Resources dynamics impact to fishers’ resilience

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Abstract. Fishers residing in small islands are heavily dependent on the surrounding resources. The dynamics of these resources influence the fishers' level of resilience. The purpose of this study is to analyze the correlation between the fishers' resilience and available resources using a dynamic model. The method used is dynamic system analysis. The research site is located in the Karimunjawa islands, Central Java, Indonesia. The primary data collection was conducted between March-April 2018. The dynamic model consists of ecological and economical subsystems. The findings show that fishers' resilience experienced a downward trend yearly. Based on the simulation of resources dynamic on the Karimunjawa islands, changes in resource conditions forced fishers to adapt to ongoing changes. The dynamics of marine and fishery resources in the Karimunjawa Islands have forced the fishers to adapt to the changing conditions. The adaptation made is that fishermen change their fishing grounds, especially as they adopted a new technology of GPS and fishfinder. Efforts can be made to improve the fishers' resilience by increasing their productivity and fishing results. It can be achieved by improving the fishers' capacity through training programs to improve their fishing skills.

Keywords: dependency; fisher’s capacity; Karimunjawa; system dynamics

1. Introduction

Fishers are heavily reliant on the surrounding resources, especially those who reside in small islands. Unfortunately, the resources in small islands are more prone to disruptions. Disruptions can be natural and unnatural, such as the growth of civilization that may damage and change natural states. Imprecise management of resources in small islands can lead to a decrease in access to resources compared to fishers who reside in bigger islands.

Karimunjawa Islands are groups of small islands located in Jepara, West Java. Since 1982, the government has stated Karimunjawa Islands as sea conservation which later on became the Karimunjawa National Park i.e., Taman Nasional Karimunjawa (TNKJ). Karimunjawa Islands consists of 5 ecosystems: reef, seagrass, beach forest, mangrove, and low-land forests. These
ecosystems create such diversity, of which the marine and fishery resources have become the source of life for the fishers in Karimunjawa. This diversity is also the reason for its conservation.

As other small islands prone to changes, the marine and fishery resources experience changing dynamics. The massive potential of the resources led to exploitation with the use of damaging fishing tools. In 1991–1995, potassium was heavily used to fish as demands from Hong Kong were increasing. Another harmful tool was *muroami*, which caused damage to the reef ecosystem. This led to damages to fish habitats and other ocean biotas as well. The BTNKJ stated that reef damage before 2013 was caused by fish bombs, *muroami*, and potassium [1].

These changes inevitably affect the fishers’ lives in Karimunjawa Islands. This is also shown by the decrease in fish production reported by the fishers and aligned with the study conducted by Yulianto et al. [2] and Yuliana [3]. In addition, fishing grounds are becoming further away. Initially, fishing grounds cover areas around their islands, but the extreme changes have driven them to explore further and venture out of the National Park area. This adaptation process is also a part of the fishers’ resilience.

The assets owned by fishers (social, economic, institutional, infrastructure, and resources) have become the aspects that shape fishers’ resilience. Fishers’ resilience also influences their capacity to develop adapting strategies, which can lead to the outcome: reducing susceptibility and building sustainable management of natural resources.

The dynamic spatial modelling is conducted to further investigate the marine and fishery dynamics and their impact on fishers’ resilience in Karimunjawa Islands. The purpose of this study is to analyze the correlation between the fishers’ resilience and available resources using a dynamic model.

2. Research methods

2.1. Research time and location

The research was conducted from March - April 2018 in four populated islands in the National Park (TKNJ) area, Karimunjawa islands, Jepara, Central Java. The four islands are divided into four villages which are Karimunjawa, Kemujan, Parang, and Nyamuk. The socio-economic characteristics of the fishers are the main object of the research. The fishers are those who reside in the National Park area, which is Karimunjawa, Kemujan, Parang, and Nyamuk islands. The marine and fishery resources focused on this study are the reef area and reef fish resources in Karimunjawa Islands. The following in figure 1, presents the location of the research.

![Location Map](image1.jpg)

**Figure 1.** Research location.
2.2. Data collection and analysis
The method used in the study is a survey-based method. The data is collected from primary and secondary sources. The primary sources collected data are related to fishing grounds and the fishers’ perception of ecological conditions of Karimunjawa Islands, particularly reef and fishery resources.

The sampling method in selecting respondents is stratified random sampling. First, the respondents chosen were fishermen on four islands within the Karimunjawa National Park, which is Karimunjawa, Kemujan, Parang, and Nyamuk. Second, the respondents chosen were fishermen who had an experience of 20 years or more. Finally, respondents were chosen randomly. Focus groups discussion were attended by representatives of fishers, local governments, NGOs, and fishery observers. The secondary data collected was reef fish production, reef fish biomass, demographics, and socio-economy conditions of the Karimunjawa Islands. The data was collected through a literature review of documents from previous studies as well as documents from relevant official institutions.

The data is analyzed using system dynamics. System Dynamics is a computer-aided approach to strategy and policy design. It uses simulation modelling based on feedback systems theory and is an analytical approach that complements systems thinking. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems—literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality.

The analysis is to examine the changes in resources and their correlation to fishers' resilience. The analysis is conducted to examine how the ecosystem dynamics impact fishers' resilience. Based on the simulation of the dynamic model, we can analyze the interaction between variables. The stages of dynamic modelling are as follow:

1. Creating Causal Loop Diagrams (CLD)
   This diagram is built using the parameters of dimensions that support the fishers’ resilience index. This model is a simplified version of the real system, which therefore excludes some parameters. There are two subsystems in this model: ecological and socio-economic. In the ecological subsystem, there is a correlation between reefs, fishery resources, and fishing efforts. In the social sub-system, there is a correlation between the number of fishers, the level of welfare, and the fishers' resilience. In the causal diagrams, 8 loops are consisting of 4 positive loops (R1–R4) and 4 negative loops (B5–B8). The positive loop is the correlation between the reefs and the growth rate. The negative loop is between the reefs and the damage rate. The positive marking between the two variables shows a reinforcing correlation. For example, the correlation between areas of reefs and growth rate. If the growth rate increases, then areas will also increase. Similarly, the negative marking between the two variables shows a balancing correlation. For example, the correlation between the areas and damage rate of reefs. If the damages increase, the areas will decrease. On the other hand, if the areas decrease, the damage rate will also decrease, and vice versa. The causal diagram can be seen in figure 2.

2. Modelling
   In this stage, the chosen variables are arranged into a dynamic model. The results of this stage are the CLD.

3. Data input
   After the CLDs are formed and translated into codes, the software Powersim Constructor was used. The computer code in dynamic modelling is called a stock-flow diagram (SFD). Collected data is inserted into the SFD.

4. Simulation
   After the SFD is completed with the necessary data, the process is then simulated. The result of this process is the graphs and tables of simulated data.
5. Validation
Before creating a scenario for policies, the model needs validation. This includes:

- Theoretical validation: comparing the correlation of variables between the simulated graphs with previous theories
- Consistency Test on Dimensions: the dimension used in the variables must be consistent
- Output validation: comparing the simulated graphs with graphs from referenced data. The simulated graph should have a similar trend with the referenced data. If a deviation is identified, the model needs to be reset.
- Statistical Test: the validation test is utilizing the Average Mean Error (AME). If the AME is not more than 10%, the model is considered valid and further steps can be taken. The AME formula is as follows:

\[
AME = \left( \frac{S-A}{A} \right) \times 100\%
\] (1)

Information:

\[ S \] = Average simulation score
\[ A \] = Average score from referenced data

3. Result and discussion
Geographically, Karimunjawa Islands are located on 5°49'09"S and 110°27'32"E or approximately 45 miles (83 km) of the ocean from the Jepara Region. Technically, Karimunjawa Islands are in Jepara, Central Java, and divided into three villages Karimunjawa, Kemujan, and Parang. It covers 107.225 ha, including sea (100.105 ha) and the land of about 7.120 ha, which is spread over 27 islands. Out of the 27 islands, there are only 5 islands populated: Karimunjawa, Kemujan, Parang, Nyamuk, and Genting. Most of the islands are located in the Karimunjawa National Park area. Out of the total number of islands, only 22 are a part of the Karimunjawa National Park. The five islands outside the National Park are Genting, Sambangan, Seruni, Cendikian, and Gundul.

In 1988, Karimunjawa Islands became a part of the National Ocean Park. The Ministry of Forestry designated Karimunjawa as a marine nature reserve with Decree No.123/Kpts-II/1986. The local government of Jepara has paid more attention to zone arrangement, natural conservation, development of sea tourism, and traditional fishing ground, as well as the management of natural and environmental resources. However, there is a lack of connection between the management of local resources and the establishment of activities to address various needs, due to the management is mostly still based on sectoral perspectives [4].

Anthropogenic pressures stem from population growth, demands for living space, the development of sea tourism, and increasing sea transport/traffic. Population growth has affected the environment, indicated by reef damage which led to closures in Menjangan Kecil 70%, 37%, and 35.7% in 1988, 1992, and 1999 [6]. The same declining trend is seen in mangroves as, in 1997, the area decreases from 587.88 ha to 576.81 ha in 1999, and again to 407.79 ha in 2003 [6]. This decline was caused by the conversion of land into fish ponds (0.5%), accommodation (0.08%), and moors (4.81%). The decline of mangrove occurred as it was located near habitation, whereas abrasion was seen near the coasts. Conversions to fish ponds occurred in 1998 as the aquaculture industry grew in Java [5].

The growing tourism in Karimunjawa Islands also led to the demands of demersal fish, resulting in fish exploitation and destructive fishing, and damaging the reef ecosystem [6]. Continuous exploration and damages on reefs will affect fish production and therefore the fishers’ welfare. This will eventually affect the fishers' resilience in dealing with resource dynamics. The approach of a dynamic model is used to describe the impact of marine and fishery resources on the fishers' resilience. The model consists of two sub-models: ecological and socio-economic models. Within the dynamic models, the assumptions are the following:
1. The dimension of resilience is the ecological subsystem in this dynamic model. The socio-economic sub-system consists of social and economic factors.
2. The dimension of infrastructure and institution is represented by the variable of fishers’ capacity.
3. The dimension of hazard is reflected through the variable of weather.

Figure 2 shows a causal loop diagram of the dynamic model of fishers’ resilience.

![Causal Loop Diagram](image)

**Figure 2.** Causal Loop Diagram/CLD of fisher’s resilience.

In the subsystem of reefs, there is one positive loop and one negative loop. The positive loop is the causal correlation between the reef and its growth. The negative loop is the causal correlation between reef areas, as seen in figure 3.

![CLD of reefs](image)

**Figure 3.** CLD of reefs.

Reefs are a life form that can be divided into hard coral and other faunas. Hard coral includes dead reefs, dead reefs with algae, Acropora, and non-Acropora, whereas other fauna includes soft coral, sponges, Zoanthids, and others [8]. This study does not examine the colonies of reefs in detail. The most important component in the habitat composition is the stone reefs. Based on the imaging analysis, the area of reefs has shown improvement. In the model, the data is a result of imaging analysis, which explains the areas of reef habitats, including the biotic and abiotic elements.

Based on the imaging analysis, the reef area shows steady growth every year. This is assumed from stone reefs that are covered by moss. This growth was marked in 2010 – 2012, showing an average
rate of 1.65%, and 1.2% in 2013–2017, which means that this data is still valid for the dynamic model. The reef areas can be seen in table 1.

Based on the simulation, the results align with the referenced data. The validation test calculates the average mean error (AME) score. The calculation shows the AME score of 1.85%, indicating the validity of the model. The model is considered valid if it aligns with a similar model and has an AME score of less than 10% [8]. The comparison of referenced data and simulation can be seen in figure 5.

Table 1. Reef areas in Karimunjawa islands.

| Year | Reef Areas (Ha) | Reference | Simulation |
|------|-----------------|-----------|------------|
|      | Referenced a)   | Simulation b) |
| 2010 | 3.935           | 3.935     | |
| 2011 | 3.779           | 3.959     | |
| 2012 | 3.947           | 3.984     | |
| 2013 | 4.122           | 4.009     | |
| 2014 | 4.172           | 4.033     | |
| 2015 | 4.222           | 4.058     | |
| 2016 | 4.273           | 4.082     | |
| 2017 | 4.324           | 4.106     | |
| Mean | 4.097           | 4.021     | 1.85%      |

Source:
a) Imaging analysis using Landsat 5 and Landsat 8
b) Model simulation

Figure 4. Reef behaviors as sub-model.

In the sub-system of the fish supply, there is one positive loop and one negative loop. The positive loop shows the causal correlation between fish supply and biomass growth. A positive loop means when fish supply increase and also biomass growth. If supply increases, it will increase the amount of biomass growth, and vice versa. The negative loops show a causal correlation between fish supply and fishing rate. A negative loop means if fish production increases then the fishing rate will decrease.

The fish supply in this model represents the existence of reef fish in the Karimunjawa Islands based on the biomass per hectare and the size of the reef area. Fish supply has increased with the growing number of fish influenced by the fish biomass per hectare as well as the reef areas. However, the decrease in fish supply is caused by the rate of fishing, which is also influenced by the deteriorating
conditions of reefs as well as the weather. The CLD of the fish supply as part of the ecological sub-system can be seen in figure 5.

![Diagram](image)

**Figure 5.** CLD of reef fish supply

Based on the simulation, the fish supply shows growth every year. This is caused by the efforts to increase the areas of reefs. The fishing rate is considered low compared to this growth. The simulation results show a similar trend to the referenced data. The AME score is at 1.66%, which shows the validity of the model. The comparison of referenced data and simulation can be seen in table 2 and figure 6.

| Year | Fish Supply (kg) | Referenced | Simulation |
|------|-----------------|------------|------------|
| 2010 | 961,209         | 961,209    |            |
| 2011 | 1,144,610       | 1,249,835  |            |
| 2012 | 1,482,475       | 1,447,445  |            |
| 2013 | 1,731,759       | 1,562,557  |            |
| 2014 | 1,766,560       | 1,641,057  |            |
| 2015 | 1,906,816       | 1,982,001  |            |
| Mean | 1,498,905       | 1,474,017  |            |
| AME  | 1.66%           |            |            |

**Figure 6.** Comparison of trends between referenced date and simulation results on fish supply.
In the sub-model of the fish supply, represented by total captures, the element of weather slows down the fishing rate, whereas the fishers’ capacity influences the increase in fishing rate and fish supply. Fishers’ capacity is a variable that represents their socio-economic standing. The social, economic, infrastructural, and institutional aspects are assumed to be a part of the fishers’ capacity. The score of the variable is at 0.0005%. This number is a result of comparing the total captures with the fish supply. The figure 7 shows the CLD of total captures.

![Figure 7. CLD of total captures.](image)

Based on referenced data, the total capture of reef fish in the Karimunjawa Islands has shown a decline. This is assumed from the low rate of production, which was confirmed by the fishers in the Karimunjawa Islands. Based on the simulation, the total captures behaved similarly with the referenced data, and the AME score is still below 10%, which is 7.68%, showing the validity of the model. The comparison between referenced data and simulation can be seen in table 3 and figure 8.

| Year | Total capture (kg) | Referenced | Simulation |
|------|--------------------|------------|------------|
| 2010 | 21,455             | 21,455     |            |
| 2011 | 11,333             | 14,379     |            |
| 2012 | 8,056              | 9,638      |            |
| 2013 | 5,544              | 6,463      |            |
| 2014 | 5,871              | 4,336      |            |
| Mean | 10,452             | 11,254     |            |
| AME  | -7.68%             |            |            |

![Figure 8. Comparison of trends of referenced data and simulation on total fish capture.](image)
The socio-economic sub-system consists of the number of fishers influenced by the fluctuation of the fisher population. The number of fishers will affect the average income for each fisher, which then affects the fishers' resilience. The CLD of the socio-economic subsystem can be seen in figure 9.

![Socio-economic Subsystem Diagram]

**Figure 9.** CLD of socio-economy sub-model.

Based on the simulation, fishers’ growth is seen to be positive. The AME score is at 1.5%, indicating the validity of the model. The consequence of this growth will be seen in the fisher population described in table 4 and figure 10.

**Table 4.** Total captures in Karimunjawa Islands.

| Year | Number of Fishers (org) |
|------|-------------------------|
|      | Referenced | Simulated |
| 2010 | 4.105       | 4.105     |
| 2011 | 4.242       | 4.208     |
| 2012 | 4.238       | 4.313     |
| 2013 | 4.329       | 4.421     |
| 2014 | 4.344       | 4.531     |

AMEMean = 4.252 4.315

| AME  |
|------|
| -1.50% |

![Fishers' Trends Graph]

**Figure 10.** Trends of Fishers.
In calculating the resilience index, the fishers’ resilience is an average score between the socio-economic and ecological subsystems. Ecological resilience is the comparison of reef areas and the number of fishers, whereas socio-economy resilience is the comparison between the average income and decent life (Kebutuhan Hidup Layak). The CLD of fishers’ resilience can be seen in figure 11.

**Figure 11.** CLD of fishers’ resilience.

Based on the simulation, the fishers’ resilience is seen to have a downward trend. This is caused by the decrease of total captures in the Karimunjawa Islands. The resilience index can be seen in table 5 and figure 12.

**Table 5.** Index of fishers’ resilience in Karimunjawa Islands.

| Year | Socio-economic | Ecological | Fishers |
|------|----------------|------------|---------|
| 2010 | 0.36           | 0.96       | 0.66    |
| 2011 | 0.24           | 0.94       | 0.59    |
| 2012 | 0.16           | 0.92       | 0.54    |
| 2013 | 0.10           | 0.91       | 0.50    |
| 2014 | 0.05           | 0.89       | 0.47    |
| 2015 | 0.03           | 0.87       | 0.45    |
| 2016 | 0.03           | 0.86       | 0.44    |
| 2017 | 0.02           | 0.84       | 0.43    |

**Figure 12.** Index of fishers’ resilience.
4. Conclusion and suggestion
The dynamics of marine and fishery resources in the Karimunjawa Islands have forced the fishers to adapt to the changing conditions. This was done by altering fishing grounds, especially as they adopted a new technology of GPS and fishfinder. The availability of supportive tools allowed fishers to explore further locations away from Karimunjawa Islands. The fishing location can be as far as 125 miles from Karimunjawa Islands. The first to venture out and adopt the technology was the fishers in Parang Island.

In windy seasons, access to resources becomes very limited. As the wind reaches up to 30 knots and waves can go up to 6 meters, fishing efforts may halt. Fishers will have more activities as the wind speed decreases, and this limits them to areas around the islands. When there are no fishing activities, the fishers become idle or spend their time fixing their fishing tools or vessels. The dynamic models consist of ecological and socio-economic subsystems. Based on the simulation, fishers’ resilience has shown a downward trend from year to year. Efforts can be made to improve their resilience by also increasing their fish captures. This can be achieved by developing the fishers’ capacity with training programs to improve their fishing skills.

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