the reduced number of fishing gear, which at the same time decreasing fishing effort. Thus, the wider area of the MPA will result in a decrease in actual production.

Figure 3 shows the comparison between actual efforts with MPAs, with actual effort without MPAs. Actual efficiency with MPAs was under actual effort without MPAs. Then the actual effort with the MPA tends to decrease along with the increase in MPA area. The wider the MPA area will cause a decrease in effort in the region with MPAs. However, it was different from the actual effort without the MPA, that the actual effort without the MPA tends to be stable even though there was an increase in MPA area, meaning that it had not experienced a significant decrease or increase. This condition, if not controlled, will cause degradation of reef fish resources as demersal fish in the waters of Raja Ampat Regency. Therefore, the role of the MPA is very important as a control of effort, so fisheries resources degradation can be controlled. It is clear that the development of effort can be seen in figure 3 which shows that, with the existence of MPAs there is a significant reduction in effort, from the conditions before the existence of the MPA.

The highest level of the actual effort was is in the area of 0.1 (10%) which is at the level of effort of 38.07 trips per week. Figure 3 shows that the actual effort with MPAs shows a downward trend to a level of 25.77 trips per week. Whereas rent earned with MPAs tends to decrease along with the increase in MPA area (figure 4). With an MPA area of 0.1 (10%), a rent of Rp36.52 million rupiah per week was earned, while with an MPA area of 0.2 (20%), the rent decreased to Rp30.39 million rupiah per week. Rent with the existence of MPAs continued to decline, due to the decreasing production and effort. Thus, the wider the MPA area, the smaller the rent obtained.
In figure 4 above, it can also be seen that the rent obtained without MPA tends not to be affected by the addition of the MPA area. If the area was increased to 0.6 (60%), then the rent obtained with the MPA would be much smaller than the rent obtained without the MPA. The relationship between the extent of MPAs and the economic benefits obtained can be seen in figure 4. This shows that, increasing the extent of MPAs in Raja Ampat Regency would increase economic benefits in certain ranges. In this case, the increase in MPA area below 0.6 (60%) can still increase economic benefits, which was still above the actual economic benefits without MPAs. But beyond this range, the wider the MPA will result in smaller economic benefits obtained, or under the actual economic benefits without MPAs (figure 4). This is in line with the predictions put forward by [6], referred to in [3], regarding the relationship between the extent of MPAs and economic benefits in the form of concave (convex). In addition, the results of the study also prove that “bigger is better” in the case of MPAs does not apply to all cases of MPAs.

Then similarly conveyed by [7], that MPAs on a certain broad scale can be used as effective fisheries management tools, rather than traditional quota systems. Reef fish gather in certain places to spawn. The existence of MPAs can help protecting these spawning sites, which are very vulnerable to fishing activities, both traditional and commercial. The existence of MPAs in important spawning sites can be used as a basis for determining the location of MPAs. In large and large multipurpose MPA areas, spawning sites can be determined as restricted areas for capture [8].

The results of analytic solutions using the MAPLE 11 program obtained curves from various coral fish or demersal fish management regimes with boat fishing fleet units. Figure 5 to figure 9 show that the KKL yield curve increased significantly. This was due to the increase in fish abundance and biomass.
Figure 5. Yield-effort Curve and Total Revenue With MPA Area (σ = 10%).

Figure 6. Yield-effort Curve and Total Revenue With MPA Area (σ = 20%).

Figure 7. Yield-effort Curve and Total Revenue With MPA Area (σ = 30%).
Figure 8. Yield-effort Curve and Total Revenue With MPA Area ($\sigma = 40\%$).

Figure 9. Yield-effort Curve and Total Revenue With MPA Area ($\sigma = 50\%$).

Figure 5 through figure 9 show that with an MPA area of 0.1 (10\%) to 0.5 (50\%) of the total fishing area, effort without MPA is lower than the effort with an MPA, or effort without the MPA is under the effort with MPAs. This shows that changes in MPA area greatly affect productions and effort, as well as the effects on economic rent generated.

The optimal area for MPAs was between 15-25\% (from fishing grounds), if the intensity of fisheries in the surrounding area did not exceed 40\% of the total exploitable biomass [9]. MPAs have a potential role in promoting successful fisheries management in coral reef areas and other related ecosystems.

4. Conclusions and Suggestions

The results of the study show that the establishment of MPAs in capture fisheries areas could produce sustainable economic benefits by reducing effort and resulting in sustainable yield from spill-over effect. Changes in the area of MPAs under baseline conditions only had little influence on effort and production, but had a considerable influence on the economic rent generated. The bioeconomic
model can be used as an instrument to produce measurable MPA management indicators that can be used as reference points in controlling input and output in capture fisheries management.

The application of MPAs to be immediately followed by an effective management, given that from the bioeconomic analysis, it is clear that MPAs are profitable. This study only uses the area parameter as a variable scenario (exogenous). It is recommended that further research can use other biophysical parameters and area parameters can be used as endogenous variables. The livelihood impacts of regional users in this model are not explicitly accommodated. Therefore, it is suggested that this aspect to be further investigated by developing existing models. MPA management policies should be based on science and this requires a thorough understanding of the local LGs. Therefore, intensive communication with the LG regarding these scientific results needs to be done, so that they can be used as materials for policy making. The problem that often arises in MPA management is sustainable financing. The results of this study can be used as a basis for determining baseline sustainable financing in MPA management.

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