Analysis of human activities and socioeconomic development on the marine ecological carrying capacity (MECC) evaluation index to climate change adaptation in Nunukan Regency, North Kalimantan, Indonesia

A Susandi1,2, A Wijaya1, W S Kuntoro1, I Faisal1, F G Kertabudi1 and I Nurdin1

1Bandung Institute of Technology, Bandung, Indonesia
2Sekolah Tinggi Intelijen Negara (STIN), Bogor, Indonesia
*Corresponding author: armi@meteo.itb.ac.id

Abstract. Research on human activities and socioeconomic development analysis on the Marine Ecological Carrying Capacity (MECC) evaluation index to climate change adaptation at the Sentra Kelautan dan Perikanan Terpadu (SKPT) Nunukan Regency, North Kalimantan in 2015-2019 has been carried out. The purpose of this study was to determine changes in human activity and socioeconomic development of MECC as an evaluation of adaptation and mitigation to climate change. The method used in this research is an approach to the concept of Integrated Ocean Management (IOM) in the form of MECC. MECC can be used as a tool to see the effectiveness and efficiency of a policy on the environment. MECC consists of two components, namely carrying object (OI) and carrier resilience (RI). Carrying object analysis was performed to determine changes in the value of the human activity index and socioeconomic development. The value of the carrying index which consists of human activities (HI) and socio-economic development (SI) activities in Nunukan Regency shows a decline during 2015-2019. The value of HI decreased by 82% from 0.19 in 2015 to 0.03 in 2019 due to increased activity in the fisheries and marine transportation sectors. Meanwhile, the SI value in 2014 was 0.25, down 57% to 0.11 in 2019. This was due to the increase in socio-economic activities in Nunukan Regency. Adaptive capacity can be the main key in preventing a decrease in the carrying index. The form of adaptive capacity carried out by utilizing information, building partnerships among the private and non-private sectors, strengthening stakeholder involvement and control, growing capacity constructing, enforcing regulatory frameworks, and protecting weather change and different environmental adjustments in adaptive management structures.

1. Introduction
In the near future as human population growth, human needs for food, energy, transportation, recreation and other services from the ocean are increasing rapidly [1]. Hence resulted in an unprecedented rate of ocean economy growth. Existing ocean industries are expanding, and with innovation and technology, new ones are appearing. Following the unprecedented growth in economic activities relating to the ocean, the need for a sustainable concept where socioeconomic development can occur without environmental degradation or inequity is widely recognized [2]. Today, sectoral interests and conflicts between short-term economic gains or immediate needs versus long-term prosperity and a healthy ocean are increasingly apparent, creating dilemmas for governance [3]. Meanwhile, marine ecosystems are by nature very dynamic over space and time. There are strong variations in physical, chemical and biological characteristics with depth as a third dimension, unlike
in terrestrial systems. Thus, ocean governance needs to reflect the dynamism of the ocean. Today, the dynamic nature of the ocean is amplified by climate change, which, in the author’s view, is the most serious of all pressures the ocean is currently facing. Many regions already suffer from the effects of climate change and are further complicated by compounding pressures such as pollution and widespread loss of biodiversity, especially the least-developed countries and small island states where coastal communities and even whole countries are threatened, especially Indonesia. These challenges are further exacerbated when ocean management systems are not holistic and adaptable.

Climate change is manifesting itself in tropical marine environments. Sea level rise, ocean warming and deoxygenation, ocean acidification, changing storm intensities, and melting sea ice, as well as migrating species, are examples of consequences of climate change already representing major challenges to ocean management [4]. Current climate projections indicate that societies must prepare for an even more disturbing situation in the future. On the other hand, Indonesia as a country impacted by climate change is not yet ready to address this sudden paradigm in their sustainability development. Henceforth it the forward-looking term, adaptive solutions where risk is explicitly considered will become an even more important element of Ocean Governance. As argued before that there is an increasing need for a holistic, ecosystem-based and knowledge-based overarching approach that ensures the sustainability and resilience of marine ecosystems. This approach must at the same time integrate and balance different ocean uses to optimize the overall ocean economy, as well as maintain and further develop the sector-based management required for effective management of ocean industries (Figure 1). Integrated ocean management (IOM) brings collectively relevant actors from government, business, academia and civil society from the whole spectrum of ocean-related human activities (as an instance, fishing, recreation, petroleum, delivery, renewable strength, aquaculture, tourism and mining) to engage closer to a sustainable future for our ocean surroundings. A key to a hit IOM is the usage of a expertise-based totally and ecosystem-based totally approach. Stakeholder engagement and coordinated selection-making, specifically with ocean organizations, is some other crucial element of successful IOM. IOM in the form Marine Ecological Carrying Capacity (MECC) offers such an approach.

![Figure 1. The ocean industries sector which required effective management [5].](image-url)
In this paper, the authors identify universal characteristics of successful MECC, and the need for tailor-made solutions to address human activities and socioeconomic development for ocean and coastal management for Nunukan regency in different contexts including local knowledge, environmental conditions, scaling-up of local actions, and the need for data sharing and capacity building. The goal of MECC is to preserve the long-term health and resilience of marine ecosystems while improving livelihoods and creating jobs that support a sustainable ocean economy by managing ocean resources in an integrated way. Developing an integrated and adaptive framework for IOM requires forming partnerships between public authorities, businesses, civil societies, academia and the financial sector the so-called penta-helix model. In this respect, MECC represents an important tool that implements IOM for addressing multiple uses while considering the impacts of climate change and improving the resilience of marine ecosystems. With increasing uses of and pressures on the ocean, concerns regarding the cumulative impacts on marine ecosystems have grown. United Nations Convention on the Law of the Sea (UNCLOS) recognizes these concerns on a general basis, while some national governance plans address them specifically and take the approach, such as MECC, that cumulative impacts need to be an integrated part of IOM [5].

To the best of our knowledge, the research on the analysis of the MECC evaluation index to climate change adaptation at the Sentra Kelautan dan Perikanan Terpadu (SKPT) Nunukan Regency, North Kalimantan especially the effect of human activities and socio-economic development is still limited. MECC can be used as a tool to see the effectiveness and efficiency of a policy on the environment. For this reason, this research is very interesting to do and becomes a pioneer in the application of the IOM concept through the MECC approach in the Nunukan Regency.

2. Method

2.1. Study area
Nunukan Regency in North Kalimantan was chosen as the research location for this study. Nunukan Regency is part of the Sentra Kelautan dan Perikanan Tangkap (SKPT) system, which was developed by the Ministry of Marine Affairs and Fisheries (KKP) in one of the 3T areas (Figure 2).

Figure 2. Location of Applied Prototype Test in Nunukan Regency, North Kalimantan.

2.2. Concept of Marine Ecological Carrying Capacity (MECC)
Carrying Capacity is an ecological principle that suggests that a given consumption value will accommodate a limited number of individuals as long as the surrounding ecosystem is not degraded.
This concept explicitly aims to illustrate the relationship between the community as a supported entity (carrying object) and the environment as a support (carrier) to ensure sustainability [6]. Population carrying capacity is theoretically followed by resource carrying capacity, environmental carrying capacity, and finally ecological carrying capacity (ECC) [7]. Many studies have been conducted with a focus on comprehensive regional carrying capacity since the sustainable development policy has become the key guideline in regional socio-economic development. Compared to other ecosystem assessments used in sustainability research, such as those used in health and climate risk studies, the results of this study are more promising [8], the ECC assessment looks at the ocean-atmosphere climate, living things, and their relationships from a more holistic perspective. This metric is easier to understand by the public and policy makers because it offers a holistic understanding of the environmental effects of sustainable economic and social change, as well as revealing capacity deficits and surpluses for specific ecosystem components [9], [10]. The ECC has become a widely used index for the creation of a sustainable regional ecological environment [9]. Human activities (such as fishing), coastal growth, and pollution have all changed and disrupted the ability of marine ecosystems as the marine economy has developed [6] (Figure 3).

**Figure 3.** Marine Ecological Carrying Capacity (MECC) Modeling Concept Chart was adopted from [6].

2.1 Method

Figure 4 represents the method of calculating the carrying index value. The carrying object’s components reflect human activities, such as coastal and aquatic activities that directly suppress the environment (carrier), and socio-economic development, which includes elements that represent coastal communities and economies, as well as coastal security action steps, as shown in Table 1. During the period 2015-2019, data for carrying indicators of Marine Ecological Carrying Capacity...
were collected by combining data from the Nunukan Regency’s Badan Pusat Statistik (BPS) and data from the Visible Infrared Imaging Radiometer (VIIRS).

According to local conditions and data availability, the elements measured for each variable can be modified. The carrying variable is calculated in three steps: (1) standardizing the value of each indicator (element), (2) determining the weight of each indicator (element), and (3) calculating the value of the carrying index. Equations (1) and (2) are used in the first stage to standardize the value of each indicator (element) into the range 0-1. By giving weight to each item, the principal component analysis (PCA) approach is used to extract important information from each indicator in the carrying component, namely the human activity index (HI) and the socio-economic growth index (SI). The following equation (equation 1) can be used to calculate the values for HI and SI based on these two stages:

\[
I_m = \sum_{j=1}^{n} W_j Y_{ij}
\]  

where \( I_m \) is HI or SI; \( W_j \) is the weight for each indicator, and \( Y_{ij} \) is the normalized value for each indicator. For each indicator of these elements can be seen in Table 1.

**Table 1. Indicator of carrying object in Nunukan Regency.**

| Component                      | Elements           | Sub-element          | Indicator                        |
|--------------------------------|--------------------|----------------------|----------------------------------|
| Carrying Objects (OI)          | Human Activities   | Tourism              | Number of visitors               |
| (HI)                           | Fishing            | Annual production of fishing |
| Marine culture                 | Fishing            | Number of aquaculture households |
| Fishing                        |                    | Number of shipping vessel |
| Socio-economic development (SI)| Economy           | Population density    |
| Protective Actions             |                    | PDRB per capita       |
|                                |                    | Number of electricity customers |
|                                |                    | Human development index |
3. Results and discussion

The graph of the carrying index value in Nunukan Regency in 2015-2019 is shown in Figure 5. The carrying index consisting of human activities (HI) and socio-economic development (SI) activities shows a decrease from 2014 to 2019. The value of HI has decreased by 82% from 0.19 in 2015 to 0.03 in 2019, which shows that there is an effect of increasing human activity which continues to increase. Meanwhile, the SI value in 2014 was 0.25, decreasing 57% to 0.11 in 2019. This indicates that the increase in the development of socio-economic activities is not proportional to the increase in the human development index in Nunukan Regency.

![Graph of human activity carrying index (HI) and index carrying socio-economic development activities (SI) in Nunukan Regency 2015-2019.](image)

Figure 5. Graph of human activity carrying index (HI) and index carrying socio-economic development activities (SI) in Nunukan Regency 2015-2019.

Figure 6 shows the value of each HI and SI indicator in 2016, 2017 and 2019 to further explain the trend of each indicator. In the human activity indicator (H1-H4), the value for fish catches production (H2) and the number of ships (H4) in the waters of Nunukan Regency decreased from 2015 to 2019. This indicates that the fisheries industry, both capture fisheries and aquaculture and marine transportation in Nunukan Regency has continued to increase during 2015 to 2019. This can be seen from the increase in the number of captured fisheries products (H2, the average rate of increase is 6%) and the number of fishermen households (H3, the average rate of increase is 1%). In addition, sea transportation activities also increased as seen from the number of ships operating in Nunukan waters (H4, the average rate of increase increased by 4%) while the number of tourists experienced a decline (H1, the average rate of increase decreased by 2%). The increase in activity in this area shows that there has been excessive exploitation in the coastal areas, and it can result in disruption of the stability of the coastal ecosystem in Nunukan Regency.

As the economy increases, the value of each indicator of socio-economic development (S1-S4) also changes. The decline in the value of the socio-economic development indicators (S1-S4) was caused by an increase in socio-economic activities in Natuna Regency from 2015-2019. This can be seen from the increase in population density (S1, the average rate of increase increases by 4%), GDP per capita (S2, the average rate of increase increases by 6%), and the number of electricity users (S3, the average rate of increase increases by 15%). This increase can cause a burden on the coastal environment in Nunukan Regency. Even so, the value of the human development index in Nunukan Regency (S4, the average rate of increase is 1%) which increases can slightly reduce the environmental burden caused by human activities and socio-economic activities that continue to increase.
Based on the explanation of each component in HI and SI, human activities such as the fisheries industry, both capture fisheries and aquaculture and marine transportation as well as an increase in population density are the main factors that cause a decrease in the carrying index value in Nunukan Regency. Therefore, we need a policy step to overcome this. Judging from the IOM approach, adaptive capacity can be the main key in preventing a decrease in the carrying index. The adaptive capacity efforts that are built also function as a form of community adaptation in facing climate change. The form of adaptive capacity carried out in the form of Environmental sustainability includes the efficient utilization of natural resources, pollution prevention, and biodiversity conservation. Economic sustainability focuses on the efficient use of financial resources, economic feasibility, resilience, and the capacity to absorb negative external expenses, and generation of funds for re-investment, while social sustainability focuses on the capacity of aquaculture to provide benefits to communities, such as food security, employment, equality of income and opportunity distribution, and inclusion of the vulnerable population [11].

Figure 6. The value of 8 carrying indicators in Nunukan Regency in 2016, 2017, and 2019.

4. Conclusion
The analysis of the results of carrying index values consisting of human activities (HI) and socio-economic development (SI) activities in Nunukan District shows a decline during 2015-2019. The value of HI decreased by 82% from 0.19 in 2015 to 0.03 in 2019 due to increased activity in the fisheries and marine transportation sectors. Meanwhile, the SI value in 2014 was 0.25, decreasing 57% to 0.11 in 2019. This is due to the increase in socio-economic activities in Nunukan Regency which is not comparable to the increase in the human development index in Nunukan district. The increase in activity in this area shows that there has been excessive exploitation in the coastal area, and it can result in disruption of the stability of the coastal ecosystem in Nunukan Regency. Adaptive capacity can be the main key in preventing a decrease in the carrying index. The form of adaptive capacity carried out in the form of environmental sustainability, economic sustainability, and social
sustainability by utilizing information, building partnerships among the private and non-private sectors, strengthening stakeholder involvement and control, growing capacity constructing, enforcing regulatory frameworks, and protecting weather change and different environmental adjustments in adaptive management structures.

References
[1] OECD 2016 The Ocean Economy in 2030 (Paris: OECD Publishing)
[2] Bennett N J, Cisneros-Montemayor A M, Blythe J, et al. 2019 Nat. Sustain. 2(11) 991–3
[3] Visbeck M 2018 Nat. Commun. 9(1) 1-4
[4] Arnason R, Battista W, Bradley D, Cheung W, et al. 2019 The Expected Impacts of Climate Change on the Ocean Economy [Online] Available: https://www.oceanpanel.org/sites/default/files/2019-12/expected-impacts-climate-change-on-the-ocean-economy.pdf
[5] Winther J G, Dai M, Rist T, et al. 2020 Nat. Ecol. Evol. 4(11) 1451-1458
[6] Ma P, Ye G, Peng X, Liu J, Qi J and Jia S 2017 Ocean Coast Manag 144 23-30
[7] Martire S, Castellani V and Sala S 2015 Resour Conserv Recy 94 11-20
[8] Gaillard J 2010 J. Int. Dev 22(2) 218-232
[9] Wang S, Xu L, Yang F and Wang H 2014 Science of The Total Environment 472 1070-1081
[10] Peng J, Du Y, Liu Y and Hu X 2016 Ecol 60 1017-1030
[11] Valenti W C, Kimpara J M, Preto B L and Moraes-Valenti P 2018 Ecol. Indic. 88 402–413