Ecosystem approach reef fisheries management model in Ternate Island, North Maluku, Indonesia

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Abstract. The policy determination for an ecosystem approach to the reef fisheries management was based on static and dynamic models to address the problem of the utilization rate and sustainability status of reef fisheries on Ternate Island. There were identified 6 dimensions related to the: coral reef ecosystems, reef fish resources, reef fishing techniques, social aspects of theof fishing communities, economic aspectsof the fishing communities, and the involved government institutions. The results showed that the utilization of reef fisheries on Ternate Island was classified as moderate with an average utilization rate of 11.62%. The simulation scenario output fitting the best to the reef fisheries management plan was generated for a level of the fishing effort at 180 trip year^{-1} and a capacity of the fishing fleet of 750 boats, with a catch of 2,139.28 tons for the dynamic model and 2,843.83 tons in the static model. The utilization rate of reef fisheries is <50% of the carrying capacity of reef fishes, namely 28.63% for the dynamic models and 38.02% for the static models. The sustainability status of reef fisheries is classified as good with an average value of 73.65, but some policies have to focus on the indicators related to the dimensions of the coral reef ecosystem. The reef management policy can be determined from the models scenarios results, based on the sustainability status behavior under the fishing capacity and effort variation, in order to make environmentally friendly Fish Aggregating Devices (FAD), and to improve the condition of the coral reefs.
Key Words: carrying capacity, catch, coral reef ecosystem, dynamic model, static model.

Introduction. The reef fisheries management has been focused on the target species catch and on the fishing gear, without taking into account the ecosystem factors. The principles to be considered in the implementation of the ecosystem approach to the management of coral fisheries included: (1) fisheries must be managed at a boundary that prevents any damaging impacts on the ecosystem; (2) ecological interactions between fish resources and their ecosystems must be maintained; (3) management tools should be compatible with the whole fish resource distribution; (4) the precautionary principle applies to the fisheries management and decision-making processes; (5) fisheries governance includes the interests of the ecological systems and human systems (Charles 2001; Garcia et al 2003; FAO 2003).

Reef fishing activities on Ternate Island have been running since before the kingdom of Ternate existed, which is evidenced by the discovery of fossil shells in the former settlement in the middle of the mountain the fishing gear used being the spears and the salapa (woven from coconut leaves shaped like a net). The targeted species were of the type of: reef fish, mollusks, gastropods, and crustaceans. The process of arrest used to be carried out at low tide. Nowadays, coral fishing continues to experience progress in both the fleet and fishing gear. The economically important targeted reef fish belong to the following families: Haemulidae, Mullidae, Carangidae, Lethrinidae, Lutjanidae, Priacanthidae, Scaridae and Serranidae.

The utilization of reef fish in the last 5 years on the island of Ternate has increased by 5.7% (Marine and Fisheries Official of Ternate City 2018), along with the increase in populations demand for fish. Most of the catches of reef fish meet the needs of households consumption, the quantitiesi in excess being sold on the market for reef fish on Ternate Island. The fishing gear used is the handline, which is environmentally friendly and selective, and the navigation to the fishing waters is realized the most often with a fleet of motorized boats <5 GT.

Reef fishing activities are carried out every day, therefore in addition to the reef fish resources the most important factor that must be considered is the sustainability of the coral reef ecosystems. In order to support sustainable fishing activities it is necessary to establish a reef fisheries management policy with an ecosystem approach involving all stakeholders, including the government, private sector, non-governmental organizations, universities and the community. This research was conducted to support the reef fisheries management by determining the appropriate policies based on the utilization rate and sustainability status.

Material and Method

Description of the study sites. This study was conducted in Ternate Island, North Maluku, at 13 research locations spread in the southern, central and northern parts of the Ternate Island, over a research period between November 2017 and November 2018 (Figure 1).

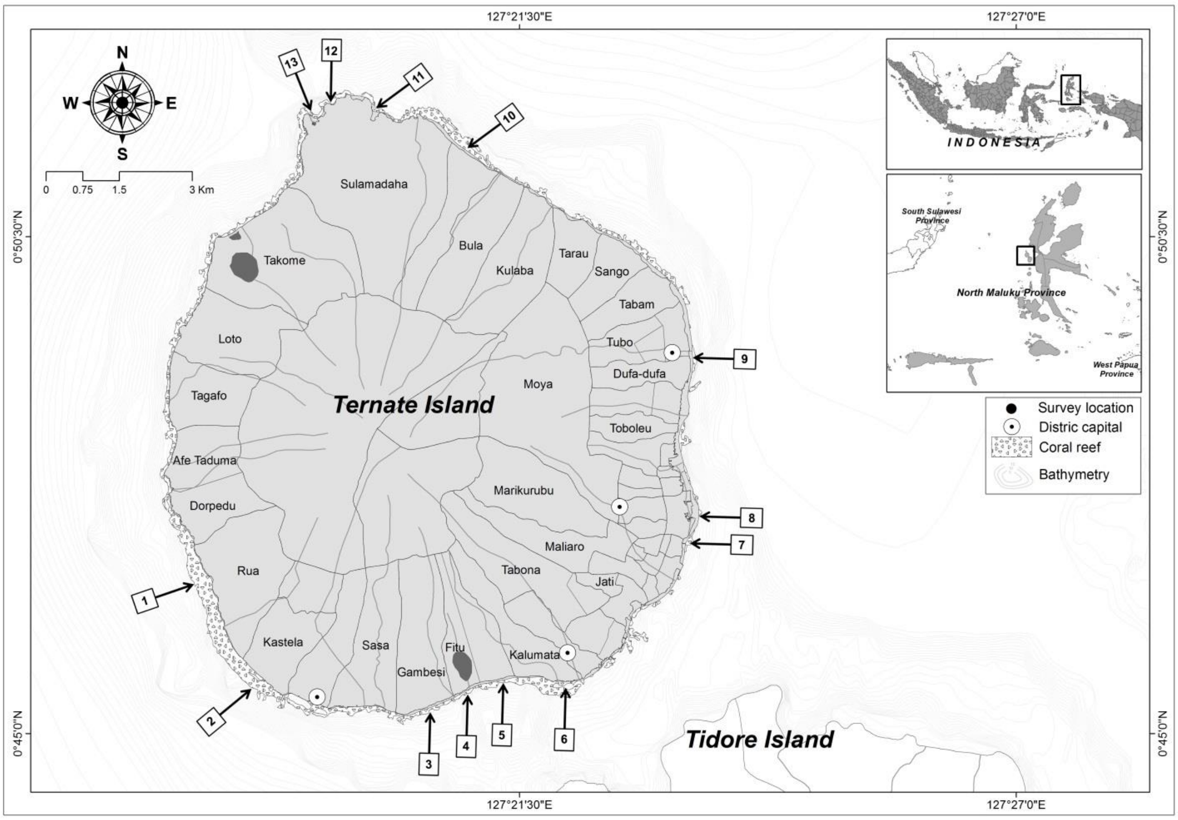


Figure 1. Map of the study site at Ternate Island, North Maluku, Indonesia.

Management model. Data collection was carried out in accordance with the research needs including supporting data related to the assessment of the reef fish utilization rate and an assessment of the status of the coral reef sustainability. The assessment of the utilization rate was based on the carrying capacity of the coral reef ecosystems, related to the fish biomass volume per surface area and limiting the fishing intensity of the catches. The sustainability status assessment of the reef fisheries used 35 indicators on the 6-dimensions (Table 1). The method approach used is a survey and interview technique (Table 1). In order to determine the appropriate policies for an ecosystem approach to the reef fisheries management, the assessments of the utilization rate and sustainability status were necessary.

Table 1

The methods of survey and interview technique

Dimensions	*Indicators*	*Method*	*Reference*
Coral reef ecosystem	Water quality Percent cover Coral diversity Coral reef area Rugosity Species abundance Frequency of coral size Coral recruitment Coral:algae ratio Coral mortality	Line Intercept Transect (LIT), Underwater Photo Transect (UPT)	Rogers et al (1983), English et al (1997), Clua et al (2006), Giyanto et al (2014), Mukhtasor et al (2015), Facon et al (2016)
Reef fish resources	Utilization rate Species composition Range collapse ETP species Reef fish biomass Fish size Juvenile proportions	Survey & analysis, Visual census, Belt transect, Underwater video transect, Underwater photo transect, Interview	Kulbicki (1998), Tessier et al (2005), English et al (1997), Pelletier et al (2011), Pink & Fulton (2015)
Reef fishing techniques	Fishing method Fishing capacity & effort Fishing selectivity Suitability of function and size Ship crew certification Modification of fishing gear	Interview	FAO (2003)
Social	Stakeholder participation Fisheries conflict Utilization local knowledge	Interview	FAO (2003)
Economic	Asset ownership Income Saving ratio	Interview	FAO (2003)
Government institutions	Stakeholder capacity Policy synergy Fisheries management plan Decision making mechanism Rules of the game Compliance with fisheries principles	Interview	FAO (2003)

A dynamic model was used for the reef fisheries management policy determination, based on a utilization rate, considering the catch and the carrying capacity of the coral reef ecosystems (Figure 2). The utilization rate model used the modified formula from Yeeting et al (2001):

$$HT = f\left(ht_1 + ht_2 + \ldots + ht_n\right)$$

$$DD = f\left(\beta_1 a_1 + \beta_2 a_2 + \ldots + \beta_n a_n\right)$$

$$TP = \frac{\sum f\left(ht_1 + ht_2 + \ldots + ht_n\right)}{\sum f\left(\beta_1 a_1 + \beta_2 a_2 + \ldots + \beta_n a_n\right)} x\, 100\%$$

Where:
β $\beta_{1..n}$ is reef fish biomass (ton.ha^{-1})
$a_{1..n}$ is the area of coral reefs in each study location (ha)
$ht_{1..n}$ is the catch of each study location (ton)
HT is a total catch (ton)
DD is the total carrying capacity (ton),
TP is the utilization rate of reef fish (%)

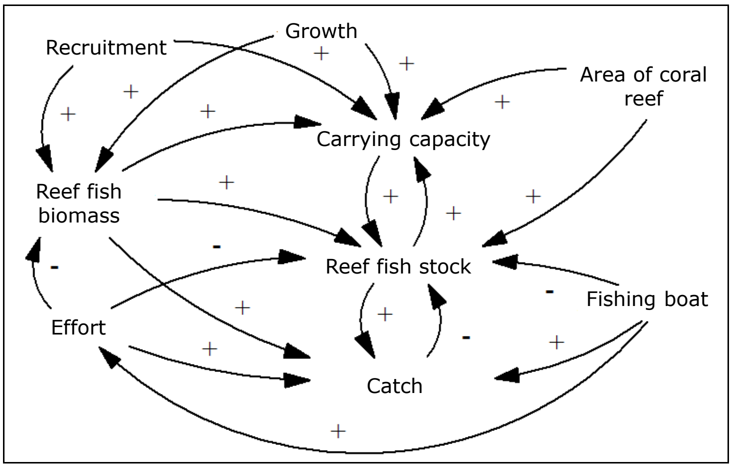


Figure 2. The dynamic model of ecosystem approach reef fisheries management based on utilization rates.

The analytical method applied to the strategies for reef fisheries management policy determination, based on the sustainability status, is the multi-dimensional scaling (MDS), using rapfish. Considering the MDS results, further analysis was performed with a dynamic model in order to produce strategy scenarios future projections for reef fisheries policying, with probability values for each indicator (Figure 3).

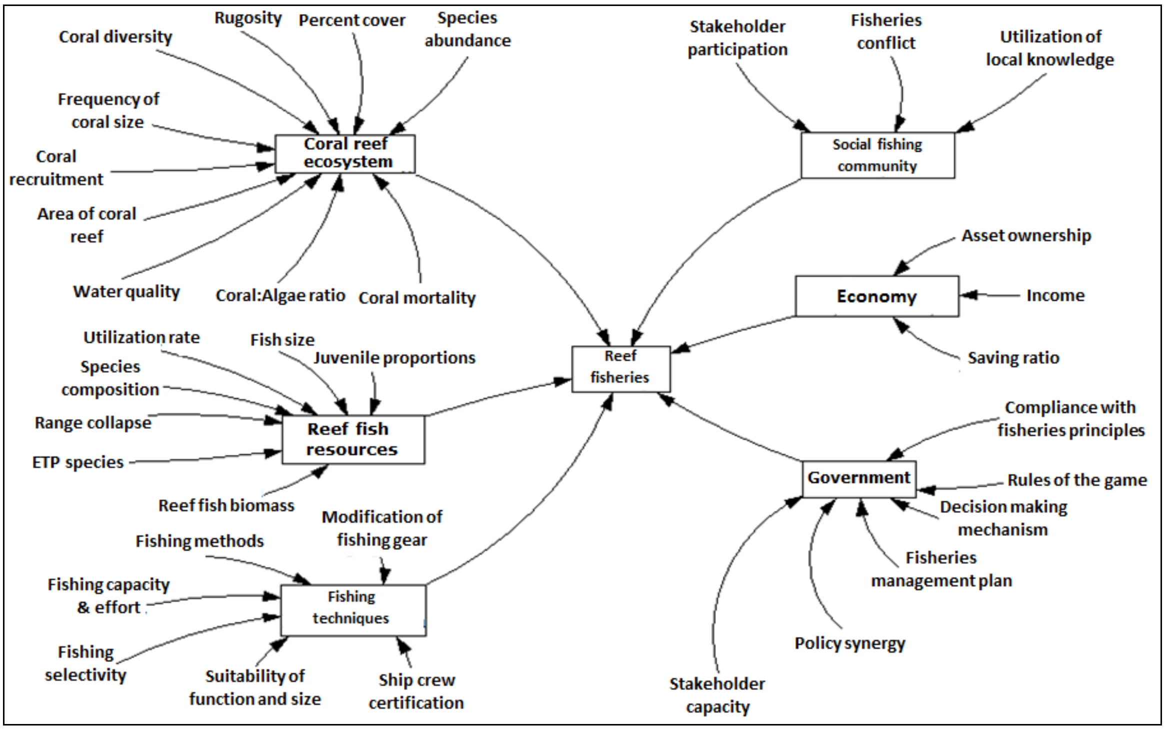


Figure 3. The dynamic model of ecosystem approach reef fisheries management based on sustainability status.

Results. Utilization of reef fisheries on Ternate Island was classified as moderate, meaning that efforts to catch reef fish could be increased, as evidenced by the reef fish stock use rate of less than 30% at the 13 research sites of the study, with an average utilization rate of 11.62% (Table 2).

Table 2

The utilization rates of reef fisheries at Ternate Island

Site number	*Location*	*HT (tons)*	*DD (tons)*
1	Rua	93.94	395.66
2	Kastela	92.90	1,306.34
3	Gambesi	47.43	2,185.17
4	Fitu	78.57	1,038.93
5	Ngade	34.92	299.78
6	Kalumata	209.52	858.50
7	Falajawa	7.56	150.51
8	Gamalama	21.42	117.51
9	Daulasi	82.80	99.79
10	Tobololo	26.46	414.38
11	Sulamadaha	91.08	192.38
12	Talaga Nita	20.70	152.29
13	Jikomalamo	62.10	269.34
Total		869.40	7,480.58
Utilization rates			11.62%

HT – total catch; DD - the total carrying capacity.

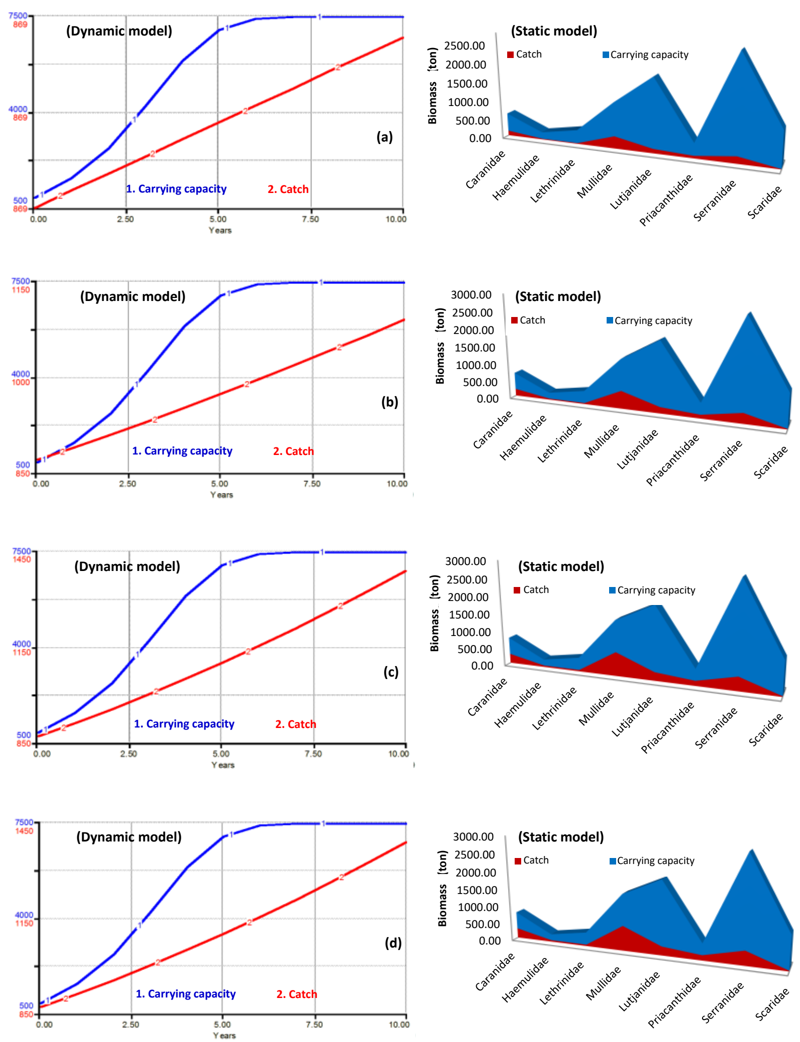
Based on the fishing area, the utilization rates of reef fish were also classified as moderate with a value of 9.23% in the southern zone and of 25.10% in the northern zone (Table 3).

Table 3

The utilization rates of reef fisheries is based on the fishing ground at Ternate Island

Fishing ground	*Utilization rate (%)*	*Category*
South zone	9.23	Moderate
North zone	25.10	Moderate

Reef fisheries management based on utilization rate. The utilization rate of reef fish was used as a comparison referencefor determining reef fisheries policies, based on the probability value of the catch and the carrying capacity as a limiting factor. Management of reef fisheries at Ternate Island was determined based on static and dynamic models. The total catch of reef fish in 2018 was 869.40 tons and the carrying capacity was 7,480.58 tons (Figure 4a). The low reef fish catch rate at Ternate Island was due to the small number of fishing boats, the average fishing effort being of 10 trips per month per boat, with 239 boats available. Static and dynamic models used scenario simulations with an increase of the number of capture attempts from 120 trips year^{-1} or 10 trips month^{-1} to 180 trips year^{-1} or 15 trips month^{-1}. For each scenario, the number of fishing boats was different, ranging from 239 to 750. This simulation was conducted to evaluate the possibility to progressively increase the utilization rate of the reef fish from the previously found level of 11.62%. The simulation was carried out with the assumption that the carrying capacity, growth rate, recruitment, and natural mortality of the reef fish are fixed (Figure 4).



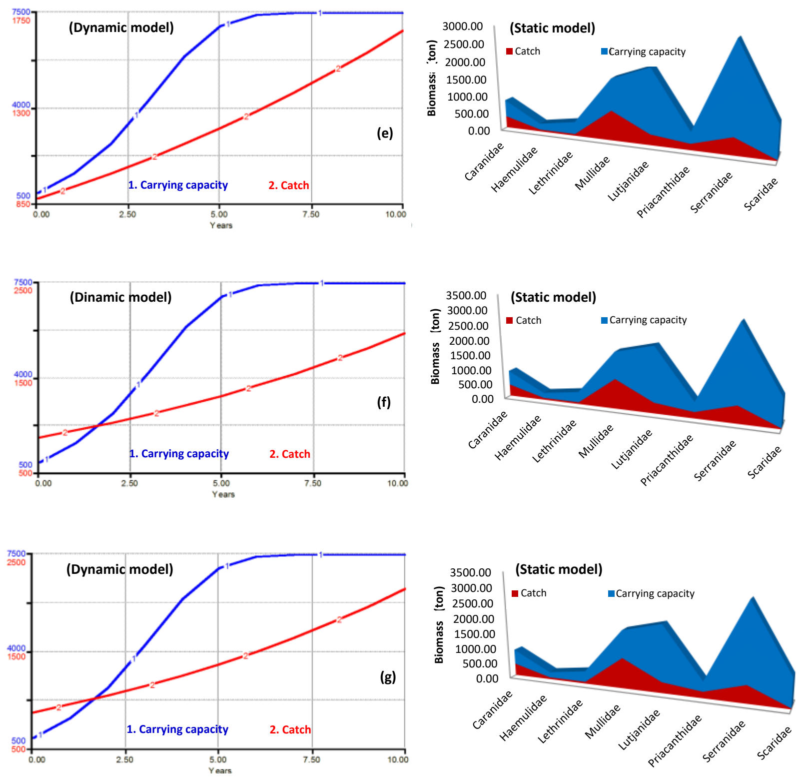


Figure 4. Dynamic and static simulation models of catches, carrying capacity, and utilization rates of reef fisheries; (a) 120 trip year^{-1} with 239 units; (b) 180 trip year^{-1} with 360 units; (c) 180 trip year^{-1} with 478 units; (d) 180 trip year^{-1} with 500 units; (e) 180 trip year^{-1} with 600 units; (f) 180 trip year^{-1} with 700 units; (g) 180 trip year^{-1} with 750 units.

Dynamic and static model simulation results suggested the catch rate could be increased (Tables 4 and 5) in the management plan for reef fisheries at Ternate Island, up to a number of 180 fishing trips year^{-1} with a number of 750 fishing boats and a catch of 2,139.28 tons for the dynamic model and 2,843.83 tons in the static model. The scenario in Figure 4 was preferred, with utilization rates of reef fisheries <50% and an average of 28.63% for the dynamic model and 38.02% of the carrying capacity of the reef fish for the static model.

Table 4

Results of dynamic model simulations

Figure	*Effort (trip year^{-1})*	*Fishing boat (unit)*	*Catch (ton)*	*Increased catch (%)*	*Utilization rate (%)*
4a	120	239	869.40	0	11.62
4b	180	360	1,089.45	20.20	14.58
4c	180	478	1,389.68	37.44	18.60
4d	180	500	1,395.26	37.69	18.67
4e	180	600	1,661.65	47.68	22.24
4f	180	700	1,965.34	55.76	26.30
4g	180	750	2,139.28	59.36	28.63

Table 5

Results of static model simulations

Figure	*Effort (trip year^{-1})*	*Fishing boat (unit)*	*Catch (ton)*	*Increased catch (%)*	*Utilization rate (%)*
4a	120	239	869.40	0	11.62
4b	180	360	1,365.04	36.31	18.25
4c	180	478	1,812.47	52.03	24.23
4d	180	500	1,895.89	54.14	25.34
4e	180	600	2,275.06	61.79	30.41
4f	180	700	2,654.24	67.24	35.48
4g	180	750	2,843.83	69.43	38.02

The results of the analysis and simulation can determine a policy for the Ternate Island reef fisheries management with the following utilization rate approach:

1) Increased fishing effort from 120 trips year^{-1} or 10 trips month^{-1} to 180 trips year^{-1} or 15 trips month^{-1};
2) Increasing the number of a fishing boat from 239 units to 750 units.

Reef fisheries management based on the sustainability status. The sustainability status of the reef fisheries at the research sites on Ternate Island was classified as good with an average value of 73.65 (Table 6). Based on the fishing ground, the sustainability status of reef fisheries was also classified as good, with a value of 72.42 in the southern zone and 75.61 in the northern zone (Table 7).

Table 6

Sustainability status of reef fisheries at Ternate Island

Site number	*Location*	*Value*	*Category*
1	Rua	72.75	Good
2	Kastela	72.59	Good
3	Gambesi	70.91	Good
4	Fitu	76.33	Good
5	Ngade	70.54	Good
6	Kalumata	71.44	Good
7	Falajawa	72.40	Good
8	Gamalama	72.43	Good
9	Daulasi	73.46	Good
10	Tobololo	74.34	Good
11	Sulamadaha	79.47	Good
12	Talaga Nita	76.30	Good
13	Jikomalamo	74.50	Good
Average		73.65	Good

Table 7

Sustainability status of reef fisheries by fishing ground at Ternate Island

Fishing ground	*Value*	*Category*
South zone	72.42	Good
North zone	75.61	Good

In general, the sustainability status of reef fisheries at Ternate Island was classified as good. However, issues might occur if the indicators of each dimension are not properly addressed, with impacts on the reef fisheries management. Based on the sustainability analysis, the most at risk indicators were related to the coral reef ecosystem dimension, the reef fish resources dimension being in a medium category and the governance dimension being in a very good category. The social and economic dimensions of the fishing community had also a good sustainability ranking (Figure 5).

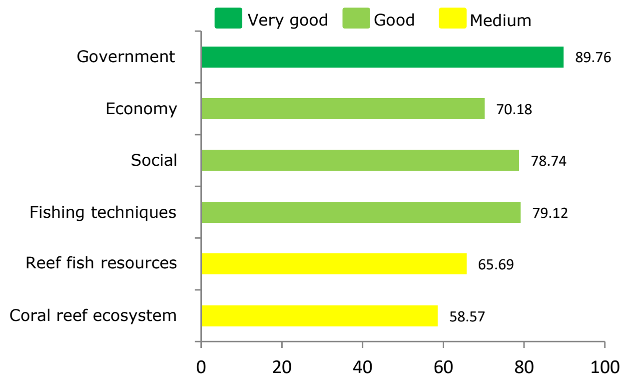


Figure 5. Value of the sustainability status of reef fisheries.

The policy determination for the reef fisheries management, based on their sustainability status, was carried out through a dynamic model approach considering the analysis of the indicators of each of the interrelated dimensions. The initial step taken was to analyze the current reef fisheries management policy without any treatment on the dimensions; the results were used as a comparison reference (Figure 6). In the strategy determination for an ecosystem approach to the reef fisheries management, all the indicators of the coral reef ecosystems sustainability dimensions had to be considered.

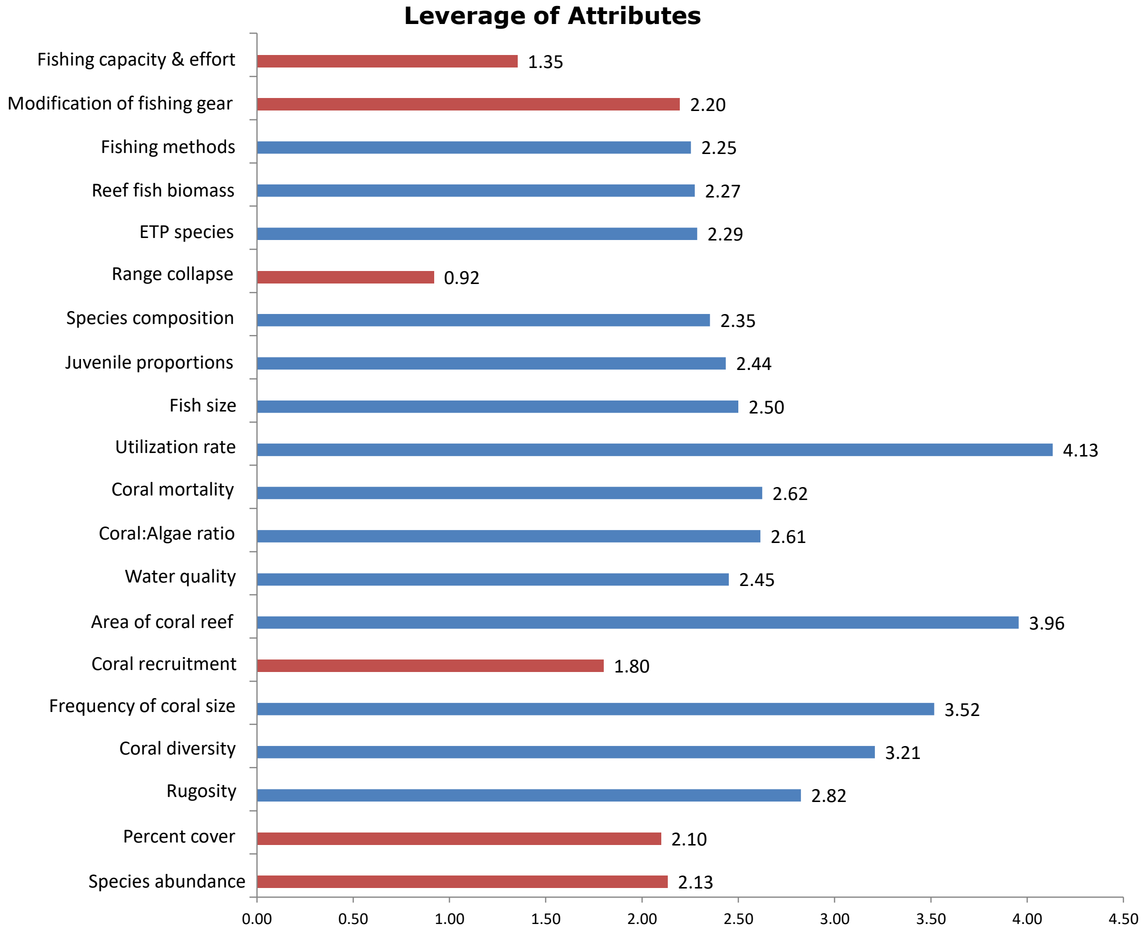


Figure 6. Indicators that must be considered in the strategy of an ecosystem approach to the reef fisheries management.

The current Ternate Island governance reached a good performance for the reef fisheries social-economic management, with a sustainability value of 73.65, but supplementary environmental policies needed to be developed by considering several indicators related to the coral reef ecosystem dimensions, synthesizing the ecosystem health. From the results of the analysis, there could be determined strategy scenarios for an ecosystem approach to the reef fisheries management at Ternate Island:

1) Scenario 1: sustainability status in the current strategy of reef fisheries management. This scenario is based on the results of a study from 2018 about the sustainability status of the policy implementation of reef fisheries management at Ternate Island, simulating the coral reef ecosystems resilience for 10 years, without any treatment, evaluating the influence of the reef fish resources dimensions: fishing techniques, social, economy and ecological governance.
2) Scenario 2: increasing the fishing capacity and effort. This scenario is correlated with the scenario 3 and they are mutually dependent, both scenarios being indicators of the fishing techniques dimensions and candidates for determining the sustainability status of the policy implementation at the Ternate Island reef fisheries over 10 years. The scenario is carried out for fishing ratio value >=1.
3) Scenario 3: modifying the fishing gear and size of the fishing boat. In this scenario the fishing gear and size of the fishing boat are modified with the aim to increase the fishing capacity and catch, in such a way that the size of the target reef fish is at most 25% inferior to the maturity size (Lm), in order to secure fish breeding and growing up, while maintaining the stocks and sustaining the utilization activities for the next 10 years.
4) Scenario 4: preventing increasingly difficult types of target catches and fishing ground.

This scenario is related to the range collapse indicator on the reef fish resources dimensions, a potential issue at the Ternate Island reef fisheries: the results of the MDS analysis in Figure 6 show the low value of the range collapse. The scenario has been carried out over the next 10 years by increasing the value of a relatively fixed range of collapse, for simplicity.

5) Scenario 5: increasing the value of coral recruitment, percent cover, and species abundance.
This scenario is related to coral recruitment indicators, percent cover, and species abundance in the coral reef ecosystems dimensions. The scenario is done by increasing the recruitment value from 2-3 recruits m^{-2} to >3 recruits m^{-2}, increasing the cover percentage from 25-75% to >75%, and increasing the value of species abundance from 10-50 species $100m^{-2}$ to >50 species $100m^{-2}$, for the next 10 years. Increasing the value of the 3 indicators can affect other indicators and the sustainability status of the reef fisheries in the coral reef ecosystem.

The scenario results of the dynamic model can be seen in Figure 7 for scenario 1 and Figure 8 for scenarios 2 to 5. From the scenario results a reef fisheries management strategy is determined based on its sustainability status.

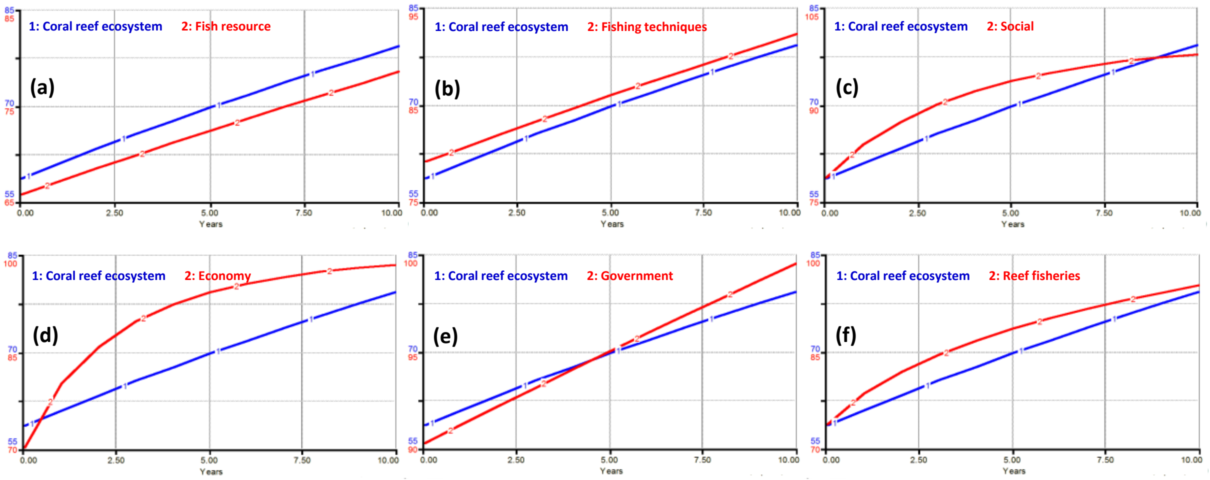


Figure 7. Results of scenario 1; (a) fish resources to the coral reef ecosystems; (b) fishing techniques to the coral reef ecosystems; (c) social community to the coral reef ecosystems; (d) economy community to the coral reef ecosystems; (e) governance to the coral reef ecosystems; (f) reef fisheries management to the coral reef ecosystems.

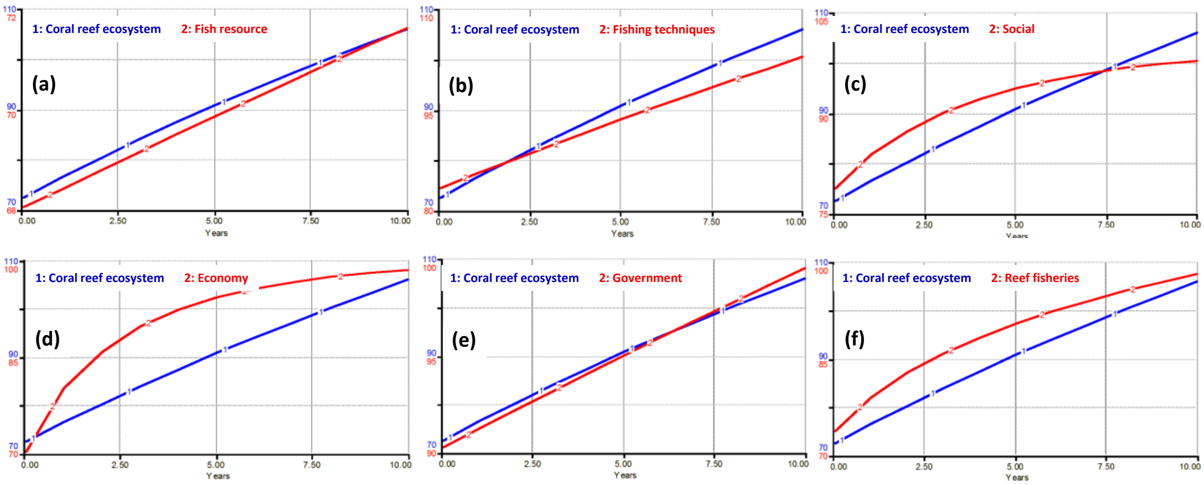


Figure 8. Results of scenario 2 to 5; (a) fish resources to the coral reef ecosystems; (b) fishing techniques to the coral reef ecosystems; (c) social community to the coral reef ecosystems; (d) economy community to the coral reef ecosystems; (e) governanceto the coral reef ecosystems; (f) reef fisheries management to the coral reef ecosystems.

In scenario 1 the sustainability status category is good, but the value of the coral reef ecosystem dimension and fish resource dimension are in the moderate category. The results of scenarios 2 to 5 show a good sustainability status category, with increasing dimension values for the coral reef ecosystem and fish resources (Figure 9).

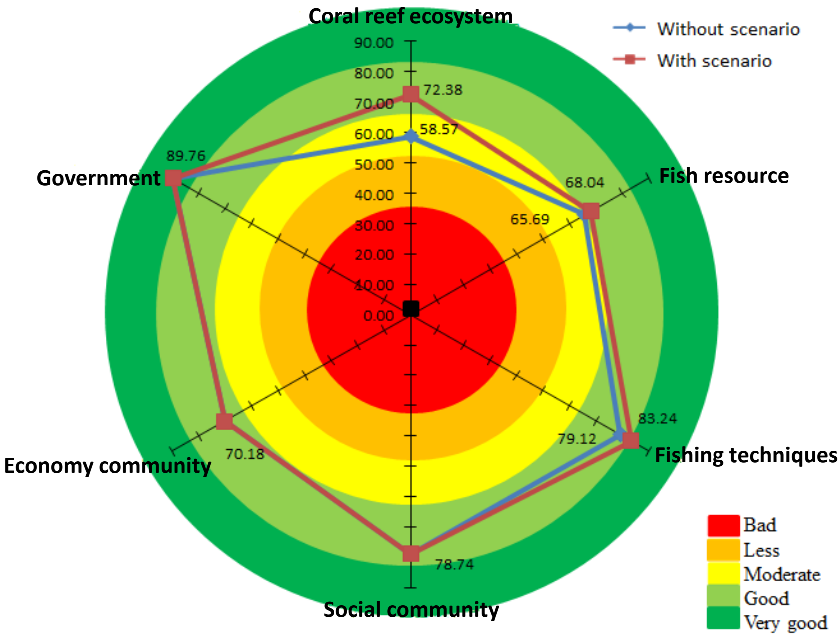


Figure 9. Results of the sustainability status scenario of reef fisheries on Ternate Island.

From the scenario results, a reef fisheries management policy can be determined based on the sustainability status, in order to increase the fishing capacity and effort, making environmentally friendly Fish Aggregating Devices (FADs), and to improve the condition of the coral reefs.

Discussion. The utilization rate and sustainability status are indicator for the assessment of an ecosystem approach to the reef fisheries management, enabling the fish catches targets adjustment to the coral reef ecosystems carrying capacity.

Reef fisheries management based on the utilization rate. The low utilization rate of reef fish on Ternate Island is caused by several factors including the effort level, the fishermen population, the fishing techniques and yield, the fishing boats availability. The effort to catch reef fish is relatively low due to the low frequency of the fishing sessions, at an average of 10 times per month, with a number of only 239 active fishermen and a low capacity of the boats, 30% of which were lacking of engines. Boats without engines are used for the households consumption, only the quantities in excess being marketed.

The parameters used for a static and dynamic models approach to the management of Ternate Island reef fisheries are the catch biomass and carrying capacity, where the catch is determined based on the effort and fishing boats. The model is simulated by increasing the number of effort and fishing boats, aiming to obtain the optimal catch for a given carrying capacity. The model results are used as a reference in determining the fisheries management strategy. The static and dynamic models parameters are: the reef fish utilization rate as a comparison value, the probability value of the catch yield and the carrying capacity as a limiting factor.

The outputsof the dynamic and static simulation models show that the policy for the reef fisheries management should adjust the utilization rate according to the carrying capacity of the coral reef ecosystem, by supporting the increase of the reef fish catch yield.based on. The optimal management strategy would be to increase the effort and the number of fishing boats. This simulation shows that increasing the effort from 120 trips year^{-1} to 180 trips year^{-1} and increasing the number of fishing boats from 239 units to 750 units can increase the catch volumes. Simulations results are of 2,843.83 tons for static models with an increase of 69.43% and 2,139.28 tons for dynamic models with an increase of 59.36%. The utilization rate of the reef fish is 38.02% for the static model and 28.63% for the dynamic model. The above mentioned strategy can be applied to the sustainable management of reef fisheries on Ternate Island, due to a reef fish utilization rate <50% of the carrying capacity.

Reef fisheries management based on the sustainability status*.* Simulation results in scenarios 2 to 5 (Figure 8) show an increasing effect on the dimensions of coral reef ecosystems and reef fish resources. Based on the sustainability status of an ecosystem approach to the reef fisheries management, the results of the simulation can be applied on Ternate Island. Each dimension has a positive influence on the the coral reef ecosystem dimension.

Fish resources to coral reef ecosystems. The results of scenario 1 in Figure 7a show that there is no influence of the fish resources dimensions on coral reef ecosystems, inthe sustainability status determination forthe implementation of the current reef fisheries 10 years management strategy. This is evidenced by an increase in the utilization of reef fish resources followed by a permanent optimization of the condition of the coral reef ecosystems, avoiding significant fluctuations. The results of scenario 4 in Figure 8a show an improvement in the condition of coral reef ecosystems by increasing the value of range collapse in the dimensions of reef fish resources, under the pressure of a reef fish species catching process which is increasingly easier and potentially less disturbing for the ecosystem. This is an issue affecting the permanent reef fishing areasThe values of parameters like the coral recruitment, the percent cover and the abundance of the coral species could affect the existence of reef fish resources.

Fishing techniques to coral reef ecosystems. The process of catching reef fish with the current fishing techniques as well as the dimensions of fish resources does not have an effect on coral reef ecosystems in the sustainability status computation for the implementation of reef fisheries management strategies over the next 10 years (Figure 7b). For the results of scenarios 2 and 3 in Figure 8b show an improvement in the condition of coral reef ecosystems in the first year by modifying the catch in such a way that the size of the target reef fish is at most 25% inferior to the length at first maturity (Lm), which causes an improvement of the fishing capacity and effort and the condition of ecosystems. Another explanatory factor for the above mentioned improvement is the increase in the values of coral recruitment, percent cover, and an abundance of coral species that could affect the existence of reef fish resources.

A social community of fishermen towards the coral reef ecosystem. The social condition of fishing communities in evaluating the status of reef fisheries sustainability is influenced by the stakeholders participation, fisheries conflicts and the use of knowledge in the management of fish resources, including traditional ecological knowledge (TEK). The influence of the social conditions of the fishing community on the coral reef ecosystem did not change in scenario 1 (Figure 7c) or scenarios 2 to 5 with 6 treatments (Figure 8c) over the next 10 years, which shows that the fishing community is very supportive of the implemented strategy conservation in order to maintain the condition of the coral reef ecosystems, which suggest that the current social conditions of the fishing communities can be included into the reef fisheries management policies.

The economy community of fishermen towards the coral reef ecosystems. The effect of the economic conditions of the fishing community on the coral reef ecosystems did not change in scenario 1 (Figure 7d) nor in scenarios 2 to 5 with 6 treatments (Figure 8d) over the next 10 years, which shows that the economic conditions of the community did not cause a decline in the quality of the coral reef ecosystem, in the context of the utilization of reef fish resources, the fishermen income from catches being satisfactory, as evidenced by a saving rate higher than the interest on credit loans or by the reinvested residual profit, an indicator of the increase in the assets ownership. The current economic condition of the fishing community can be maintained for the reef fisheries management policies modeling.

Governance of the coral reef ecosystems. The current governance conditions can be maintained for the reef fisheries management policies for the next 10 years, due to the acceptable results of scenario 1 (Figure 7e), but scenarios 2 to 5 with 6 treatments (Figure 8e) might significantly improve the condition of the coral reef ecosystems. Any law infringement could be found in the process of reef fish resource use and the decision-making mechanism was performant, due to an effective communication between institutions, in accordance with their respectiveprerogatives.

Reef fisheries management to coral reef ecosystems. The reef fisheries management is determined by fish resources, fishing techniques, social community, economic community and governance, and it is intended to maintain the sustainability of coral reef ecosystems under the pressure of the exploiting activities. The scenario scores show a good sustainability status of the reef fisheries and an increased sustainability status value in scenario 1 (Figure 7f) and scenarios 2 to 5 (Figure 8f), which suggest that the 6 treatments applied in the scenario can be used for the Ternate Island reef fisheries management for the next 10 years.

Conclusions. The policy required for an ecosystem approach to the reef fisheries management based on the utilization rate and sustainability status on Ternate Island should focus on: (1) Increasing fishing capacity and catches by rising the effort from 120 trips year^{-1} to 180 trips year^{-1}, modifying fishing equipment and increasing the number of fishing boats from 239 units to 750 units based on the carrying capacity of the coral reef ecosystem; (2) Making environmentally friendly FADs as reef fishing areas; (3) Improving the condition of coral reefs by providing coral planulae growing media.

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