Omni-Akuatika, 19 (1): 15 - 26, 2023
ISSN: 1858-3873 print / 2476-9347 online

Research Article

journal homepage: http://ojs.omniakuatika.net

Sustainability Development Index of Reef Fisheries in Indonesia: A Case Study of Reef Fisheries at Ternate Island, North Maluku Province

Faizal Rumagia[1]*, Mennofatria Boer[2], Rahmat Kurnia[2], Rahmat Kurnia[2], Mohammad Mukhlis Kamal[2]

[1]Study Program of Fisheries Resource Utilization, Faculty of Fisheries and Marine, Khairun University, Jl. Yusuf Abdurrahman, Gambesi, Ternate 97719, North Maluku, Indonesia
[2]Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, IPB University, Jl. Agatis, Lingkar Kampus IPB Dramaga, Bogor 16680, West Java, Indonesia

**Corresponding author: faiz.spl14@gmail.com*

Received 14 August 2019; Accepted 12 January 2023; Available 31 May 2023

ABSTRACT

Increasing of the fisheries problems, especially the decline of fisheries resources stock, made the sustainable issues become intense discussed in fisheries. The importance of the system indicator for fisheries sustainable development are widely known and have been done in several countries through tremendous effort in their fisheries development. In Indonesia, the assessment of fisheries sustainability has been carried out with various approaches to sustainability assessment, mostly on management status. This study aimed to assess the rate of sustainable development and management of the reef fisheries in Indonesia using the integrated index approach of sustainability aspect using the multi-dimensional scaling procedures with a case study of reef fisheries at Ternate Island. The result showed that the sustainable development index of reef fisheries at the coastal area of Ternate Island tends to move toward sustainable development within integrated management from all sustainable dimensions. Dimensionally, economic and social dimensions show a positive trend on sustainable development, while ecological and technological dimensions tend to show the inverse direction. The relationship between economic and social benefits obtained from reef fisheries to improve the community well-being will provide a positive trend for the sustainability of reef fisheries. However, the increase in production may lead to overfishing for the reef fisheries resources. Management policy that integrated every indicator of sustainable fisheries dimension may extend the chance to develop reef fisheries at the coastal area of Ternate Island within the sustainability of the resources and ecosystems management.

Keywords: Sustainable development, integrated management, fisheries management, sustainability index, coral reef

ABSTRAK

Meningkatnya permasalahan dalam bidang perikanan, terutama menurunnya sejumlah stok sumber daya perikanan, isu-isu tentang keberlanjutan semakin sering menjadi pembahasan dalam bidang perikanan. Pentingnya pengembangan sistem indikator untuk pembangunan perikanan berkelanjutan telah dikenal secara luas dan dilakukan oleh beberapa negara melalui upaya yang luar biasa dalam proses pembangunan dan pengembangan sektor perikanannya. Di Indonesia, penilaian keberlanjutan perikanan telah dilakukan melalui berbagai pendekatan penilaian keberlanjutan, dimana sebagian besar terkait pada status pengelolaannya. Penelitian ini bertujuan untuk menilai tingkat keberlanjutan pembangunan dan pengelolaan perikanan karang di Indonesia dengan pendekatan indeks keterpaduan aspek keberlanjutan melalui pendekatan penskalaan multidimensi dengan studi kasus pada kegiatan perikan karang di Pulau Ternate. Hasil penelitian menunjukkan bahwa indeks pembangunan berkelanjutan perikanan karang di wilayah pesisir Pulau Ternate cenderung bergerak ke arah pembangunan yang berkelanjutan melalui pengelolaan terpadu pada seluruh dimensi keberlanjutan. Secara dimensional, dimensi ekonomi dan sosial menunjukkan tren positif dalam pembangunan berkelanjutan, sementara dimensi ekologi dan teknologi menunjukkan kebalikannya. Keterkaitan antara keuntungan ekonomi dan sosial yang dapat diperoleh dari kegiatan perikanan karang untuk meningkatkan kesejahteraan masyarakat, akan memberikan sebuah tren positif bagi keberlanjutan

http://dx.doi.org/10.20884/1.oa.2023.19.1.731

perikanan karang. Akan tetapi, peningkatan produksi dapat mengarah pada terjadinya tangkap lebih bagi sumberdaya perikanan karang. Kebijakan pengelolaan yang mengintegrasikan setiap indikator dari dimensi keberlanjutan perikanan dapat memperbesar peluang pengembangan perikanan karang di wilayah pesisir Pulau Ternate, melalui pengelolaan sumberdaya dan ekosistem yang berkelanjutan.

Kata kunci: Pembangunan berkelanjutan, manajemen terpadu, pengelolaan perikanan, indeks keberlanjutan, terumbu karang

1. Introduction

The prosperity of the present generation can characterize sustainable development without sacrificing the future generations (WCED, 1987). The need to balancing yield from the present and the future, and preserve renewable resources, has become an interest of fisheries scientists since the 1950s (Garcia and Staples, 2000a). However, with the increase of the fisheries problems, especially the decline of fisheries resources stock, sustainable issues have become often discussed in fisheries.

The importance of the system indicator for fisheries sustainable development are widely known and have been done in several countries through tremendous effort in their fisheries development (Liu and Ou, 2007). Different regions will need a different indicator to fulfil their development needs, based on local interest and understanding sustainability itself (Dahl, 2000).

The core of the sustainable development concept came from three fundamental concepts that imply the balancing of three pillars of sustainability, which is (1) environmental sustainability that focuses on maintaining the environmental quality that needs to move the economy and preserve the quality of life of society; (2) social sustainability that makes sure the human rights and equity, conserving the culture identity, awarding the diversity of culture, ethnic, and religion; and (3) economic sustainability that requires to preserve the value of nature, social, and human, also need for incomes and living standards (Klarin, 2018).

The need for a sustainable view in an integrated perspective that includes an ecological, economic, social and institutional aspect in all fisheries systems is acknowledged worldwide. Ecological sustainability involves a long-term awareness of their sustainable use, avoiding the loss of fish stock, and the awareness to conserve and manage the natural resources and species on a specific level within their probability of being developed (Charles, 1994, 2001). Socio-economic sustainability focuses on maintaining or increasing long-term well-fare in the social and economic context, which is based on the integration of the economic and social criteria and cannot be applied separately at the policy level (Adrianto et al., 2005; McClanahan, 2018). Last, institutional sustainability is related to the availability of management regulation tools and their policy where fisheries work, including proper financing management, administration capability, and long-term organizing, as the prerequisite from the three sustainability components explained earlier (Charles, 2001).

It is not easy to understand the interaction of several trends from different indicators. It is more complicated to translate their aim and meaning to the policymakers and the public (Garcia and Staples, 2000a). There are several things to be considered in the development of indicators that integrating different sustainable development dimensions (Dahl, 2000; Garcia and Staples, 2000a; Malkina-Pykh, 2002), which would produce new policy guidance and the better integration of decision making, as well as the public participation in discussion of sustainability status (Krajnc and Glavič, 2005).

The analysis and evaluation of fisheries sustainability have been made through several methods, such as FAO Code of Conduct Compliance (Garcia et al., 1999; Pitcher, 1999), International Instrument Compliance (Alder et al., 2001), RAPFISH method (Pitcher and Preikshot, 2001; Baeta et al., 2005), Traffic Light method (Caddy, 1998, 1999, 2002; Caddy et al., 2005), Sustainable Fisheries Development Indicator System (SFDIS) that developed by Liu et al. (2005), and also the scaling method that describes by Chuenpadgee and Alder (2001) that combine the three methods that mention earlier.

In Indonesia, the assessment of fisheries sustainability has been carried out with various approaches to sustainability assessment, especially on the aspect of management status. The assessment was mainly done using the multi-dimensional approaches through rapid assessment, implemented in various fisheries activities that aim to assess the management and monitoring of fisheries resources through an assessment of the dimension of fisheries development (ecological, economic, social, technological, and institutional). The management assessments mostly only show how much the opportunity can be obtained in managing and utilizing the fisheries resources based on their management attributes. The fisheries sustainability development sometimes only provides a temporary status of what must be done to maintain or improve the related aspects in fisheries management, without giving an idea of how much change had to happen and how sustainable management is needed to improve the utilization and management of the fisheries resource based on the trend of change that occurs. Also, the rapid assessment methods assessment sometimes only assesses the general opinions where problems of each dimension of sustainability are only general, without providing a clear picture of the change that occurs substantively on each of the sustainability dimensions. As a result, the management recommendation is sometimes only temporally and does not provide an overview of the change faced in long-term development. Therefore, this study was carried out to assess the rate of sustainable development and management of fisheries, especially the reef fisheries in Indonesia, using an integrated index approach of sustainability aspect through the multi-dimensional scaling procedures, with the case studies of reef fisheries in the coastal area of Ternate Island, North Maluku Province.

2. Materials and methods

The data was collected through surveys and interview procedures in each stakeholder related to the research objectives, using the purposive sampling method. Several data were collected from the literature study and related institution information. The data collected is data related to reef fisheries in the coastal area of Ternate Island (Figure 1) in six years period, from 2012 to 2017.

The data were analyzed using the multi-dimensional scaling (MDS) procedures to the sustainable development index of ecological, economic, social, and technological dimensions (Pitcher, 1999; Pitcher and Preikshot, 2001; Kavanagh and Pitcher, 2004; Tesfamichael and Pitcher, 2006; Pitcher et al., 2013; Adiga et al., 2015). Attributes that have an influence (positive and negative) on reef fisheries management are assumed to be a factor that is an indicator in the sustainability of reef fisheries management in the coastal area of Ternate Island (Table 1).

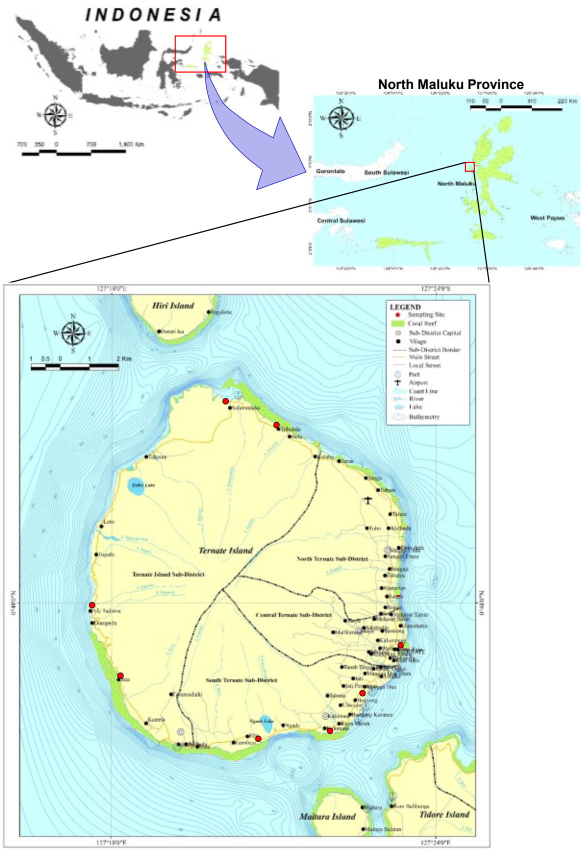

Figure 1. Map of the study area

The integration of development indicators is made through the normalization procedure, in which indicators are scaled to be comparable (Halliday et al., 2001; Reisi et al., 2014). The attribute weighting procedure for all reef fisheries sustainable development indicators was adopted from Krajnc and Glavič (2005). For each dimension, indicators were classified either as positive indicators (I^{+}), indicators whose increasing value has a positive impact on fisheries sustainability and as negative indicators (I^{-}), indicators whose increasing value contributes to the decrease of sustainability. Subsequently, each type of indicator was normalized using the following equations:

$$I^{+}_{N,ijt}=(I^{+}_{ijt}-I^{+}_{min,jt})/(I^{+}_{max,jt}-I^{+}_{min,jt})$$

$$I^{-}_{N,ijt}=1-(I^{-}_{ijt}-I^{-}_{min,jt})/(I^{-}_{max,jt}-I^{-}_{min,jt})$$

where I^{+}_{ijt} and I^{-}_{ijt} is the positive and negative indicators of i from j dimension in time t (year), $I^{+}_{N,ijt}$ and $I^{-}_{N,ijt}$ are the standardized positive and negative of i, and $I^{+}_{min,jt}$ and $I^{+}_{max,jt}$ are the minimum and maximum value attained by each indicator in the time periods considered. Concerning the negative indicators $I^{-}_{min,jt}$ and $I^{-}_{max,jt}$, the nomenclature is the same. The indicator value will range between zero and one.

Table 1. Sustainable reef fisheries development indicators system in the coastal areas of Ternate Island

Dimension	Indicator	Definition	Sustainability
Ecological	Catch per Unit of Effort (CPUE)	Ratio between landings and number of fishing fleet	I^+
	Exploitation rate	The rate of exploitation of target species in reef fisheries	I^-
	Habitat area	Extent of habitat distribution area of the target species	I^+
	Species caught	Number of species that caught, both target and non-target in reef fisheries	I^+
	Water temperature	Average value of annual water temperature	I^-
Economic	Production	Production value of landings	I^+
	Fish prices	Average market price of landings	I^+
	Ratio of production to regional production value	Presentation of the number of production from reef fisheries to the total value of regional fisheries production	I^+
	Fisherman earnings	Earning obtain by fisher from reef fisheries activities	I^+
	Investment	The amount of capital costs incurred in reef fisheries, i.e. for fishing gear, fleet, and maintenance costs	I^-
	Employment	Costs needed to obtain labour needed in reef fisheries	I^+
Social	Fisherman	Number of fisherman that involved in the reef fisheries	I^+
	Aging	Average fishers age	I^-
	Training courses	Number of fishermen that attended training courses	I^+
	Weight of consumed fish per inhabitant	Average weight of consumed fish per capita	I^+
Technological	Fishing day	Average of fishing day in reef fisheries	I^+
	Fishing gear	Various of fishing gear used in reef fisheries	I^-
	Fishing vessel	Number of fishing vessel used in reef fisheries	I^-
	Size of fishing vessel	The size of the fishing vessel used in reef fisheries	I^-

Note: I^+ and I^-: Indicators whose increasing values have a positive and negative impact, respectively, in reef fisheries sustainability. The indicators is modified from Krajnc & Glavič (2005); Pitcher et al. (2013); Adiga et al. (2015).

The integration of normalized indicators from each dimension of sustainable reef fisheries development is adopted from Krajnc and Glavič (2005), where each dimension j a sub-index ($I_{S,j}$) was derived using the equation:

$$I_{S,jt}=\sum_{ji}^{n}(\frac{1}{n_{ij}})I_{N,ijt}^{+}+\sum_{ji}^{n}(\frac{1}{n_{ij}})\ I_{N,ijt}^{-}$$

where $I_{S,jt}$ is sustainability sub-index for j dimension in year t, and nij is the number of indicators of j dimension. $I_{S,ECL}$, $I_{S,ECN}$, $I_{S,SOC}$ and $I_{S,TECH}$ represents the ecological, economic, social and technological sub-indices.

Finally, all the sustainability sub-indices were combined into a composite sustainable development index ($I_{CSD,t}$):

$$I_{CSD,t}=\sum_{ji}^{n}W_j\cdot I_{S,jt}$$

where W_j donates the factors representing a priori weight given to group j of sustainable development indicators, and n is the number of dimensions. I_{CSD} and sub-indices can show in what direction and rate the reef fisheries dimension is moving either towards or away from sustainable development. The parameter rate of sustainable development is calculated as the slope of a linear trend line through the value of IC (r_C) and sub-indices ($r_{S,j}$) in the all-time period. The higher the value, the more significant the improvement of the reef fisheries sector towards sustainability. The procedure for calculating the composite index of sustainable development (I_{CSD}) for reef fisheries at the coastal area of Ternate Island are presented in Figure 2.

The Traffic Light method (TL) (Caddy, 1998, 1999) was first proposed as a system of red (dangerous values), yellow and green (safe values) lights to categories multiple indicators of the state of a fishery and ecosystem to defined Limit Reference Points (Halliday et al., 2001). In this study, instead of the primary or "Strict" TL method, the Fuzzy TL method was adapted (Halliday et al., 2001), which has transitions zones between colours that are fractions of the neighbouring colours. In these transition zones, a given value of an indicator belongs, to some degree, to more than one colour set.

In the absence of external criteria that would convert the colour boundaries into formal reference points, the range of normalized indicators was divided into three equal sectors (Caddy et al., 2005), being the transition zones intervals whose average values are the 33rd and 67th percentiles: the red-yellow transition was from 0.28 to 0.38 and the yellow-green from 0.62 to 0.72. Normalized indicators were compared to this set of decision levels. Simple integration of colours integrated indicators from each dimension: the total area of each colour of the various indicators was added and renormalized to sum to 1 (Halliday et al., 2001).

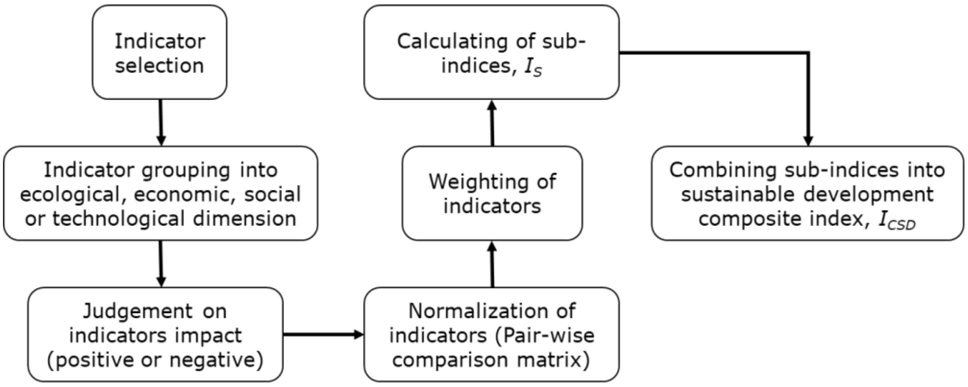

Figure 2. The reef fisheries I_{CSD} calculating procedure (Modified from Krajnc and Glavič 2005).

3. Results and Discussion

The input parameter for each dimension used in the analysis of the sustainable development index of reef fisheries at the coastal area of Ternate Island is shown in **Table 2**. Each indicator was symbolized within their unit measurement. The composite index (ICSD) explains the sustainable development index of reef fisheries at Ternate Island. Data availability gave a limit to the indicators that will be used. However, some other indicators can provide valuable information. Unavailable data at one period will influence the analysis process. Despite the limitations of the data, the indicators used in this study have been able to provide an overview of the sustainability condition of reef fisheries at the study area in the period studied (2012-2017).

Good management requires development actors' broader and active participation in decision-making through transparency works and integrated systematic management. This insistence requires sustainability indicator frameworks in the decision-making and monitoring process (Garcia and Staples, 2000a). Various scientific efforts have been dedicated to sustainable fisheries development and management, with several studies related to sustainability indicators, both in fisheries and other supporting sectors. So they can be helpful to support fisheries science that is related to sustainability fisheries studies (Garcia and Staples, 2000b), as succeed in the present study. The index used in this study was created

Table 2. Input value for sustainable development of reef fisheries at the coastal area of Ternate Island in the period of 2012 – 2017.

Indicator	Symbol	Unit	2012	2013	2014	2015	2016	2017
Ecological ($I_{S,ECL}$)								
• CPUE	CPUE	ton year^{-1}	5,3809	7,9785	6,8943	6,1779	5,8907	5,7789
• Exploitation rate	E_{rate}	-	0,1449	0,2854	0,3262	0,3874	0,4600	0,5624
• Habitat area	$H_{loc.}$	km^2	156,90	155,34	153,81	152,28	149,30	146,37
• Species caught	$N_{fish\ sp.}$	Species	14	14	12	12	11	11
• Water temperature	W_{temp}	°C	29	29	28	29	28	29
Economic ($I_{S,ECN}$)								
• Production	$P_{val.}$	Rp	50007	75840	101672	127505	153338	179170
• Fish price	C_{fish}	Rp	25000	30000	25000	25000	35000	35000
• Ratio of production to regional production value	$Prod_{ratio.count.}$	-	3,43	5,06	4,43	0,95	0,62	0,50
• Fisherman earnings	R_{fisher}	Rp	1.264.000	2.300.400	2.202.900	2.762.600	4.263.600	4.981.900
• Investment	C_{Invest}	Rp	2.500.000	2.500.000	3.000.000	3.000.000	3.500.000	3.500.000
• Employment	C_{temp}	Rp	500.000	750.000	550.000	650.000	1.500.000	1.500.000
Social ($I_{S,SOC}$)								
• Fisherman	N_{fisher}	Pearson	337	359	382	407	432	458
• Aging	F_{age}	-	30	30	25	25	30	35
• Training course	$N_{F.trained}$	Person per activity	101	108	153	140	173	206
• Weight of consumed fish per inhabitant	$Fish_{cons}$	kg per capita	46,37	46,71	48,88	50,75	51,86	52,97
Technological ($I_{S,TECH}$)								
• Fishing day	$N_{fish.\ day}$	day	300	312	312	312	312	312
• Fishing gear	G_{type}	gear per person	4	5	4	5	5	5
• Fishing vessel	V_{count}	Unit	70	93	123	163	203	253
• Size of fishing vessel	V_{size}	GT	3	3	5	5	5	5

Note: Rp = Indonesia currency; GT = Gross tonnage to evaluate a company's performance with time (Krajnc and Glavič, 2005) by displaying the change patterns to preview the sustainable development of reef fisheries over time. Moreover, the traffic light (TL) method used in this study was a precautionary management framework suitable for use in fishery assessment in a data-poor situation, as in the case of the reef fisheries at the coastal area of Ternate Island.

The result shows that in the period from 2012 to 2017, the sustainability development index of reef fisheries at the coastal area of Ternate Island from ecological sustainability ($I_{S,ECL}$) has increased from 0.523 to 0.676 in 2012 until 2014, and then decreased for the next year until 2017, with sustainability rate that moving negatively towards sustainable development (at the rate r_{ECL} = -0.097) (Table 3 and Figure 3a). The $I_{S,ECL}$ had increase in 2016 (IS,ECL,2016 = 0.440), but it decline in 2017.

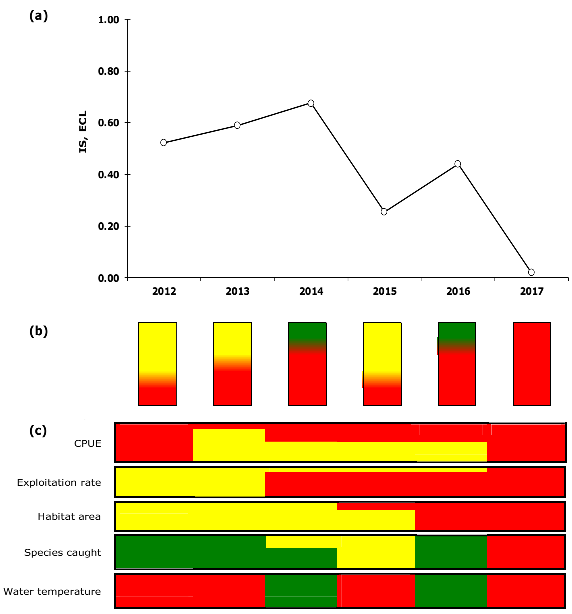

Figure 3. The status of ecological sustainability development index ($I_{S,ECL}$) of reef fisheries at the coastal area of Ternate Island. (a) variation of $I_{S,ECL}$ value, (b) traffic light model for integration of indicators, (c) traffic light conversion of ecological indicators (red = low sustainability; yellow = uncertainty value; green = good sustainability).

The assessment using the weighting method on the indicators of the ecological dimension shows that the ecological development of reef fisheries at the coastal area of Ternate Island tends to be unsustainable (Figure 3b). The sustainability of reef fisheries development had occurred in 2014 and 2016 but declined in the following year; even in 2017, sustainability has more decline. The assessment result for each ecological sustainability indicator indicated that two indicators still influence the sustainability of the reef fisheries at the coastal area of Ternate Island (catches and water temperature). In contrast, other indicators tend to show the opposite pattern (Figure 3c).

The decrease of the ecological sustainability index in the assessment period is caused by the change in the input indicators, where they tend to show a decrease in value each year. Although some indicators indicate the existence of sustainability, the following year had a decrease value, e.g. the number of species caught and the distribution of annual water temperature (Figure 3c). The decline of the sustainability index value of the indicators, such as in the CPUE, exploitation rate, and habitat distribution, is possible due to the change in the number of production and the exploitation rate that occurs in the resources of reef fisheries at the coastal area of Ternate Island. There is a tendency in the change of fishing patterns that capturing at the low trophic level (fishing down to the web) on the resources of the coral reef ecosystem at the study area, may have caused the change in the structure and dynamics of the coral reef population as the fishing ground of the reef fisheries. Moreover, the change of the target species and degradation of the habitat structure are also caused by the high infrastructure development activities along the coastal area of Ternate Island. Those changes lead to the change in the ecological dimensions of reef fisheries so that it affects the value of the sustainability index of reef fisheries in ecological aspects.

Several works of literature documenting the significant changes in the abundance of fish stocks that are unrelated to fishing activities.

Table 3. The ecological sustainability development index ($I_{S,ECL}$) for reef fisheries at the coastal area of Ternate Island

Indicator	2012	2013	2014	2015	2016	2017
CPUE	0.000	0.131	0.076	0.040	0.026	0.020
Exploitation rate	0.131	0.087	0.074	0.055	0.032	0.000
Habitat area	0.131	0.111	0.092	0.073	0.036	0.000
Species caught	0.262	0.262	0.087	0.087	0.000	0.000
Water temperature	0.000	0.000	0.346	0.000	0.346	0.000
Sum ($I_{S,ECL}$)	0.523	0.591	0.676	0.256	0.440	0.020

The results of the latest meta-data analysis show that changes do not occur evenly and often occur in the main parameters of population growth (recruitment, somatic growth, and natural mortality), both from natural or anthropogenic causes (Gilbert, 1997; Vert-pre et al., 2013; Rogers et al., 2013). These changes are often known as regime shifts, where such changes can affect the dynamics of ecosystems and the sustainability of the exploitation of fisheries resources. For example, if the condition of the stock moves to a less productive regime due to changes in water temperature or a decrease in the number of catches, the sustainable catch and exploitation that can maximize yield, in the long run, will also decrease. While this does not mean that stocks are no longer "sustainable", this means that sustainable management of non-reproductive regimes must be different from the productive ones. If the population moves to a more productive regime, the condition of the exploitation rate that was previously unsustainable will again become sustainable (Hilborn et al., 2015).

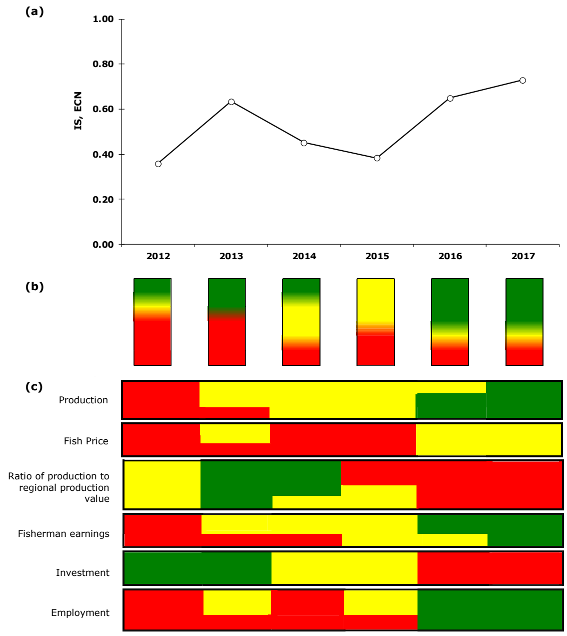

Figure 4. The status of economic sustainability development index ($I_{S,ECN}$) of reef fisheries at the coastal area of Ternate Island. (a) variation of $I_{S,ECN}$ value, (b) traffic light model for integration of indicators, (c) traffic light conversion of economic indicators (red = low sustainability; yellow = uncertainty value; green = good sustainability)

Economically ($I_{S,ECN}$), the sustainability development index for reef fisheries at the coastal area of Ternate Island showed an increase, from 0.359 in 2012 to 0.729 in 2017. However, there was a decrease between 2014 and 2015, but it ascended again in 2016 and 2017 (Table 4 and Figure 4a), with sustainability rates moving positively towards sustainable development (at the rate r_{ECN} = +0.052). The lowest index value is in 2012 (0.359) and increases in the following years with a slight descend in 2014 and 2015. The weighting result shows that the economic dimension tends to increase, although there were declines in 2014 and 2015 (Figure 4b). The fraction of green colour (sustainability indicator) had decreased in 2014, and was even less sustain in 2015 with the dominance of yellow and red colour, but has increased mainly in the following years within the change of green fraction of around 60%. Three of the six indicators used in the assessment (production, fisherman earning, and employment) evolved towards sustainability. In contrast, the other three showed the opposite trend (fish price, the ratio of production to regional production value, and investment) (Figure 4c).

The social sustainability ($I_{S,SOC}$) increased over the assessment period (2012 – 2017), with the sustainability rate tend to move positively towards sustainable development of reef fisheries at the coastal area of Ternate Island (at the rate r_{SOC} = +0.143) (Table 5 and Figure 5a). The highest sustainability value is in 2017 ($I_{S,SOC,2017}$ = 0.778). The weighting result shows that the sustainability of the social dimension began to increase from 2016 to 2017 (Figure 5b), although in the previous years, it tends unsustainable, especially from 2012 until 2013. The assessment of each social indicator reveals that only two indicators tended toward sustainability (training course and weight of consumed fish per inhabitant). In contrast, the other two (fisherman and ageing) tend to show the inverse direction (Figure 5c).

Table 4. The economic sustainability development index ($I_{S,ECN}$) for reef fisheries at the coastal area of Ternate Island

Indicator	2012	2013	2014	2015	2016	2017
Production	0.000	0.044	0.088	0.131	0.175	0.219
Fish price	0.000	0.036	0.000	0.000	0.073	0.073
Ratio of production to regional production value	0.140	0.219	0.188	0.021	0.006	0.000
Fisherman earning	0.000	0.061	0.055	0.088	0.176	0.219
Investment	0.219	0.219	0.109	0.109	0.000	0.000
Employment	0.000	0.055	0.011	0.033	0.219	0.219
Sum ($I_{S,ECN}$)	0.359	0.633	0.451	0.383	0.649	0.729

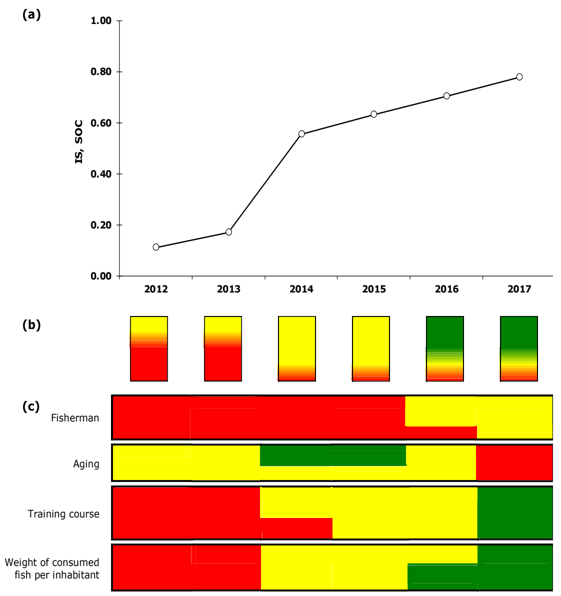

Figure 5. The status of social sustainability development index ($I_{S,SOC}$) of reef fisheries at the coastal area of Ternate Island. (a) variation of $I_{S,SOC}$ value, (b) traffic light model for integration of indicators, (c) traffic light conversion of social indicators (red = low sustainability; yellow = uncertainty value; green = good sustainability).

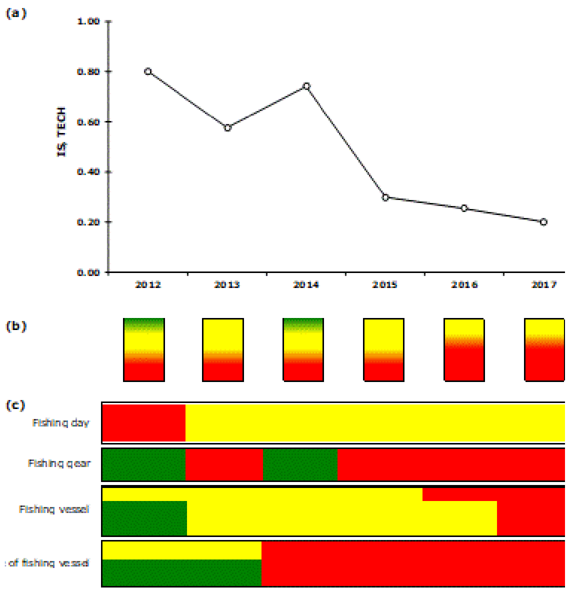

Figure 6. The status of technological sustainability development index ($I_{S,TECH}$) of reef fisheries at the coastal area of Ternate Island. (a) variation of $I_{S,TECH}$ value, (b) traffic light model for integration of indicators, (c) traffic light conversion of technological indicators (red = low sustainability; yellow = uncertainty value; green = good sustainability).

The increasing value of sustainability index in both economic and social dimension (Figure 4 and Figure 5) have previewed the chance of sustainable development of reef fisheries at Ternate Island, where it can influence the rise of state fisheries production, fisherman earning, providing employment for the local community, made a chance for the society to earn better training course for sound fisheries management, also providing added value to the amount of fish consumption per capita for the community at the island.

The technological sustainable development index ($I_{S,TECH}$) for reef fisheries at the coastal area of Ternate Island shows that the sustainability of this dimension tends to be unsustainable with a sustainability rate that moving negatively towards sustainable development (at the rate r_{TECH} = -0.126) (Table 6 and Figure 6a). The $I_{S,TECH}$ had reached a high value in 2014 (0.742), after that it has been showing a decreasing trend. The weighting result shows that the sustainability development of reef fisheries at Ternate Island had unsustainable development from a technological dimension (Figure 6b). Technologically, the sustainability development of reef fisheries has occurred in 2012 and 2014 but has more decline in the next year until 2017. All the indicators of technological dimension tend to move toward unsustainable development for reef fisheries (Figure 6c).

The increase in production can be made through the motorization of fishing fleets. However, consideration for the fleet's number and size is essential for the development stages. Refers to the result obtained from the assessment of technological dimension (Figure 6), which shows tend for unsustainable progress for the reef fisheries in the study area. Overexploitation will affect the composition of an ecosystem, where the alteration of the population and the target species will affect the food webs and the dynamic prey-predator relationship in the ecosystem. For example, the

Table 6. The technological sustainability development index ($I_{S,TECH}$) for reef fisheries at the coastal area of Ternate Island

Indicator	2012	2013	2014	2015	2016	2017
Fishing day	0.000	0.200	0.200	0.200	0.200	0.200
Fishing gear	0.400	0.000	0.400	0.000	0.000	0.000
Fishing vessel	0.200	0.175	0.142	0.098	0.055	0.000
Size of fishing vessel	0.200	0.200	0.000	0.000	0.000	0.000
Sum ($I_{S,TECH}$)	0.800	0.575	0.742	0.298	0.255	0.200

large and high trophic fish population in ecosystem food webs sometimes decreases rapidly rather than the small fishes. Over time, fishing pressure on the ecosystem will change the average size of the catches and the decline of the trophic level of the food webs. This decrease is known as fishing down marine food webs (Kleisner et al., 2015). The use of different fishing gears also extends the negative impact on the marine environment through the destruction of the biological structure of the marine ecosystem. As an example, bottom trawl can cause high mortality to the marine organism and extensive damage to the fish habitat (Clark et al., 2015; Collie et al., 2016).

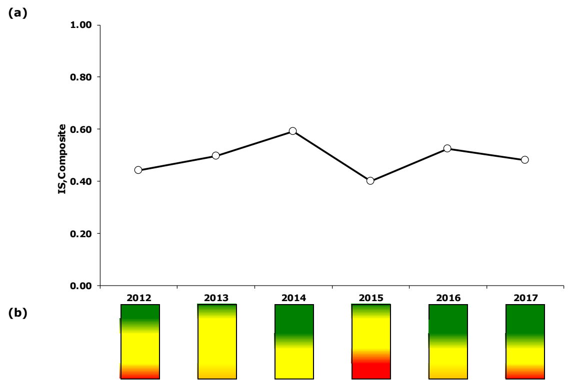

Figure 7. The status of composite sustainable development index (I_{CSD}) of reef fisheries at the coastal area of Ternate Island. (a) Variation of composite sustainable development index (I_{CSD}), (b) overall traffic light result (red = low sustainability; yellow = uncertainty value; green = good sustainability).

Moreover, other marine resources besides the target species can be caught by unselective fishing gears. This bycatch will increase the mortality rate of the resources in the fishing ground (Hilborn and Hilborn, 2012). Pauly and Zeller (2016) stated that between 2000 and 2010, there were 10.3 million tons of discarded bycatch produced from industrial fisheries.

Overall, the assessment of the sustainable development of reef fisheries at the coastal area of Ternate Island from 2012 to 2017 shows that the composite sustainable development index (I_{CSD}) has progressed towards sustainable development, with index value ranging from 0.400 to 0.591 within sustainability rate (r_C) = +0.0023. The highest value was in 2014 ($I_{CSD,2014}$ = 0.591) and the lowest in 2015 ($I_{CSD,2015}$ = 0.400) (Figure 7a). The weighting of all dimensions of sustainability indicated that the sustainability of reef fisheries at the coastal area of Ternate Island tends to increase. However, it had a slight descend in 2015 (Figure 7b). The comparison changes of sustainability index value between the I_{CSD} and the change of each development dimension is presented in Figure 8.

The judgment for the impact of increasing the reef fisheries production at the coastal area of Ternate Island is essential in integrating each sustainable development dimension, i.e. ecological, economic, social and technological dimensions. In their paper, Chapin et al. (2010) state that the integration approaches in the sustainability assessment aim to address socio-ecological sustainability within the recognizing

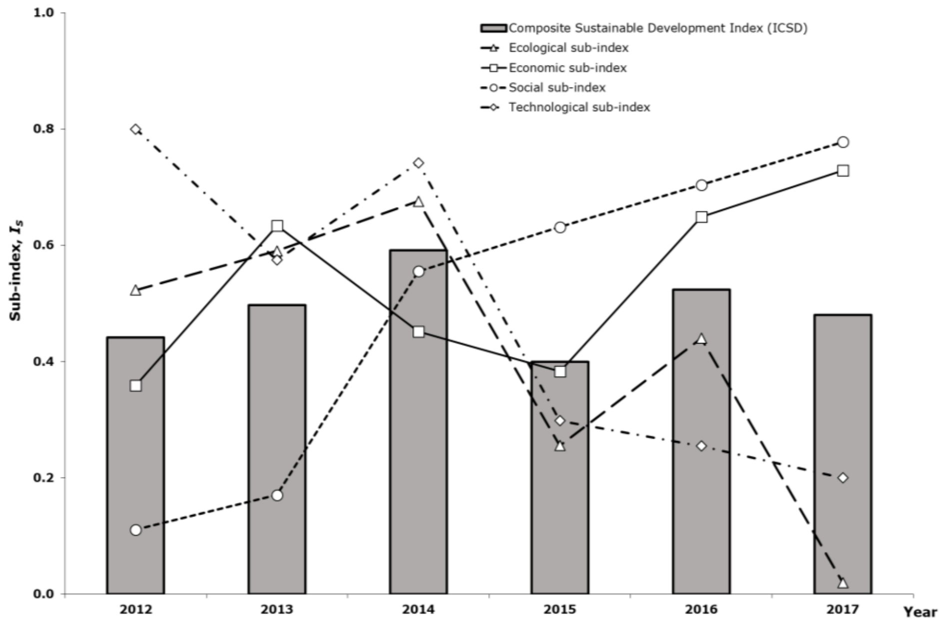

Figure 8. The variation of sustainability sub-indices and composite sustainable development index (I_{CSD}) of the reef fisheries at the coastal area of Ternate Island over a time period of years 2012-2017.

that the society is the integrated component of the system and will both affect and respond to the ecosystem processes. All effort that fails to address the synergies and trade-offs between ecological and societal well-being is unlikely to have a sustainable system.

The relationship between economic and social benefits obtained from reef fisheries to improving the community welfare, especially the fisherman, will provide a positive trend for the sustainability of reef fisheries at Ternate Island. However, on the other hand, the increase in production can lead to overfishing for the reef fisheries resources. Management policy that integrated every indicator of sustainable fisheries dimension may extend the chance to develop reef fisheries at the coastal area of Ternate Island while maintaining the sustainability of the resources and ecosystems.

The global fisheries resources are essential for food security, as well as employment and income. In developing countries, fisheries provide essential protein and micronutrients for their growth (Golden et al., 2016). Since 2014, more than 56 million people have worked in capture fishing and aquaculture (FAO, 2016). Despite their importance and the attention on the overfishing status, the fish stock continues to decline worldwide. Unsustainable fishing is one of the leading causes of this decline, with 31% of the stocks were overfished (WWF, 2016). The scientists predicted that this decline would continue until no more fish stock is expected to be underexploited within twenty years (Pauly and Zeller, 2017). The dramatic changes in fisheries management are needed to protect the global marine system and the community dependence upon the resources. That is why the importance of sustainable development management was needed in the fisheries systems, including the reef fisheries development system in Indonesia.

4. Conclusion

The sustainable development index of reef fisheries at the coastal area of Ternate Island would show a sustainable trend if the development management were done through integrated management of sustainable development dimensions. The change that emerges from each indicator can be a reference point in the management policy. Any problems that arise from these changes can be solved for the sustainable development and management of reef fisheries. The cross-sectoral policy is expected to provide the chance for sustainability management and the utilization of fisheries resources without omitting the resources' sustainability, so sustainable development on each dimension can be achieved.

Acknowledgements

We want to be grateful to all field teams that assist in the research. Special acknowledgement to Mr Aditiyawan Ahmad and Lembaga Kajian Pesisir (M-JIKO Pesisir) for data recorded. Also, we thank all the fisherman at Ternate Island that has provided information about their catch data to support the research.

References

Adiga, M.S., Ananthan, P.S., Ramasubramanian, V., Kumari, H.V.D. 2015. Validating RAPFISH sustainability indicators: Focus on multi-disciplinary aspects of Indian marine fisheries. Marine Policy 60: 202–207. doi:10.1016/j.marpol.2015.06.032.

Adrianto, L., Matsuda, Y., Sakuma, Y. 2005. Assessing local sustainability of fisheries system: a multi-criteria participatory approach with the case of Yoron Island, Kagoshima prefecture, Japan. Marine Policy 29: 9–23. doi:10.1016/j.marpol.2004.01.004.

Alder, J., Lugten, G., Kay, R., Feriss, B. 2001. Compliance with international fisheries instruments. In: Pitcher, T., Sumaila, U.R., Pauly, D. (Eds.), Fisheries impacts on North Atlantic ecosystems, Evaluations and policy exploitation. Fisheries Centre Research Reports Vol. 9 (5): 55-80. Fisheries Centre, University of British Columbia, Vancouver. 94 pp.

Baeta, F., Pinheiro, A., Corte-Real, M., Costa, J.L., Almeida, P.R., Cabral, H., Costa, M.J. 2005. Are the fisheries in the Tagus estuary sustainable? Fisheries Research 76: 243–251. doi:10.1016/j.fishres.2005.06.012.

Caddy, J.F. 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. FAO Fisheries Technical Paper No. 379, Rome. 30 pp.

Caddy, J.F. 1999. Deciding on precautionary management measures for a stock based on a suite of Limit Reference Points (LRPs) as a basis for a multi-LRP harvest law. NAFO Scientific Council Studies 32: 55–68. http://www.fao.org/3/X0550E/x0550e00.htm#Contents.

Caddy, J.F. 2002. Viewpoint: Limit reference points, traffic lights, and holistic approaches to fisheries management with minimal stock assessment input. Fisheries Research 56: 133–137. doi:10.1016/s0165-7836(01)00343-5.
Caddy, J.F., Wade, E., Surette, T., Hebert, M., Moriyasu, M. 2005. Using an empirical traffic light procedure for monitoring and forecasting in the Gulf of St. Lawrence fishery for the snow crab, Chionoecetes opilio. Fisheries Research 76: 123–145. doi:10.1016/j.fishres.2005.06.003.
Chapin, F.S. III., Carpenter, S.R., Kofinas, G.P., Folke, C., Abel, N., Clark, W.C., Olsson, P., Smith, D., Walker, B., Young, O.R., Berkes, F., Biggs, R., Grove, J.M., Naylor, R.L., Pinkerton, E., Steffen, W., Swanson, F.J. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. Trends in Ecology and Evolution 25: 241–249. doi:10.1016/j.tree.2009.10.008.
Charles, A.T. 1994. Toward sustainability: the fishery experience. Ecological Economics 11: 201–211.
Charles, A.T. 2001. Sustainable Fishery Systems. Blackwell Science, Oxford. 370 pp.
Chuenpagdee, R., Alder, J. 2001. Sustainability ranking of North Atlantic fisheries. In: Pitcher, T., Sumaila, U.R., Pauly, D. (Eds.), Fisheries impacts on North Atlantic ecosystems: Evaluations and policy exploitation. Fisheries Centre Research Reports Vol. 9 (5), 49-54. Fisheries Centre, University of British Columbia, Vancouver. 94 pp.
Clark, M.R., Althaus, F., Schlacher, T.A., Williams, A., Bowden, D.A., Rowden, A.A. 2015. The impacts of deep-sea fisheries on benthic communities: a review. ICES Journal of Marine Science: Journal Du Conseil 73 (suppl 1): i51–i69. doi:10.1093/icesjms/fsv123.
Collie, J., Hiddink, J.G., van Kooten, T., Rijnsdorp, A.D., Kaiser, M.J., Jennings, S., Hilborn, R. 2016. Indirect effects of bottom fishing on the productivity of marine fish. Fish and Fisheries 18(4): 619–637. doi:10.1111/faf.12193.
Dahl, A.L. 2000. Using indicators to measure sustainability: recent methodological and conceptual frameworks. Marine Freshwater Research 51(5): 427–433. doi:10.1071/MF99056.
Food and Agriculture Organization (FAO). 2016. The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome. 200 pp. Available from: http://www.fao.org/3/a-i5555e.pdf, Accessed date: 11 November 2018.
Garcia, S.M., Cochrane, K., Van Santen, G., Christy, F. 1999. Towards sustainable fisheries: a strategy for FAO and the World Bank. Ocean and Coastal Management 42: 369–398. doi:10.1016/s0964-5691(99)00026-5.
Garcia, S.M., Staples, D. 2000a. Sustainability indicators in marine capture fisheries: introduction to the special issue. Marine Freshwater Research 51: 381–384. doi:10.1071/MF00000.
Garcia, S.M., Staples, D. 2000b. Sustainability reference system and indicators for responsible marine capture fisheries: a review of concepts and elements for a set of guidelines. Marine Freshwater Research 51: 385–426. doi:10.1071/MF99092.
Gilbert, D.J. 1997. Towards a new recruitment paradigm for fish stocks. Canadian Journal of Fisheries and Aquatic Sciences 54 (4): 969–977.
Golden, C.D., Allison, E.H., Cheung, W.W.L., Dey, M.M., Halpern, B.S., McCauley, D.J., Smith, M., Vaitla, B., Zeller, D., Myers, S.S. 2016. Fall in fish catch threatens human health. Nature 534 (7607): 317–320. doi:10.1038/534317a.
Halliday, R.G., Fanning, L.P., Mohn, R.K. 2001. Use of the traffic light method in fishery management planning. Research Document 2001/108. Canadian Science Advisory Secretariat, Ottawa. 41 pp.
Hilborn, R., Hilborn, U. 2012. Overfishing: what everyone needs to know. Oxford University Press, New York. 150 pp.
Hilborn, R., Fulton, E.A., Green, B.S., Hartmann, K., Tracey, S.R., Watson, R.A. 2015. When is a fishery sustainable? Canadian Journal of Fisheries and Aquatic Sciences 72 (9): 1433–1441. doi:10.1139/cjfas-2015-0062.
Kavanagh, P., Pitcher, T.J. 2004. Implementing Microsoft Excel Software for Rapfish: A Technique for the Rapid Appraisal of Fisheries Status. Fisheries Centre Research Reports 12 (2). The Fisheries Centre, University of British Columbia, Vancouver. 75 pp.
Klarin, T. 2018. The concept of sustainable development: from its beginning to the contemporary issues. Zagreb International Review of Economics and

Business 21 (1): 67–94. doi:10.2478/zireb-2018-0005.
Kleisner, K., Mansour, H., Pauly, D. 2015. The MTI and RMTI as tools for unmasking the fishing down phenomenon. Sea Around Us-University of British Columbia, Vancouver. 12 pp.
Krajnc, D., Glavič, P. 2005. A model for integrated assessment of sustainable development. Resources, Conservation and Recycling 43: 189–208. doi:10.1016/j.resconrec.2004.06.002.
Liu, W.H., Ou, C.H., Ting, K.H. 2005. Sustainable coastal fishery development indicator system: a case of Gungliau, Taiwan. Marine Policy 29: 199–210. doi:10.1016/j.marpol.2004.04.007.
Liu, W.H., Ou, C.H. 2007. A comparative analysis of sustainable fishery development indicator systems in Australia and Canada. Sustainable Development 15: 28–40. doi:10.1002/sd.291.
Malkina-Pykh, I.G. 2002. Integrated assessment models and response function models: pros and cons for sustainable development indices design. Ecological Indicators 2: 93–108. doi:10.1016/S1470-160X(02)00048-1.
McClanahan, T.R. 2018. Multicriteria estimate of coral reef fishery sustainability. Fish and Fisheries 19: 807–820. doi:10.1111/faf.12293.
Pauly, D., Zeller, D. 2016. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nature Communications 7: 10244. doi:10.1038/ncomms10244.
Pauly, D., Zeller, D. 2017. Comments on FAOs State of World Fisheries and Aquaculture (SOFIA 2016). Marine Policy 77: 176–181. doi:10.1016/j.marpol.2017.01.006.
Pitcher, T.J. 1999. Rapfish, a rapid appraisal technique for fisheries, and its application to the code of conduct for responsible fisheries. FAO Fisheries Circular No. 947, Rome. 47 pp.
Pitcher, T.J., Preikshot, D. 2001. RAPFISH: a Rapid Appraisal Technique to Evaluate the Sustainability Status of Fisheries. Fisheries Research. 49: 255–270. doi:10.1016/s0165-7836(00)00205-8.
Pitcher, T.J., Lam, M.E., Ainsworth, C., Martindale, A., Nakamura, K., Perry, R.I., Ward, T. 2013. Improvements to Rapfish: a rapid evaluation technique for fisheries integrating ecological and human dimensions. Journal of Fish Biology 83: 865–889. doi:10.1111/jfb.12122.
Reisi, M., Aye, L., Rajabifard, A., Ngo, T. 2014. Transport sustainability index: Melbourne case study. Ecological Indicators 43: 288–296. doi:10.1016/j.ecolind.2014.03.004.
Rogers, L.A., Schindler, D.E., Lisi, P.J., Holtgrieve, G.W., Leavitt, P.R., Bunting, L., Finney, B.P., Selbie, D.T., Chen, G.J., Gregory-Eaves, I., Lisac, M.J., Walsh, P.B. 2013. Centennial-scale fluctuations and regional complexity characterize Pacific salmon population dynamics over the past five centuries. Proceedings of the National Academy of Sciences 110 (5): 1750–1755. http://www.pnas.org/cgi/doi/10.1073/pnas.1212858110.
Tesfamichael, D., Pitcher, T.J. 2006. Multidisciplinary evaluation of the sustainability of Red Sea fisheries using Rapfish. Fisheries Research 78: 227–235. doi:10.1016/j.fishres.2006.01.005.
Vert-pre, K.A., Amoroso, R.O., Jensen, O.P., Hilborn, R., 2013. Frequency and intensity of productivity regime shifts in marine fish stocks. Proceedings of the National Academy of Sciences 110 (5): 1779–1784. http://www.pnas.org/cgi/doi/10.1073/pnas.1214879110.
World Conference on Environment and Development (WCED). 1987. Our Common Future. Oxford University Press.
World Wilde Fund (WWF), 2016. Living planet report 2016: risk and resilience in a new era. Available from: http://awsassets.panda.org/downloads/lpr_2016_full_report_low_res.pdf, Accessed date: 11 November 2018.