A system dynamics model for marine conservation area management – a case study of Pulo Pasi Gusung local marine conservation area, Selayar, Indonesia

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Abstract. Decision making in a social-ecological system approach requires studies in the decision-making process, in both the modeling and the simulation of the model. The system dynamic model can support finding an optimal policy in managing the Local Marine Conservation Area of Pulo Pasi Gusung (LMCA-PPG), South Sulawesi, Indonesia. The objective of the study was to develop a system dynamic model, as a decision support system, to manage the coral reef ecosystem at LMCA-PPG. There are several scenarios of decision making that can be simulated to assess what impacts will occur. System dynamic (SD) modeling can be used to understand the behavior of the complex problems of a particular system. The community-based system development approach is used to construct a conceptual model by involving all interested parties. Surveillance has the highest impact on live coral cover, the biomass of herbivore fish and the net income of fishermen. Live coral cover is affected by the alteration of surveillance, because it increases the occurrence of destructive fishing. It is also affected by the availability of alternative livelihoods and by the status of a restricted zone of LMCA-PPG. There is no alternative livelihood for fishermen, highly affecting their income. Maintaining the fishermen income and livelihood will also maintain the coral reef ecosystem. The recommendations for managing the LMCA-PPG are: surveillance carried out for 20 days a month and 6 hours every day; availability of alternative livelihood for up to 45% of the fishermen population; the extension of the core zone and utilization zone up to 40% of the coral reef area, to 230 hectares.
Key Words: community-based, coral reef, system dynamics.

Introduction. Effective environmental management requires a good understanding of the interactions between decision making and complex problems that occur among social, economic and ecological factors (Kelly et al 2013). Decisions taken must be able to represent problems related to social, economic and environmental issues, especially in conservation areas, which have many conflicts because of ecosystem services. Social, economic and ecological dimensions should be introduced in a systematic approach. The socio-ecological system approach used in this study will be related to the utilization of coral reef ecosystem services.

Decision making with a socio-ecological system approach requires study in the decision-making process, both in the modeling and simulation of the framework. Several scenarios for decision making can be simulated to assess what impacts will occur if a particular management scenario is chosen.

Forrester developed System Dynamics (SD) in the 1960s at the Sloan School of Management, Massachusetts Institute of Technology, United States (Ford 1999). SD are dynamic mathematical models that help understanding a system in a specific time interval. The pattern of change can be in the form of growth, decay and oscillation. SD is not intended to obtain predictions, but rather to emphasize the trend (tendency) of the behavior or pattern of a model. SD has been used extensively in business systems, ecological systems and other systems. SD modeling is one method to answer what-if questions in decision making (Ford 1999).

System Dynamics modeling can be used to understand a complex model of a particular system. It takes a background of sufficient knowledge of a specific system in building a dynamic model. Chang et al (2008) adopted the integrated coastal zone management (ICZM) concept and developed the SD model that integrated growing human activities and reclamation pressure to a coral reef ecosystem in Taiwan. There are four sub-systems, namely socio-economic, environmental, biological and management sub-systems, with the SD model for integrated assessment of the particular problem. System analysis (SA) and SD modeling were used in analyzing the utilization of coral reef resources in the local marine conservation area of Pulo Pasi Gusung (LCMA-PPG). The system approach is to look at the performance of coral reef ecosystems by assessing the interactions between social, economic and ecological factors. The primary use of ecosystem services in LCMA-PPG is fishing carried out by local fishermen. There are still fisheries using fishing with poison because of the high demand for reef fish and the remaining suppliers of cyanide.

The objectives of this study are: analyzing coral reef fisheries using a socio-ecological system approach; building a system dynamics model that describes coral reef fisheries with a socio-ecological system approach; a recommendation for managing coral reef fisheries in LCMA-PPG.

Material and Method

Description of study sites. Pasi Gusung Island is located west of Selayar Island, Kepulauan Selayar Regebcy, South Sulawesi, Indonesia (Figure 1). The island has an area of approximately 2388.78 ha with a population of roughly 4202 people in 2017, a coastline of 29.5 km and a coral reef ecosystem with seagrass and mangroves. LCMA-PPG was established in 2011. There are four areas of LCMA-PPG: core zone (118 ha), utilization zone (197 ha), sustainable fisheries zone (4677 ha) and mangrove rehabilitation zone (26 ha) (Bupati 2011).

Model. This study uses a system analysis method and system dynamics modeling in studying the coral reef fisheries in the LCMA-PPG. The approach taken is qualitative and quantitative in system analysis and system dynamics modeling. A qualitative approach is carried out by involving community participation in the preparation of conceptual models. The information and knowledge of the local people were used in building the conceptual model in coral reef fisheries in Pasi Gusung Island. Quantitative models are built based on the conceptual model, where the model parameters were based on the variables specified in the conceptual model. Primary data was obtained by conducting field research and secondary data was acquired from the Regional Government Office. These data are used to fulfill the parameters of the quantitative model. An evaluation of the quantitative model is carried out afterwards.

There are four phases in system dynamics modeling (Grant et al 1997):

1. Conceptual model formulation;
2. Qualitative model specifications;
3. Model evaluation;
4. Model usage.

Phase 1 aims to build a conceptual model and quality model of the system. This is done by developing the conceptual model using a system approach, where any components of the system that are observed will be included in it. The elements included have a close relationship between one part and another. Phase 2 aims to build a qualitative model based on a conceptual model. The conceptual model, in the form of images and relationship diagrams, is translated into quantitative models in the form of mathematical equations, based on data and information obtained from the real world. Phase 3 aims to evaluate the quantitative model. The evaluation includes model validation and model sensitivity analysis, which takes into account the structure and behavior of the model. Model validation is done to see the performance of model simulations, by comparing simulation results with observational data. Model sensitivity analysis is performed to see any parameters in the model that are sensitive to changes compared with the parameters of other models. The general method used is to provide a variety of independent variables and see the impact on non-independent variables. Phase 4 is carried out by implementing a quantitative model. Trade-off analysis is generally carried out to see the performance of quantitative models built on different scenario schemes. Some scenarios are based on various assessments of independent variables to understand their impact on non-independent variables.

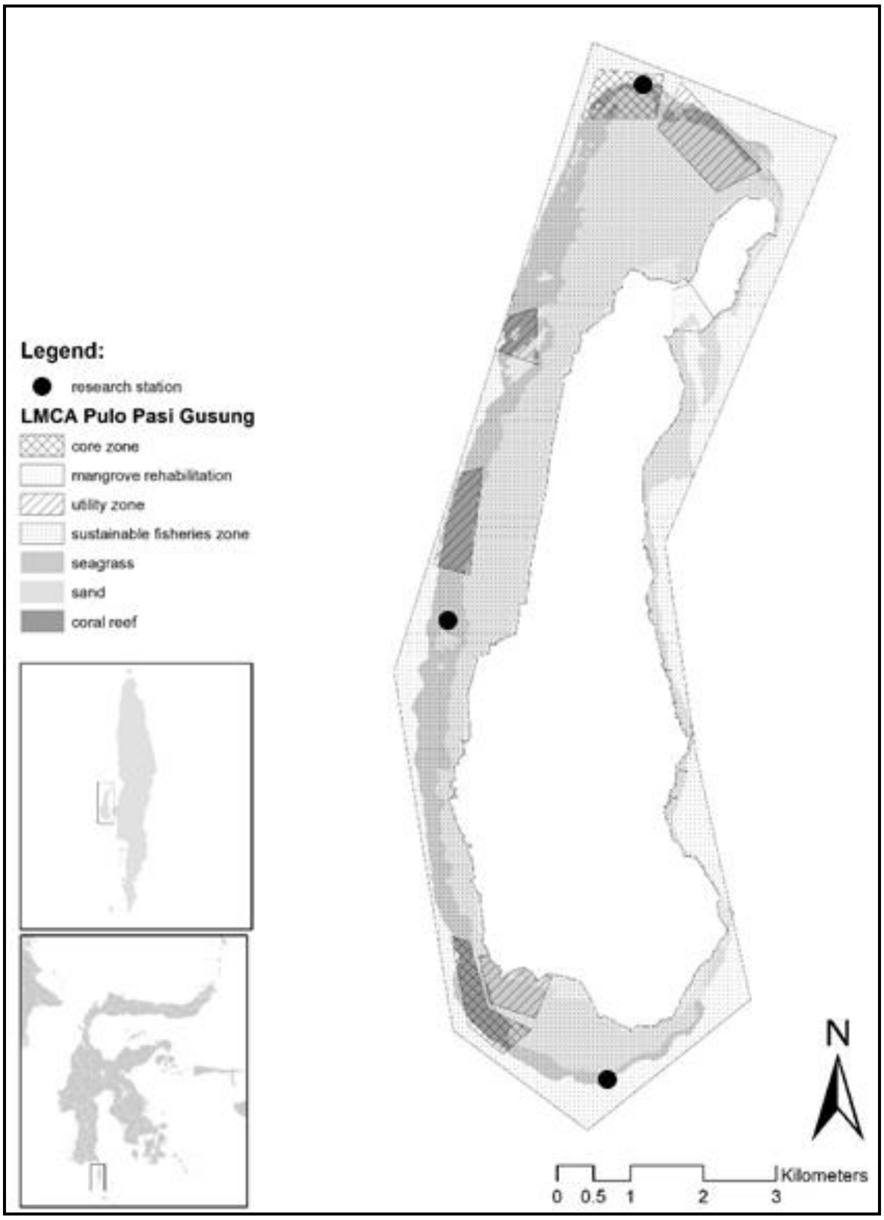


Figure 1. The location of the Local Marine Conservation Area of Pulo Pasi Gusung, Selayar, South Sulawesi, Indonesia.

Model framework. The conceptual model begins with scoping at the study location to obtain information about the problems. Scoping involves gaining information from people who play a role in the utilization of coral reef resources, including fishermen, wives, fish sellers, community leaders and village officials using the focus group discussion method. This activity was carried out in 3 villages located on Pasi Gusung Islan: Bontolebang Village, Kahu-Kahu Village and Bontoborusu Village. Information is obtained based on the community answers to these general questions: what are the primary resources that are available and utilized in the waters of the island; what are the primary problems that have been faced and what factors play a role in these problems. The primary resources are coral reefs and reef fish, based on the focus group discussion. Poison fishing is the primary problem that damages the coral reefs and threatens the reef fish population.

After scoping, a conceptual model based on the existing resources and the primary problems was built (Figure 2). This model was built on community participation using the community-based system dynamics method, which is a method of participation by involving the community in the process of understanding system changes that occur based on dynamic system perspectives in solving problems by building mental models (conceptual models) to review the whole system (Hovmand 2014).

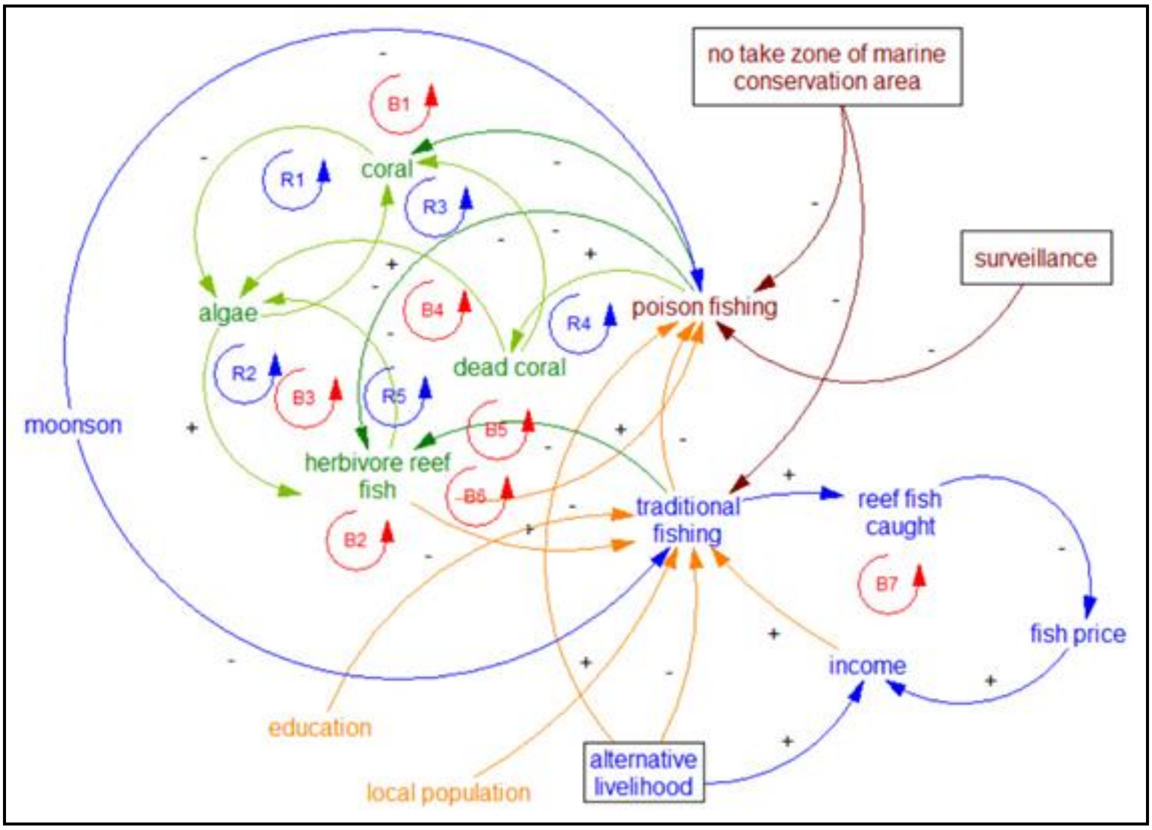


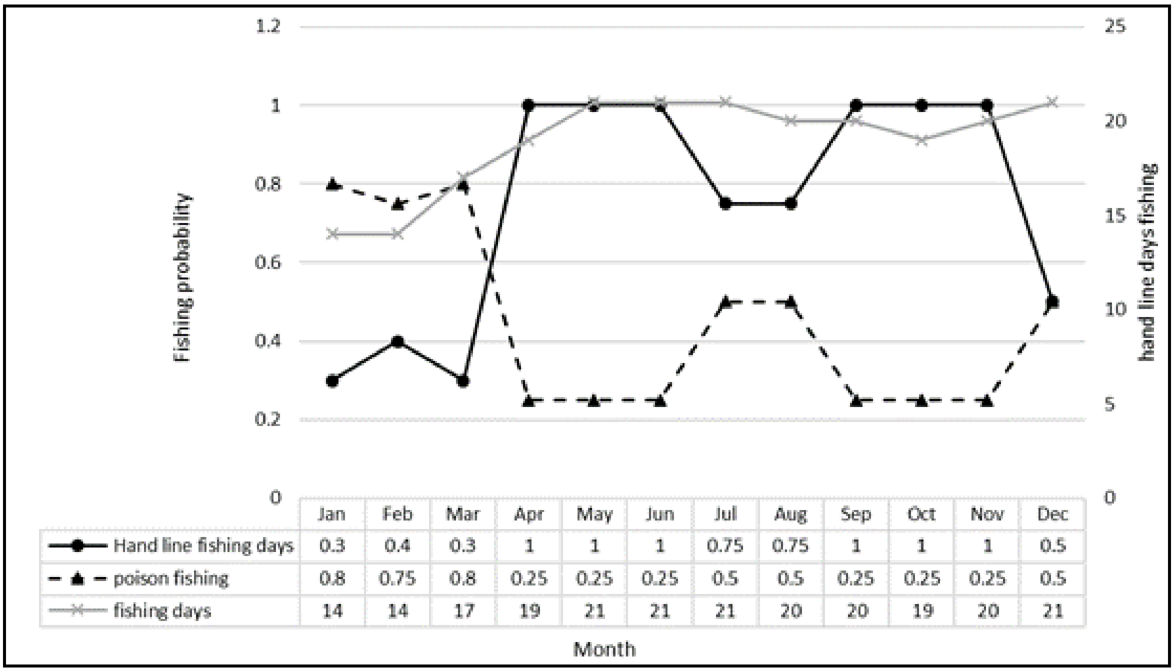
Figure 2. Conceptual model of the Local Marine Conservation Area of Pulo Pasi Gusung.

There are four sub-models based on the conceptual model. The sub-model of ecology describes the competition between live corals, algae, sand-rubble and dead corals, strongly influenced by fishing. The sub-model of surveillance describes the surveillance of the no-take (restriction) zone for traditional and poison fishing. The restriction zone includes the core zone and utilization zone. The utilization zone is especially used for tourism activities, mainly diving and snorkeling. The population sub-model is a population model of villages in Pasi Gusung and their level of education. The community suggests that the higher level of education of the children decreases their desire to become fishermen. The local population model uses model parameters based on existing data in the community, including the number of births, deaths, the number of people leaving and visiting the island, and the number of people that enter the island and settle down.

Fish catches will have a direct impact on income and profits. When the income is above a certain threshold, people will use traditional methods to catch fish. Moreover, when the income is below a certain threshold, the fishermen will try to find other fishing areas or an alternative job, and if there is no other job available, the fishermen use cyanide to catch reef fish. Poison fishing is usually carried out in the rainy season, where weather conditions are adverse and fishermen are having trouble catching fish traditionally. Blythe (2014) stated that the decline in the catch rate is the main factor of change that describes the resilience and social threshold of the fishing community.

The fisheries bioeconomics sub-model consists of the biomass of herbivorous fish, fishing efforts for both traditional and poison fishing, fish prices, fishermen income, fisheries in other areas, profits and the availability of alternative livelihood for fishermen at Pasi Gusung and nearby fishing grounds.

Sub-models. The next phase is to build a quantitative model based on the data and information obtained. The quantitative model was designed using the stock-flow model from the Stella Architect software. The unit of time is in months and the simulation starts with the initial value of each parameter. The simulation began in the 1st month and continued to the 60th month and assumed that no economic, social and ecological changes occur, so that the model is expected to describe the actual conditions. The input variables are surveillance, alternative livelihood availability and the no-take zone of LMCA-PPG based on the conceptual model. The output variables are the live coral cover, herbivore fish biomass and net income of hand line fishing. Figure 3 describes the probability of both hand line and poison fishing, and the number of fishing days of hand line fishing at Pasi Gusung fishing grounds.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hand line fishing days	0.3	0.4	0.3	1	1	1	0.75	0.75	1	1	1	0.5
poison fishing	0.8	0.75	0.8	0.25	0.25	0.25	0.5	0.5	0.25	0.25	0.25	0.5
fishing days	14	14	17	19	21	21	21	20	20	19	20	21

Figure 3. Probability of hand line fishing and poison fishing, and a number of days of hand line fishing at Pasi Gusung fishing grounds.

Sub-model of ecology. The ecological sub-model is a basic benthic space competition model between live coral, algae, dead coral, sand and rubble and other biotic and abiotic components. The space competition model built was modified from the conceptual model developed by van de Leemput et al (2016). The equations used are:

Algae (t) = algae (t - dt) + (algae rate) x dt

Dead coral (t) = dead coral (t-dt) - (coral rate + algae rate + other biota rate + abiotic change) x dt

Live coral (t) = live coral (t - dt) + (coral rate) x dt

Other biota (t) = other biota (t - dt) + (other biota rate) x dt

Sand rubble (t) = sand rubble (t - dt) + (abiotic change) x dt

Where t is time unit (month) and dt is rate change of the time unit.

The herbivory rate is between 0.023-0.067 and it is density-dependent on herbivore fish around the waters of the Makassar Strait, Indonesia (Plass-Johnson et al 2015). The benthic coral reef consists of live coral cover, dead coral cover, algae cover, sand-rubble and other biota cover. The total of all benthic cover has the value 1.

Sub-model of poison fishing. The poison fishing sub-model consists of 2 main models. There is a model of the impact of poison fishing on coral reefs and a model of the effect on herbivorous fish biomass. Initial parameters in this sub-model are the coral reef area of 551.89 ha, the maximum number of days of fishing of 25 days and the number of boats used, 20 units. The damaged reef area is approximately 10-50 m^2 per day by poison fishing. The fraction of surveillance influences the impact of surveillance on poison fishing. The availability of alternative jobs also affects poison fishing: the higher the number of alternative livelihoods are, the more fishing activities will decrease. The fishing hours are between 4 and 9 hours/day.

Effect of surveillance to poison fishing = poison fishing x (1 – surveillance fraction)

Poison fishing = poison probability x number poison fishing boats x max fishing days of poison fishing x (1 – core zone and utility area) x (1 – alternative livelihood availability)

Poison fishing effect on coral reef = area of coral reef damage due to poison fishing x poison fishing/coral reef area

Surveillance effect to coral poisoning = poison fishing effect to coral reef x (1 – surveillance fraction)

Sub-model of the local population. The population model of Pasi Gusung Island is divided into 5 groups based on age: infants 0 to 5 years; children 5 to 12 years; youth 12 to 20 years; adults 20 to 60 years; retirees over 60 years. The local population growth rate is determined by the rate of birth and the rate of immigration of the residents in Pasi Gusung Island. The rate of population reduction is determined by the rate of death and emigration. Population growth models based on age groups, both men and women, are shown in the following equations:

Infant (t) = Infant (t - dt) + (birth - child) x dt

Child (t) = child (t - dt) + (child born - child to young- child death) x dt

Young (t) = young (t - dt) + (child to young - young to adult - male young death) x dt

Adult (t) = adult (t - dt) + (young to adult - adult to retiree - adult death) x dt

Retiree (t) = retiree (t - dt) + (adult to retiree - retiree death) x dt

Where t is time unit (month) and dt is rate change of the time unit.

Sub-model of fishermen population. The population of fishermen is determined by the number of fishermen available and the number of young people who choose to become fishermen. The level of education of young people influences their desire to become fishermen. Most of the respondents suggest that the higher level of education of young people lowers their desire to become fishermen.

Fishermen (t) = fishermen (t - dt) + (fishermen recruitment - "non-fishermen") x dt

Sub-model of fishery bioeconomics. The sub-model of fisheries was developed using the Gordon-Schaefer bioeconomic fisheries model (Anderson & Seijo 2010; Seijo et al

1998) with the Cobb-Douglas production function (Hannesson 1983). The basic fisheries model was modified from the stock and flow model of fisheries bioeconomics (Ruth & Hanon 2012). There are two fishing grounds, the Pasi Gusung fishing grounds and the nearby fishing grounds. Moreover, there are two herbivore fish stocks and different efforts of fishing. Each fishing ground has a net income and the net income follows the present value of profit calculation at the time of the simulation.

E = fishing probability at Pasi Gusung x days fishing x effort

r = 0.4 x [1 - (herbivore fish biomass/K)]

K = 242831

q = 0.00002

Core zone and utility area = 0.25

Biomass rate = r x herbivore fish biomass x [1 - (herbivore fish biomass/K)] - (h + h poison fishing)

h = [(q x E x herbivore fish biomass) * (1 – core zone and utility area)]

h poison fishing = (q poison fishing x effect of surveilance on poison fishing x herbivore fish biomass)

Herbivore fish biomass (t) = herbivore fish biomass (t - dt) + (biomass_rate) x dt

Net income of Pasi Gusung fishing ground = p x h - (E x J)/E

Net income total from fisheries = net income of Pasi Gusung fishing ground + net income of other nearby fishing ground

Where: E - fishing effort; r - herbivore fish average growth rate; K - herbivore fish carrying capacity; q - catchability coefficient; h - fish catch production; t - time unit (month); dt - rate change of time unit; J - fishing cost; p - price of fish (IDR).

Sub-model of alternative livelihood and income. There are two sources of income, the net income from fisheries and the income from alternative livelihood. The total net income of fishermen is the income of Pasi Gusung fishing grounds and income of nearby fishing grounds.

Alternative livelihood availability = 0.15

Income from alternative livelihood per fishermen = real alternative income x alternative livelihood availability

Total income = net income from fisheries + income from alternative livelihood per fishermen

There are six stock and flow of all of the sub-models (Figure 4). Specific parameters connect all sub-models (Figures 4A to 4F).

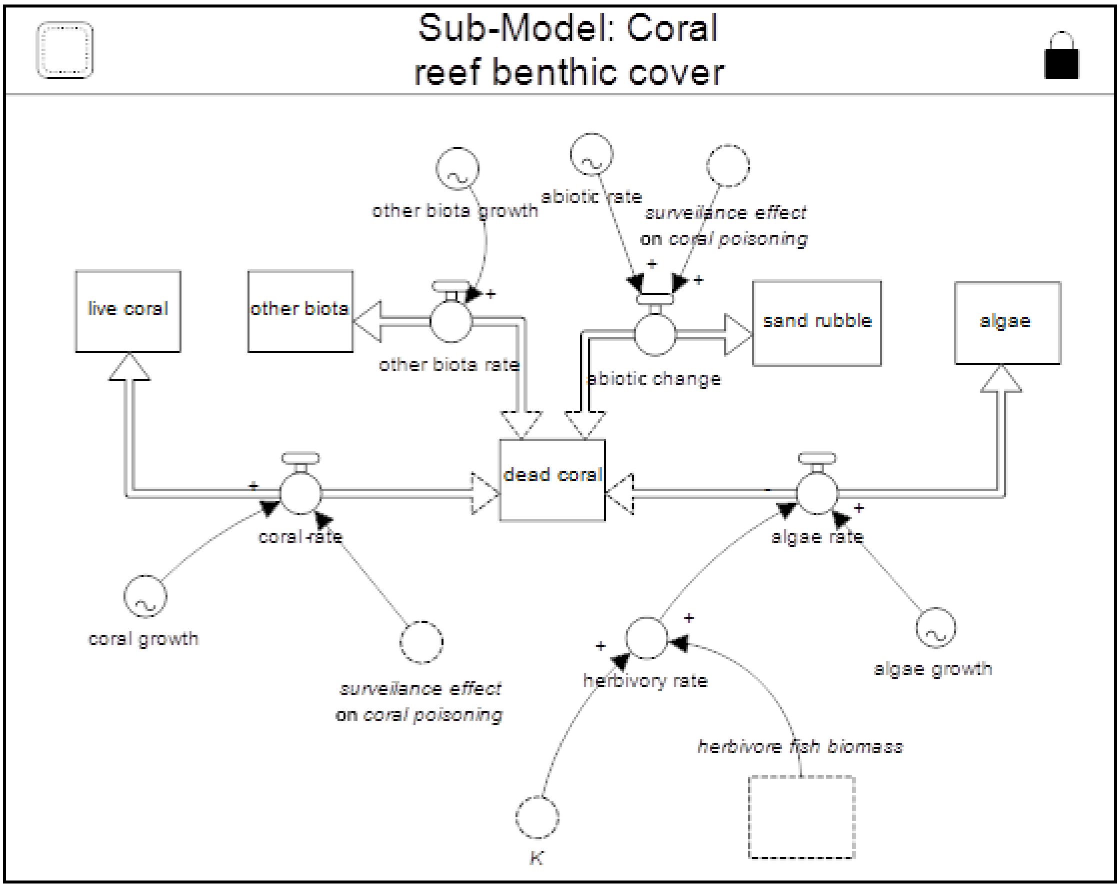


Figure 4A. Stock-flow model of LMCA Pasi Gusung. Submodel of coral reef benthic cover.

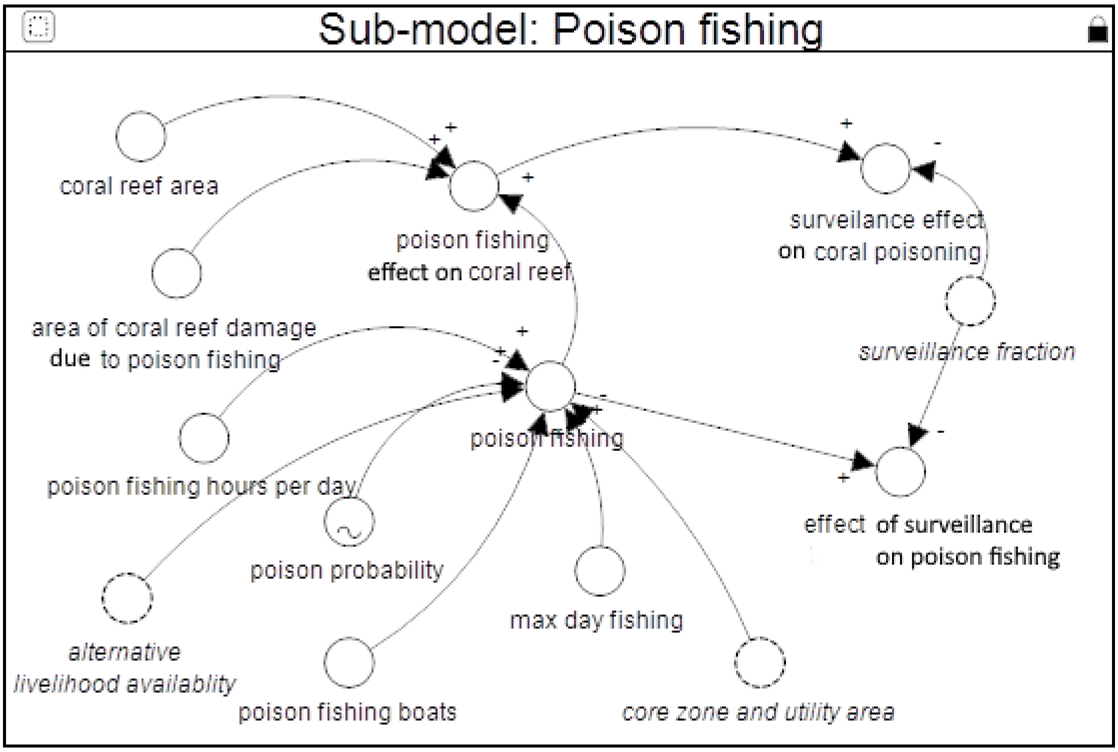


Figure 4B. Stock-flow model of LMCA Pasi Gusung. Submodel of poison fishing.

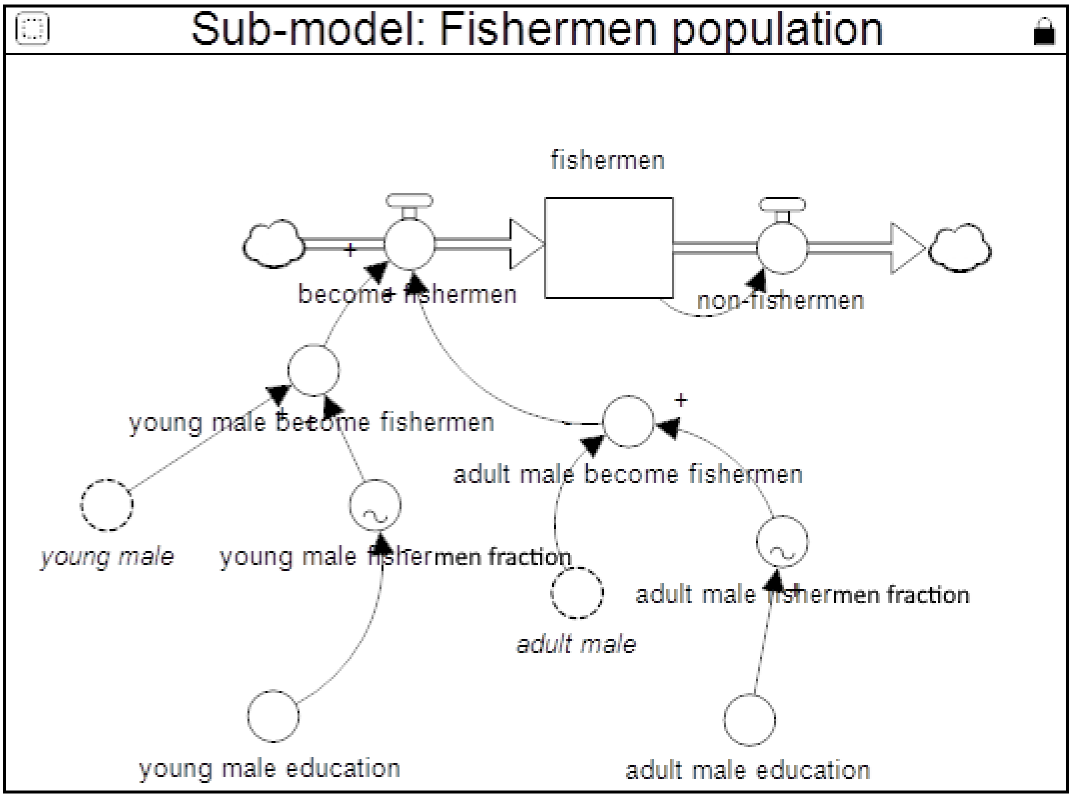


Figure 4C. Stock-flow model of LMCA Pasi Gusung. Submodel of fishermen population.

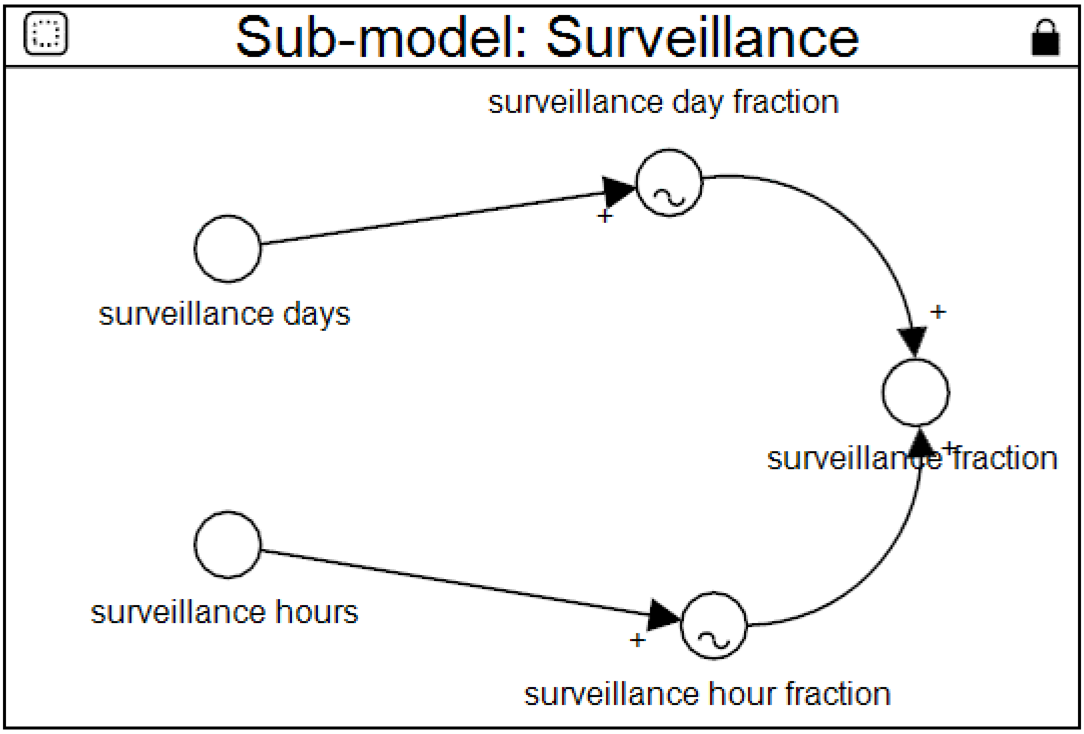


Figure 4D. Stock-flow model of LMCA Pasi Gusung. Submodel of surveillance.

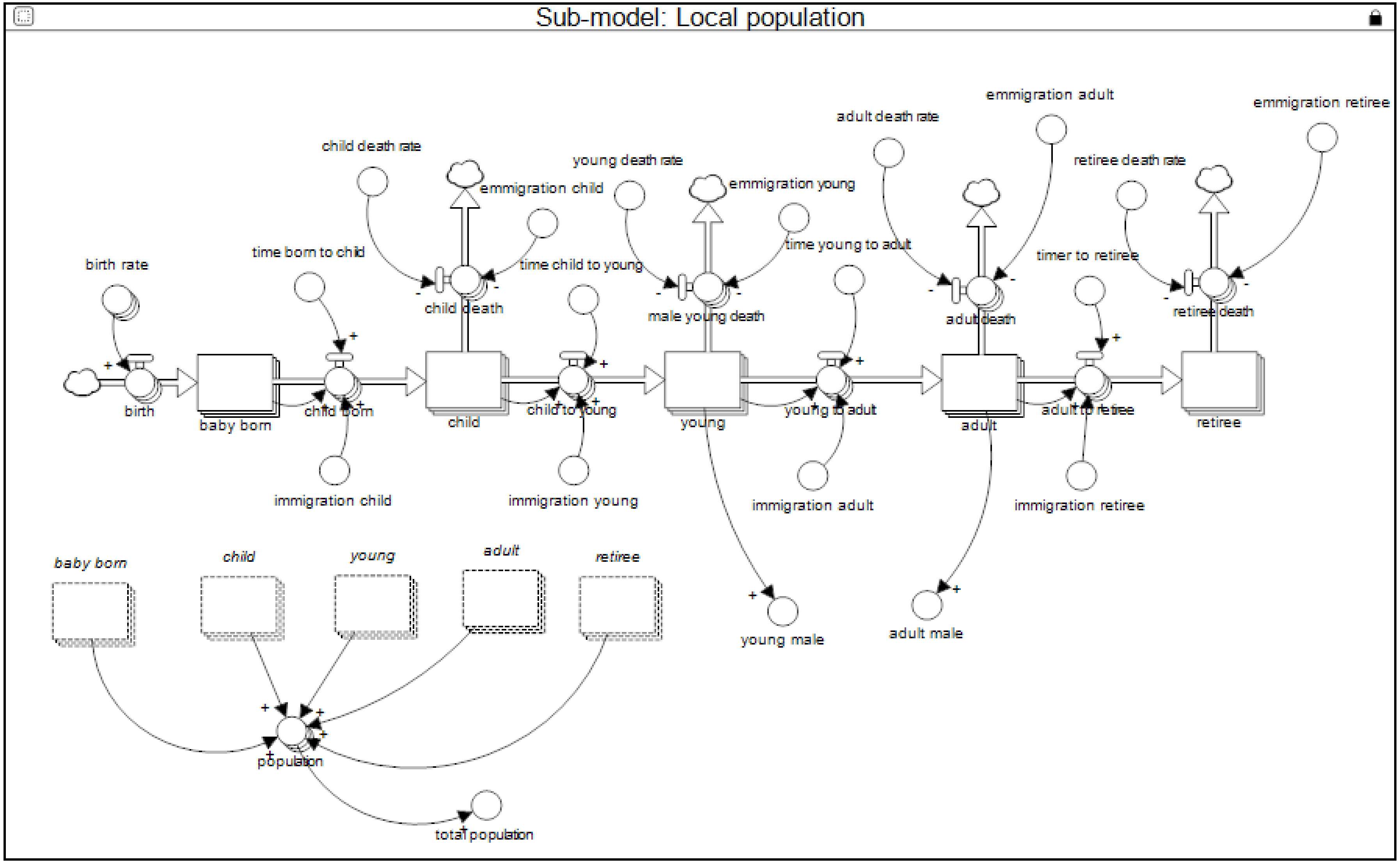


Figure 4E. Stock-flow model of LMCA Pasi Gusung. Submodel of local population.

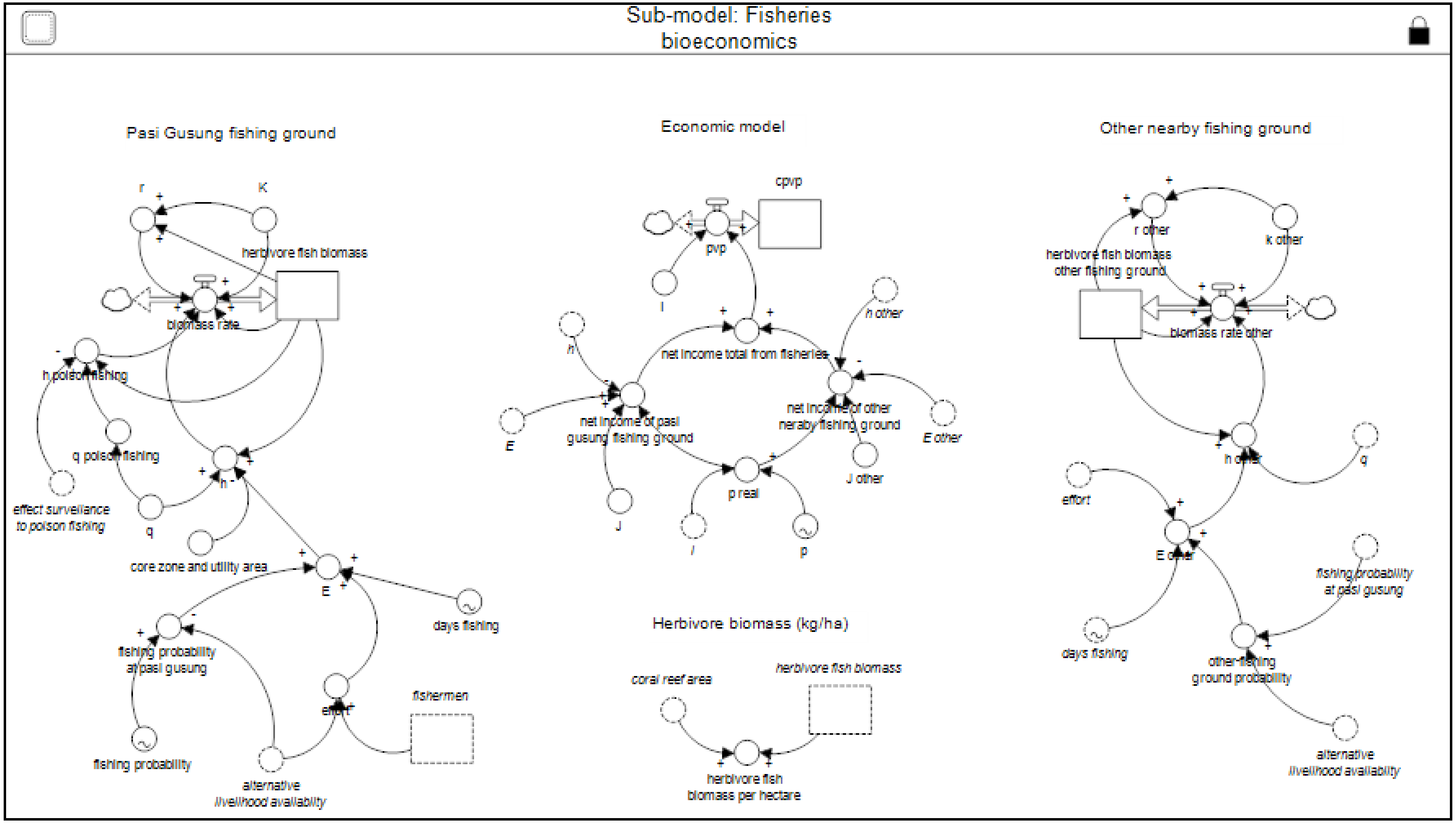


Figure 4F. Stock-flow model of LMCA Pasi Gusung. Submodel of fisheries bioeconomics.

Data collection and processing. Three research stations were set at LMCA Pulo Pasi Gusung. Data collecting started in December 2016 and continued until July 2018. Eight data collection surveys were carried out. There are ten permanent quadrat transects along 100 m of reef areas, with quadrats of 1 m^2 (English et al 1997). Data collection of benthic cover was carried out using SCUBA and underwater photo methods and the analysis was conducted using PhotoQuad ver 1.4 software (Trygonis & Sini 2012). Reef fish data was collected using the visual survey method (English et al 1997) along the permanent quadrat transects. Ecological data regards the benthic cover of coral reefs (live corals, algae, abiotic components, other biota and dead corals) and coral reef fish (abundance and biomass). Socio-economic data was obtained using a questionnaire, where the respondents were traditional fishermen, who catch reef fish at LMCA-PPG. Local population data was collected from the local offices from the villages.

Model development. The community-based system dynamics model involving all of the interested parties in the participatory approach was designed using SESAMME software (Socio-Ecological System App for Mental Model Elicitation) (Richards et al 2016). The conceptual model was designed using Vensim PLE and the system dynamics model for the marine conservation area simulation was designed using Stella Architect version 1.2 (build 0944).

Model evaluation. Model evaluation is a critical process in system dynamics modeling. There are two methods in model evaluation, model validation and sensitivity analysis.

The live coral cover simulation result from January to December 2017 was used to validate the model via comparison with the data from a field survey. The simulation of herbivore fish biomass from March 2017 to July 2018 was compared with data survey of coral reef fish. The net income of fishermen simulation results from January to December 2018 was compared with questionnaire data of income from fishermen respondents. Root Mean Square or Error (RMSE) (Chai & Draxler 2014; Willmott & Matsuura 2005) and Mean Absolute Percentage Error (MAPE) (Kim & Kim 2016; Mehdiyev et al 2016) were calculated to assess the accuracy of output variables. RMSE and MAPE follow these equations:

$$RMSE = \left[n^{-1}\sum_{i=1}^{n}|e_i|^2\right]^{1/2}$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{P_i - O_i}{O_i}\right|$$

Where: $e_i = P_i - O_i$; e_i - difference between prediction (model) and observed data at time i; P_i - prediction data at time i; O_i - observed data at time i; n - number of data.

Rigorous methods are needed to perform the validation and sensitivity analyses of model simulation. Statistical tests are one of the rigorous methods for conducting some tests. The normality test for normal distribution, t-test for the mean and F-test for variance have been applied to check the observation and simulation. The normality test was employed to check that observation and simulation data follow the normal distribution or a Gaussian distribution (Ghasemi & Zahediasl 2012). Some normality tests were utilized to study the normal distribution of the observation and simulation data: Shapiro-Wilk test, Anderson-Darling test, Lilliefors test and Jarque-Bera test (Addinsoft 2019). Two t-tests were employed to assess the model validation between the data survey and the model simulation. The two samples t-tests (α=0.05) were calculated using XLSTAT version 2019.1.2 (Addinsoft 2019). H0 is the difference between the means equal to 0. There is no difference between survey data and model simulation, and it means the model is valid. Ha hypothesis means the difference between the means is not equal to 0. There is a difference between the survey data and the model simulation and it means the model is not valid.

Uncertainty in the model input describes the output of a model (Saltelli et al 2004). Sensitivity analysis aims to determine the level of response or sensitivity of the model behavior with changes in the values of specific parameters (Grant et al 1997). Sensitivity analysis needs to be done to measure the relevance of the model to the system being studied. Also, it proves that the model can be accepted by conducting a series of tests on the results of the simulation model (Ferretti et al 2016).

Statistical analysis was employed to assess the sensitivity of the model (α=0.05). H0 is the null hypothesis in which the variations are identical. There is no difference in the model simulation, and it means the model is not sensitive. Ha means that at least one of the variances is different from another and it means the model is sensitive. Sensitivity analysis was simulated using Stella Architect version 1.2, where the input variable is using incremental data distribution. The surveillance input variables are the days of surveillance in a month and the hours of surveillance in a day. The days of surveillance simulation are 0, 10, 20 and 30 days, and the hours of surveillance in the simulation are 0, 3, 6 and 9 hours. There are 16 combinations of simulation for running the sensitivity analysis. Alternative livelihood availability and area of restriction zone have the same simulation to run the sensitivity analysis (Table 1).

Table 1

Simulation combination of input variables in the sensitivity analysis

Simulation	*Surveillance*		*Alternative livelihood availability**	*area of restriction zone***
	hours	days		
Run 1	0	0	0%	0%
Run 2	0	10	5%	5%
Run 3	0	20	10%	10%
Run 4	0	30	15%	15%
Run 5	3	0	20%	20%
Run 6	3	10	25%	25%
Run 7	3	20	30%	30%
Run 8	3	30	35%	35%
Run 9	6	0	40%	40%
Run 10	6	10	45%	45%
Run 11	6	20	50%	50%
Run 12	6	30		
Run 13	9	0		
Run 14	9	10		
Run 15	9	20		
Run 16	9	30		

Note: * - percentage of fishermen population; ** - percentage of coral reef area.

Scenario setting for marine conservation area management simulation. The model simulation under the different management policy of LMCA-PPG assesses the impact of different strategies. There are five scenarios: (1) no surveillance; (2) no alternative livelihood; (3) no restriction zone (core and utility zone); (4) existing conditions of surveillance, alternative livelihood and zonation area; (5) the sustainable scenario - the alteration of input variables under different scenarios (Table 2). Both LMCA-PPG management and all of the interested parties are directly incorporated into the trade-off approach to enhance the decision-making process for multiple uses, such as for the marine conservation area based on multi-criteria analysis (MCA) (Brown et al 2001). The trade-off approach was used to assess the simulation of all scenarios. The cost-benefit indicators with the effect table and scored effect table were employed to asses all the scenarios.

Benefit indicators:

$$X_{n\ (benefit)} = \frac{(x - X_{min})}{(X_{max} - X_{min})} \times 100\%$$

Cost indicators:

$$X_{q\ (cost)} = \frac{(X_{max} - x)}{(X_{max} - X_{min})} \times 100\%$$

Where: X - indicator; n - benefit indicator; q - cost indicator; X_{min} - minimum value of benefit or cost indicator; X_{max} - maximum value of benefit or cost indicator.

Table 2

Value of input variables under different scenarios

Scenarios	*Surveillance*		*Alternative livelihood*	*Restriction zone*
	Number of days	*Number of hours*		
1. No surveillance	0	0	0.15	0.25
2. No alternative livelihood	10	1	0	0.25
3. No restriction zone	10	1	0.15	0
4. Existing conditions	10	1	0.15	0.25
5. Sustainable scenario	20	6	0.45	0.40

Results and Discussion

Model accuracy assessment. Table 3 shows the results of the normality test. All the net income of fishermen observation data have P-value less than 0.05. However, simulation data for the Shapiro-Wilk test shows otherwise. It means the data did not follow a normal distribution. The rest of the simulation and observation data follow the normal distribution.

Table 3

Normality test of observation and simulation data

Ouput variables		*Normality test p-value (α=0.05)*			
		Shapiro-Wilk test	*Anderson-Darling test*	*Lilliefors test*	*Jarque-Bera test*
1. Live coral cover	Observation	0.912	0.832	0.598	0.856
	Simulation	0.945	0.849	0.882	0.900
2. Herbivore biomass	Observation	0.560	0.370	0.169	0.810
	Simulation	0.176	0.147	0.086	0.620
3. Net-income of fishermen	Observation	0.002*	0.001*	0.008*	0.035*
	Simulation	0.037*	0.054	0.109	0.322

Note: * - P value<0.05.

The simulation accuracy of live coral cover and herbivore fish biomass is high, but net-income of fishermen is relatively low. All of the output variables are valid because the statistical t-test P-value (α=0.05) is higher than 0.05. There is no difference between simulation and observation data. The simulation and observation data are compared in Table 3 and Table 4.

Table 4

Model validation between simulation and observation

Output variables	*RMSE*	*MAPE*	*P-value (α=0.05)*
1. Live coral cover	1.89%	4.76%	0.080
2. Herbivore fish biomass	12 kg ha^{-1}	1.48%	0.588
3. Net-income of fishermen	5.3 USD per trip	34.46%	0.058

Note: RMSE - root mean square error; MAPE - mean absolute percentage error.

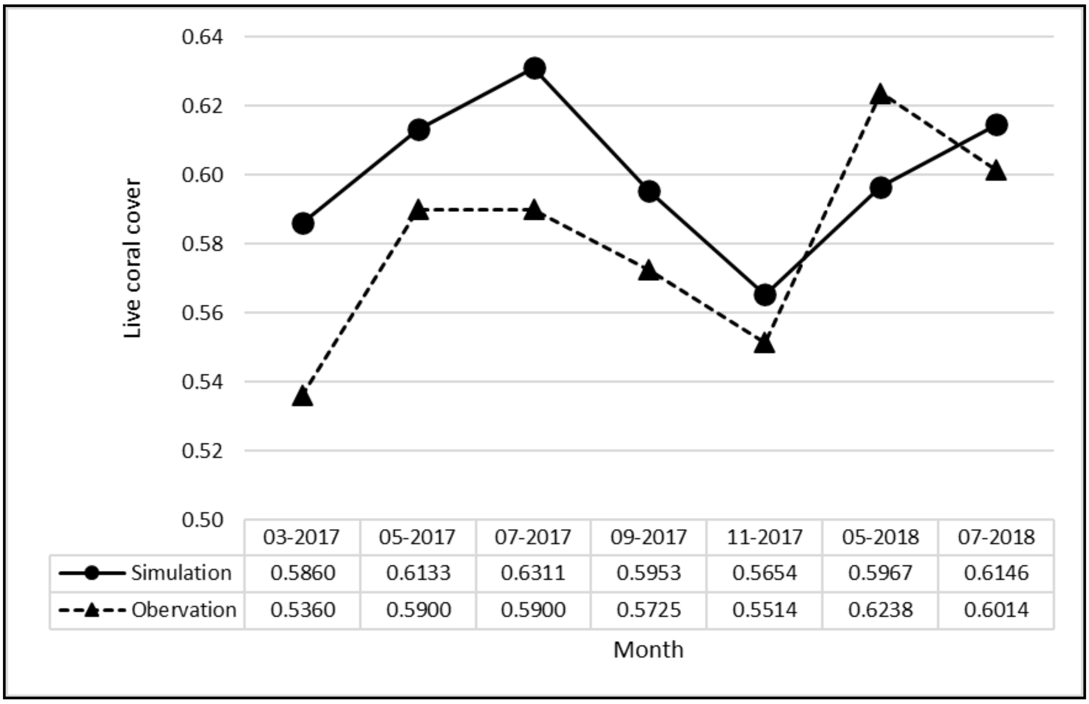


Figure 5. The comparison of modeled live coral cover and observation.

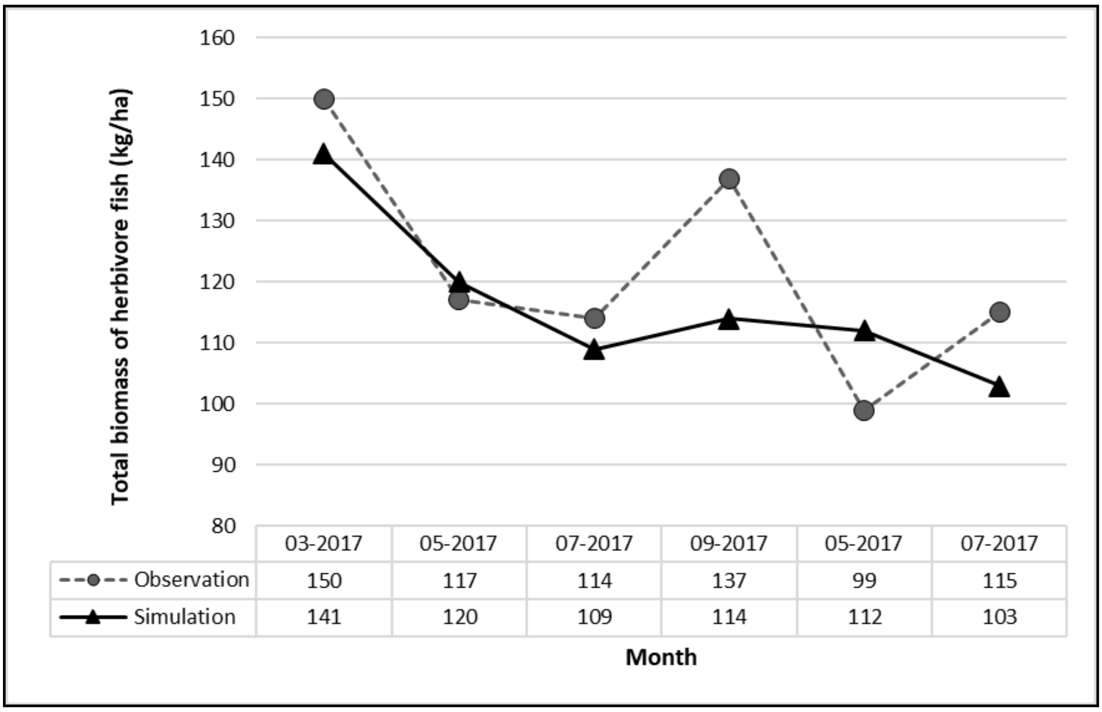
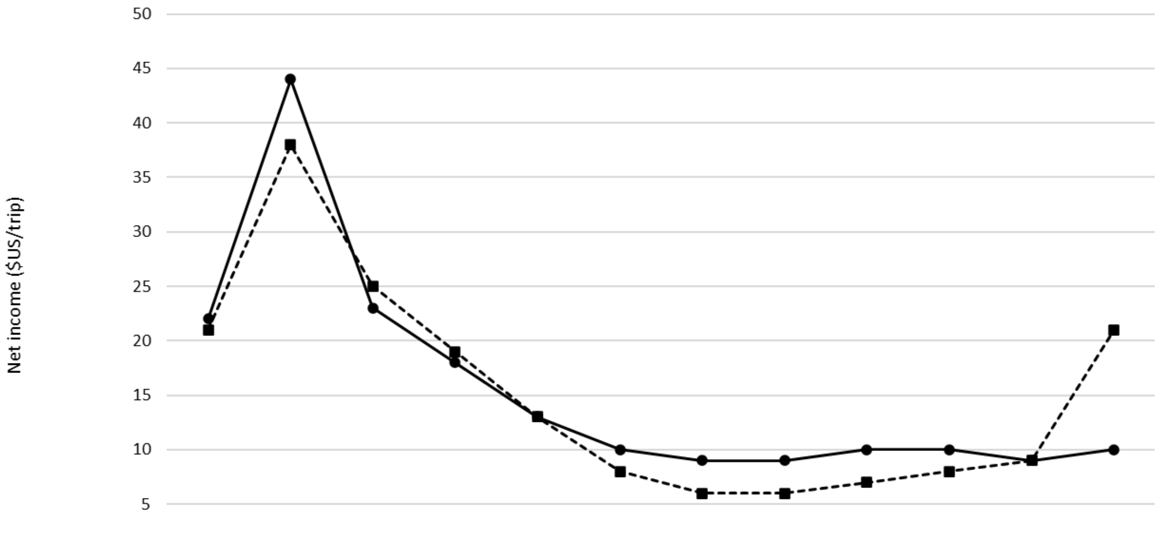


Figure 6. The comparison of modeled total herbivore fish biomass and observation.

Model sensitivity analysis. Surveillance input variable passed all of the variance tests for live cover coral, the biomass of herbivore fish, and net income of the fishermen. Surveillance is sensitive to all of the output variables. Alternative livelihood is sensitive to live coral cover, but not to herbivore biomass and net income. The restriction zone is sensitive to live coral cover and herbivore fish biomass. Restriction zone is more than 40% sensitive to the net income of fishermen. Live coral cover is sensitive to the alteration of all input variables and surveillance had a significant effect on all of the output variables. Sensitivity analysis of input variables are presented in Table 5.



	01-2018	02-2018	03-2018	04-2018	05-2018	06-2018	07-2018	08-2018	09-2018	10-2018	11-2018	12-2018
Observation	22	44	23	18	13	10	9	9	10	10	9	10
Simulation	21	38	25	19	13	8	6	6	7	8	9	21

Figure 7. The comparison of modeled net income and observation.

Table 5

Sensitivity analysis of input variables using F-test

Input variables	*F-test p-value (α=0.05)*		
	Live coral cover	*Biomass of herbivore fish*	*Net-income of fishermen*
1. Surveillance	<0.0001	0.002	0.432
2. Altenative livelihood	<0.0001	0-35%: >0.05 40%-50%: <0.05	0-45%: >0.05 50%: <0.05
3. Restriction zone	0.0001	0.994	0-35%: >0.05 40-50%: <0.05

Model simulation. Simulation of all the scenarios with the difference value of input variables is analyzed. The response of output variables in the simulation of scenario 5 is different from others (Figure 8).

Table 6

Effect of all simulated scenarios

Output variables	*Unit*	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*
Ecology						
Live coral cover	%	56.59	52.83	47.85	58.43	76.32
Algae cover	%	9.45	11.82	11.91	9.30	0
Biomass of herbivore fish	kg/ha	201	164	163	203	312
Economic						
Net income of fishermen	USD per trip	15.1812	10.6324	17.2021	15.4749	21.3644
Social						
Poison fishing effort	total trips per month	1254	1394	1579	1185	214

Trade-off analysis using effect and scored effect table shows that scenario 5 had the highest score (Table 6; Table 7). The lowest score is for scenario 2, where there are no alternative livelihoods for fishermen. The scores of scenario 1 and 4 are relatively close. The t-test statistical analysis was employed to compare the score of scenario 1 and 4. The result is that no difference exists between scenario 1 and 4 (P-value = 0.386; α = 0.05).

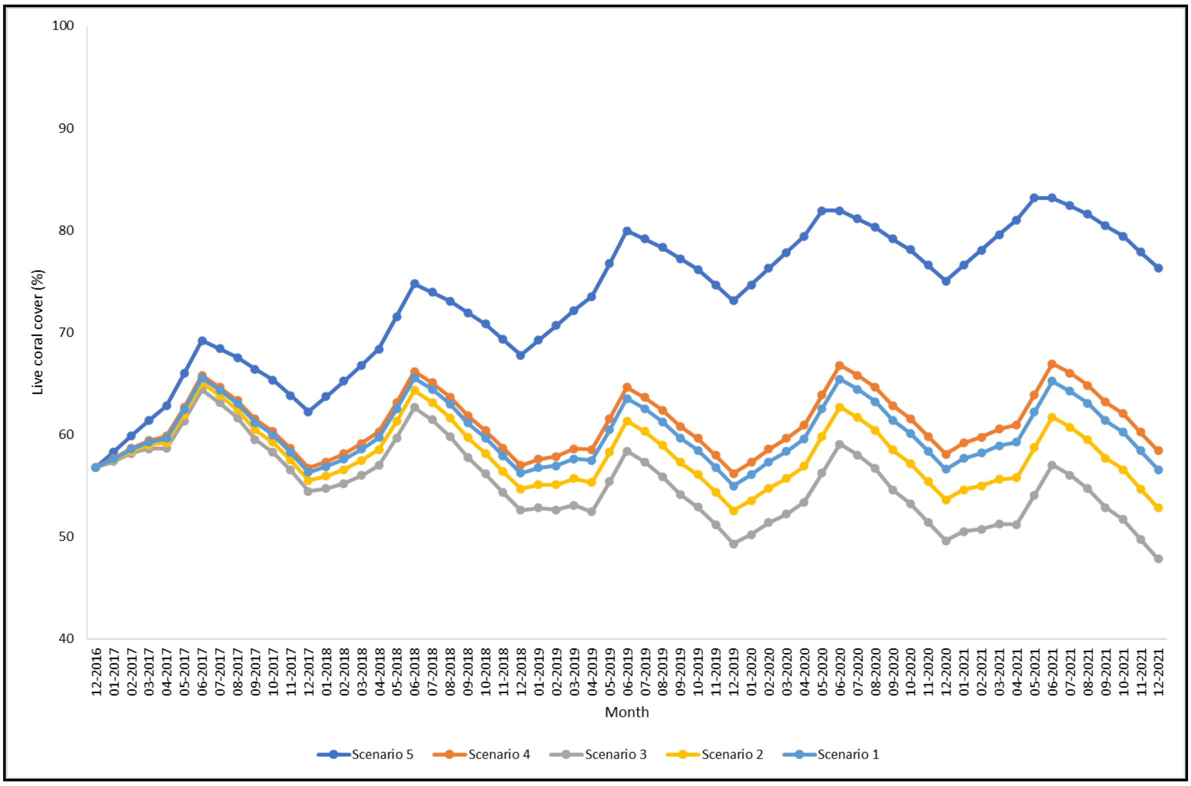


Figure 8A. Live coral cover for all scenario model simulations.

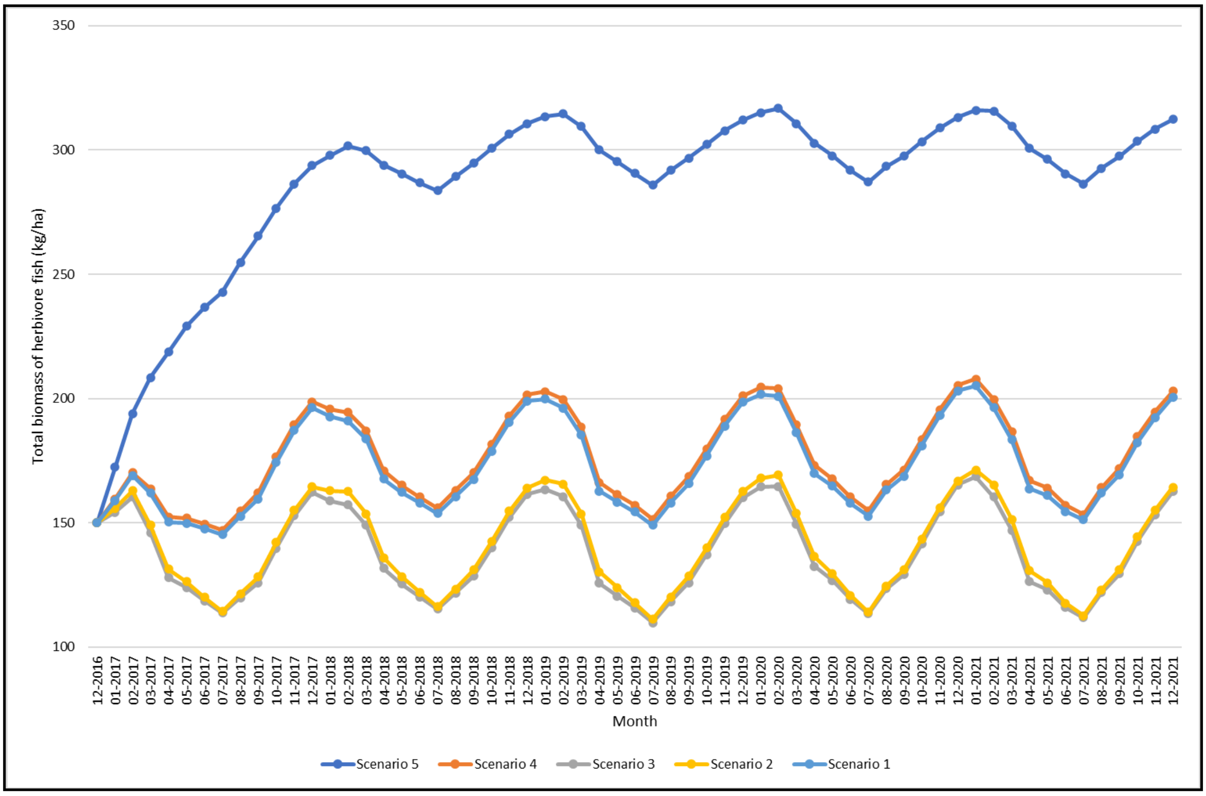


Figure 8B. Biomass of herbivore fish for all scenario model simulations.

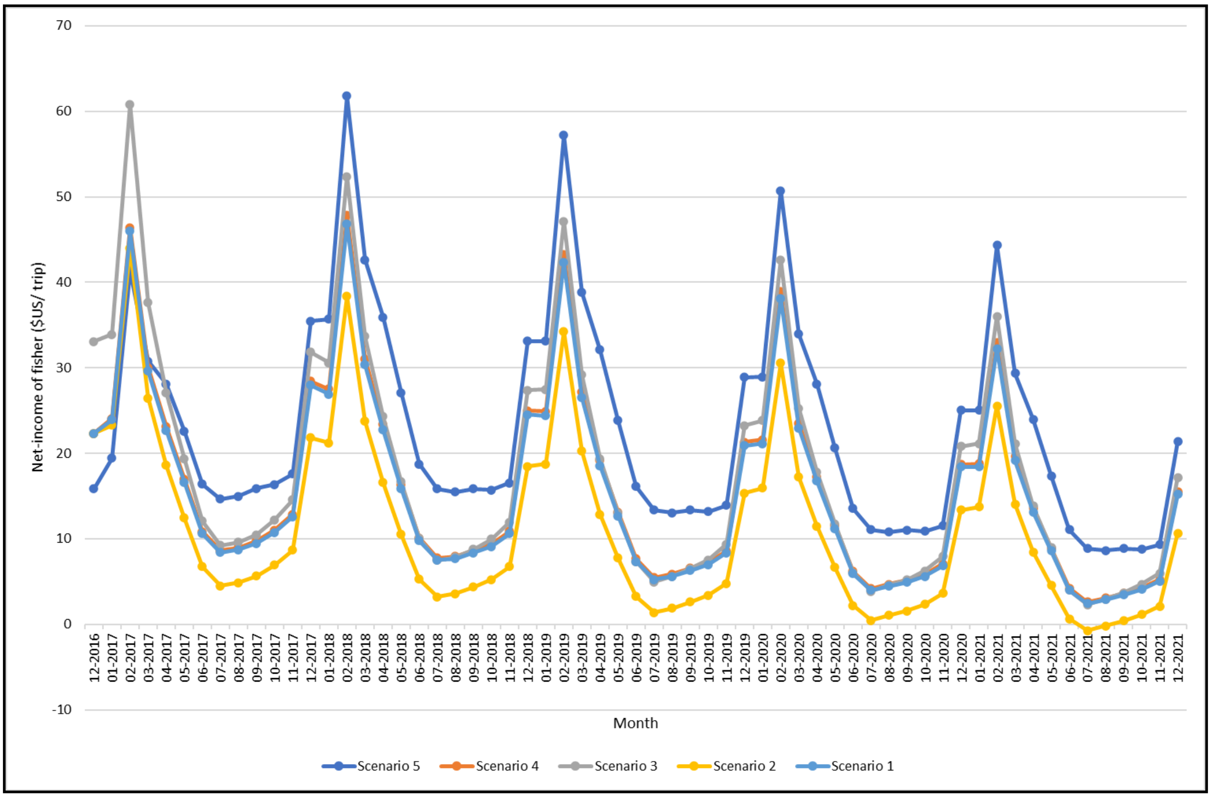


Figure 8C. Net income of fishermen for all scenario model simulations.

Table 7

Scored effect table of all scenarios simulation

Output variables	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*
Ecology					
Live coral cover	30.6934	17.4994	0	37.1862	100
Algae cover	20.6879	0.7681	0	21.9325	100
Biomass of hebivore fish	25.4183	1.2277	0	26.9800	100
Average	25.5999	6.4984	0	28.6996	100
Economic					
Net income of fishermen	42.3853	0	61.2159	45.1217	100
Social					
Poison fishing effort	23.8712	13.6099	0	28.9209	100
Average of output variables	30.6188	6.7027	20.4053	34.2474	100
Rank	3	5	4	2	1

Model validation using t-test showed that the model can predict well, so not many differences were observed from the observation data. Net income of fishermen had a higher error than other output variables, because the data obtained comes from questionnaires filled directly by fishermen. This happened because of the subjectivity of the respondents. Proven by the normality test, the net income did not show data normality because of the subjectivity of the respondents (Lamia 2013; Danapraja 2014; Hastuty et al 2015; Kurniasari 2016).

Sensitivity analysis showed that the alteration of surveillance influences output variables, both on live coral cover, the biomass of herbivore fish and net income of fishermen. Live coral cover is susceptible to the alteration of all input variables. The availability of alternative livelihoods for 40% of the fishermen population could increase the herbivore fish biomass. Fishermen income can increase significantly if alternative jobs are available for 50% of the fishermen population. The addition of the restriction zone could have substantial effects on living coral cover and herbivore fish biomass. The addition of at least 40% in coral reef area could increase the net income of fishermen.

Scenario 5 with sustainable input variables shows the highest score of trade-off analysis. The existing conditions of management and no surveillance scenarios show no significant differences, so it can be stated that there is no surveillance effort of the LMCA-PPG management. The no-alternative livelihood scenario presents the lowest score, especially to the net income of fishermen. The fishermen suggest that they would keep fishing for a living even though the income is small. They could be using cyanide for fishing to get better income, and it would translate to more pressure on the coral reef when traditional fishermen shift to using poison.

The LMCA-PPG management should increase the surveillance effort to control the pressure on coral reef, mainly from fishing activities. Efforts that can be made in reducing fishing pressure on coral reefs are allocating local government budgets and increasing investments in providing alternative jobs. The Pasi Gusung Island has potential for development with its sandy beaches, various culinary options and coral reefs for marine and cultural tourism.

Conclusions. The simulation of LCMA-PPG using different management scenarios is crucial. It can be used to predict the impact of management policies in the future. It can also be used as an evaluation or control of different strategies. In this study, the system dynamics model was developed with the participatory assistance of all interested parties at LMCA-PPG to build the conceptual model. Field survey, data and information from all interested parties parameterized the quantitative model. Model validation and sensitivity analyses were employed to build a robust model. Some scenarios show different impact on the output variables, such as live coral cover, the biomass of herbivore fish and net income of fishermen. Surveillance has the highest impact on live coral cover, the biomass of herbivore fish and net income of fishermen. There is a need for a higher surveillance effort to maintain the sustainability of coral reef resources. Live coral cover is mostly affected by the surveillance alteration, availability of alternative livelihood and the restriction zone of LMCA-PPG. The net income and livelihood of fishermen are mostly affected by alternative livelihood availability. Maintaining the fishermen income and livelihood is also sustaining the coral reef ecosystem.

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