

Ecological Footprint and Ecosystem Services Models: A Comparative Analysis of Environmental Carrying Capacity Calculation Approach in Indonesia

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Abstract. Calculation of environmental carrying capacity can be done by various approaches. The selection of an appropriate approach determines the success of determining and applying environmental carrying capacity. This study aimed to compare the ecological footprint approach and the ecosystem services approach for calculating environmental carrying capacity. It attempts to describe two relatively new models that require further explanation if they are used to calculate environmental carrying capacity. In their application, attention needs to be paid to their respective advantages and weaknesses. Conceptually, the ecological footprint model is more complete than the ecosystem services model, because it describes the supply and demand of resources, including supportive and assimilative capacity of the environment, and measurable output through a resource consumption threshold. However, this model also has weaknesses, such as not considering technological change and resources beneath the earth's surface, as well as the requirement to provide trade data between regions for calculating at provincial and district level. The ecosystem services model also has advantages, such as being in line with strategic environmental assessment (SEA) of ecosystem services, using spatial analysis based on ecoregions, and a draft regulation on calculation guidelines formulated by the government. Meanwhile, weaknesses are that it only describes the supply of resources, that the assessment of the different types of ecosystem services by experts tends to be subjective, and that the output of the calculation lacks a resource consumption threshold.

1. Introduction

Calculation of environmental carrying capacity is needed to determine the limits of a region's capacity to support population activities, such as natural resource consumption and waste discharge into nature. In Indonesia, environmental carrying capacity is normatively described in Law of the Republic Indonesia No. 26 Year 2007 on Spatial Planning, and Law of The Republic Indonesia No. 32 Year 2009 on Environmental Protection and Management.

The calculation of environmental carrying capacity can be done using various approaches. Method selection is one of the main issues in determining environmental carrying capacity. Proper selection determines the success of the establishment and implementation of environmental carrying capacity. There are two relatively new of environmental carrying capacity calculation approaches, i.e. the



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ecological footprint and the ecosystem services approach. The present study aimed to compare the implementation possibility of ecological footprint models and ecosystem services models in Indonesia.

2. Research Method

The method used in this study to compare the implementation possibility of ecological footprint and ecosystem services models is descriptive research. The aim of descriptive research is to describe phenomena related to the object of study, whether natural or human engineering [1]. Descriptive research can use a quantitative approach by collecting and measuring data in the form of numbers, or a qualitative approach by representing the situation as it is using words. This research tends more to qualitative description because it explains the differences between the two models in a narrative manner.

Each model is explained based on predetermined criteria, namely government policy, conceptualization and calculation, output and usage calculation, and data availability. The necessity of analyzing in terms of government policy is related to the mandate of Law of the Republic Indonesia No. 32 Year 2009 on Environmental Protection and Management, which states that procedures for determining environmental carrying capacity will be regulated by government regulations. In order to formulate these regulations, it is important to consider the selection of the environmental carrying capacity calculation approach. Each calculation approach requires different data and produces different outputs. The calculation thus depends on data availability and the method of data collection. Meanwhile, the calculation output is related to its use, for example for spatial planning or strategic environmental assessment (SEA).

In terms of data sources, this study used secondary data, i.e. data sourced from other parties and used by the authors as supporting data. The types of secondary data utilized in this study include research reports, scientific articles, and regulations. Data were collected through literature tracking sourced from scientific journals and government agencies. Data analysis was done by content analysis, i.e. pulling information from reports or written documents to make direct conclusions. Then the data were analyzed descriptively and compiled based on predetermined criteria.

3. Sustainable development and environmental carrying capacity

The environmental carrying capacity of a region has a close relationship with its sustainability. In the context of regional development, the environment is an important aspect to be considered as supporting development and as an object affected by it.

3.1. Sustainable development

Practically speaking, development is like two different sides of a coin. On the one hand, development is as an attempt to achieve an improved situation related to physical, social, cultural and economic aspects. On the other hand, development also has a paradoxical effect in the form of environmental degradation. Development trends that only pursue economic growth are a common threat to environmental conditions.

Reflecting this, the sustainable development paradigm currently has been adopted in almost all countries. The basic definition of sustainable development was first proposed by the Brundtland Commission or World Commission on Environment and Development in 1987, namely the development of life to meet the needs of the present generations without compromising the ability of future generations to meet their needs [2]. In brief, sustainable development is development that seeks to synergize economic, social, environmental goals and ensure a good quality of life for present and future generations. There are three main pillars of sustainable development: economic, environmental, and social, which are assumed to be interconnected. These three aspects should be applied in a balanced government policy to achieve sustainable development.

3.2. Environmental carrying capacity as a pillar of sustainable development

The process of development affects the environment as supporting development and an object affected by it. If the environment is well maintained, ecological functions and availability of natural resources

can support development well. Conversely, if the environment is damaged or polluted due to the impacts of development, sustainable development will be compromised.

The environmental carrying capacity needs to be known to determine how much development the environment can support. In addition, the ability of the environment to absorb the waste generated from development activities needs to be known in order to determine the limits of disposing waste resulting from human activities in nature. If the development exceeds the capacity of available resources and the capacity to absorb waste, the development is inefficient and will reduce the quality of the environment, or it can be said to be unsustainable. Therefore, the environmental carrying capacity has a close relationship with sustainable development.

4. Environmental carrying capacity concept

As a concept, environmental carrying capacity has a theoretical basis that continues to develop. This section discusses the development of the conceptualization and modeling of environmental carrying capacity.

4.1. Environmental carrying capacity concept

The concept of environmental carrying capacity is derived from the management of livestock and wildlife [3,4]. Environmental carrying capacity shows the magnitude of the environment's ability to support animal life expressed in number of individuals per unit area. Environmental carrying capacity can also express the number of individuals supported by their habitat to be healthy and strong. According to Rees and Wackernagel [5], environmental carrying capacity is defined as the maximum population of a particular species that can be supported in a habitat without permanently damaging habitat productivity.

Then, the concept of environmental carrying capacity was applied to human populations. In that context, the environmental carrying capacity limit is the number of individuals that can be supported by a comprehensive set of resources and an environment that can provide resources while it remains in a prosperous state [4]. In this case, environmental carrying capacity has two components, i.e. the size of the human population and the resources and environment that provide welfare to the human population. According to Guwahati [6], environmental carrying capacity is an ecological concept that also includes social and economic parameters. The quality and state of the ecosystem is affected by the social and economic conditions and likewise human life is also affected by the condition of the ecosystem. Khanna et al. [7] state that environmental carrying capacity consists of the ability to support human life (supportive capacity) and the ability to accept pollution load (assimilative capacity), as depicted in Figure 1.

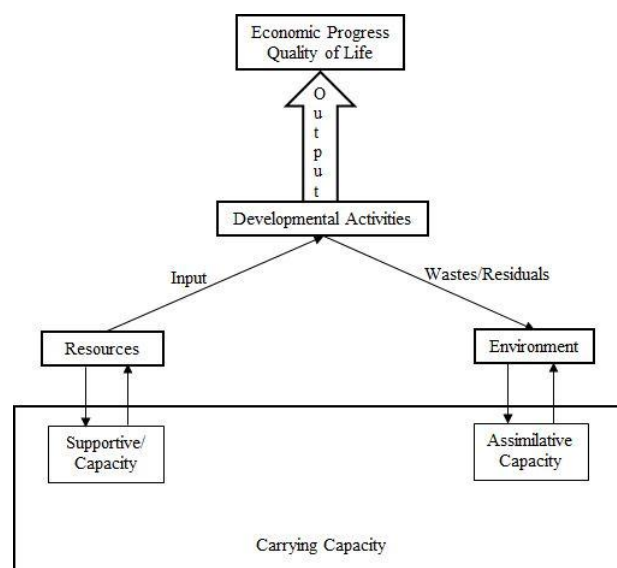


Figure 1. Elements of carrying capacity [7]

According to the above mentioned definitions of environmental carrying capacity, we can formulate the main concept of environmental carrying capacity as follows:

- environmental carrying capacity is the maximum population that can be supported in a habitat without permanently damaging the productivity of that habitat;
- environmental carrying capacity is an interaction between availability of natural resources and natural resources demand by specific populations; and
- environmental carrying capacity consists of the ability to support life (supportive capacity) and the ability to accept pollution load (assimilative capacity).

4.2. *Environmental carrying capacity policy in Indonesia*

Environmental carrying capacity in Indonesia is textually stated in some rules, especially in Law of the Republic Indonesia No. 26 Year 2007 on Spatial Planning and Law of the Republic Indonesia No. 32 Year 2009 on Environmental Protection and Management. The regulations describe the use of environmental carrying capacity in spatial planning [8, 9], natural resources utilization, and implementation of strategic environmental assessment (SEA) [9].

Law of the Republic Indonesia No. 32 Year 2009 on Environmental Protection and Management divides the concept of environmental carrying capacity into two capacities, i.e. supportive capacity and assimilative capacity [9]. The supportive capacity is the ability of the environment to support humans, other living beings, and the balance between the two. Meanwhile, assimilative capacity is the ability of the environment to absorb or incorporate substances, energy, and/or other components [9].

4.3. *Environmental carrying capacity model*

There are various approaches or models to calculate environmental carrying capacity. Regulation of the Minister of the Environment of the Republic of Indonesia No. 17 Year 2009, containing Guidelines for Determining Environmental Carrying Capacity in Spatial Planning, stipulates land carrying capacity method, land supply and demand ratio, and water supply and demand ratio [10]. In addition there are also other environmental carrying capacity calculation approaches, such as the ecological footprint model, a graphical model, the unconstraint model, the IPAT equation, the PSR (pressure, state, response) model [6], and the ecosystem services model [11]. Each of these has a correlation to the environmental carrying capacity concept as shown Table 1 below.

Table 1. Correlations between environmental carrying capacity models and concepts [12]

Environmental carrying capacity model	Concept ^a	Concept ^b	Concept ^c	Concept ^d
1. Land capability			v	
2. Land supply and demand ratio	v	v	v	
3. Water supply and demand ratio	v	v	v	
4. Graphical model (logistic growth)	v		v	
5. Uni constraint model	v	v	v	
6. IPAT equation			v	v
7. PSR model			v	v
8. Ecological footprint	v	v	v	v
9. Ecosystem service			v	v

^a Maximum population supported by a sustainable environment

^b Interaction between availability and demand resources by a certain population

^c Ability to support life

^d Ability to absorb pollutant load

4.3.1. Ecological footprints model. The ecological footprint concept was introduced by William Rees in 1992, which he then further developed together with Mathias Wackarnagel. Until now, research and development of the ecological footprint approach is being done by researchers who are members of the Global Footprint Network.

Rees [13] revealed that in relation to human life, the environmental carrying capacity can be seen as the maximum average consumption of resources and sustainable waste disposal in an area without damaging the functional unity and productivity of the ecosystem. The total amount of productive land needed by human activity is called the ecological footprint. No areas are seen as independent units [13]. In fact, the population of a region that has exceeded the area of environmental carrying capacity depends on trade to survive.

Calculation of the environmental carrying capacity by the ecological footprint model consists of three steps, as show in Figure 2 for a national footprint framework [14]:

- ecological footprint, which is a measurement of population demand and activity that occurs in the biosphere in a given year;
- biocapacity, which is the measured amount of biologically productive land and sea areas that is available to provide ecosystem services for human consumption as ecological budget or natural regeneration capacity; and
- ecological deficit/surplus, obtained by calculating the difference between ecological footprint and biocapacity.

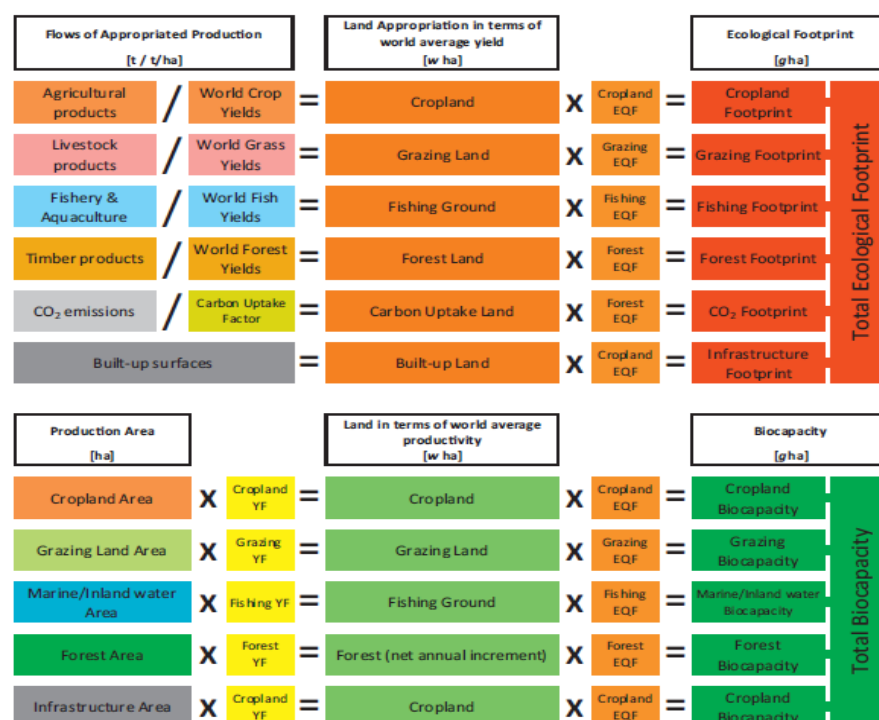


Figure 2. National Footprint Accounts (NFA) accounting framework [14]

The calculation of an ecological footprint uses two conversion factors, i.e. a yield factor and an equivalent factor. The yield factor is the ratio between the productivity within the same land category in an area and the average productivity of land in the world in the same year. The equivalent factor is a factor that converts certain local units to universal units, namely global hectares (gha). One global hectare is defined as one hectare of land (soil and water) in a given year equivalent with world average productivity, i.e. about 12 million hectares [14].

4.3.2. Ecosystem service model. The ecosystem services model was initiated by the Ministry of Environment and Forestry, Republic of Indonesia. Ecosystem services are the benefits that people

obtain from various resources and natural processes, which are jointly provided by an ecosystem [11]. Ecosystem services are grouped into four types, i.e. provisioning, regulating, supporting, and cultural, which refers to the methodological framework of Millennium Ecosystem Assessment [15], as shown in Table 2 below.

Table 2. Type of ecosystem services by benefits [15]

Type of ecosystem service	Type
1. Provisioning	1. Food 2. Fresh water 3. Fiber 4. Fuel, wood, and fossil 5. Genetic resources
2. Regulating	1. Climate regulation 1. Water regulation 2. Natural hazard regulation 3. Water purification 4. Waste treatment 5. Air quality regulation 6. Pollination 7. Pest regulation
3. Cultural	1. Residential and living space 2. Recreation and ecotourism 3. Aesthetic values
4. Supporting	1. Soil formation and fertility 2. Nutrient cycle 3. Primary production 4. Biodiversity

Environmental carrying capacity in the ecosystem services model assumes that the higher the value of the ecosystem services, the higher the environmental carrying capacity. Two estimates are used for obtaining ecosystem services, i.e. landscape or ecoregion (landscape based proxy) and land cover (landcover/landused based proxy). This information is used as a basis for mapping environmental carrying capacity [11].

Calculation of an ecosystem services model produces a map of the types of ecosystem services in an area. A specific ecosystem services map looks at each ecoregion category with a specific ecosystem services index, ranging from low, moderate and high to very high. The index of the ecosystem services map uses an ordinal scale, which is used for differentiating and sorting but without indicating amount or degree.

5. Comparison of ecological footprint and ecosystem services model

As a relatively new calculation approaches of environmental carrying capacity, the ecological footprint model and the ecosystem services model need to be further analyzed in terms of 1) government policies, 2) concept and calculation approach, 3) calculation output and usage, and 4) data availability. The following comparison of these models aims to determine the possibility of its application in Indonesia.

5.1. Government policies

The ecological footprint model has not been included in any regulations of the Indonesian government, but the government has stated that calculation of environmental carrying capacity can be established through other approaches in accordance with scientific development. According to the

Ministry of Environment and Forestry, as quoted by Subekti [12], in principle, the selection of environmental carrying capacity calculation approach should pay attention to the following:

- accuracy of information generated by needs of use and/or understanding;
- consistency of information continuation within a certain time frame for policy formulation; and
- availability of data.

In terms of policy, the ecosystem services model is in line with Law of the Republic Indonesia No. 32 Year 2009 on Environmental Protection and Management, which states that one of the strategic environmental assessment (SEA) analyses is ecosystem services [9]. Ecoregion based ecosystem services analysis is also in accordance with ecoregion zoning and environmental inventory, which are tasks of the national government and local governments. Based on this, the Ministry of Environment and Forestry has drafted regulations governing guidelines for ecosystem services based on environmental carrying capacity [12].

5.2. Concept and calculation approach

Both the ecological footprint model and the ecosystem services model have different relevance to the environmental carrying capacity concept, as can be seen in Table 1 above. The ecological footprint model conceptually shows capacity and availability of natural resources, as well as ability to absorb wastes. Capacity and availability of natural resources are shown through biocapacity, which is the productive area of land and water in the form of cropland areas, grazing land areas, marine/inland water areas, forest areas and infrastructure areas. Meanwhile, the biological capacity to absorb waste is indicated by the capacity of forests as carbon sinks. In addition to resource capacity, the ecological footprint model is also able to describe the demand for natural resources, including demands for agriculture, forestry, fisheries, animal husbandry, carbon emissions and developed land. Therefore, the model can describe supply and demand of resources in calculating environmental carrying capacity. For example, the demand for the agriculture sector is represented in the ecological footprint of agriculture related to the biological availability of land for producing agricultural products. While conceptually quite complete, the ecological footprint model also has weakness, i.e. it does not consider technological changes – one of the main factors in the utilization of resources – and does not take resources beneath the earth into account [16].

Conceptually, the ecosystem services model has common ground with environmental carrying capacity, i.e. the capacity and availability of natural resources through providing services (food and water), cultural and supporting, as well as the capacity of a region to absorb waste through regulating services (air quality, carbon sequestration, and waste absorption regulations). The ecosystem services model further represents the supply of natural resources but is not able to describe resource demand in calculating environmental carrying capacity [12].

Due to using different concepts, both models also have different calculation approaches. In terms of unit of analysis, there is not much difference between the ecological footprint and the ecosystem services model. Both models can be applied for specific areas or units of analysis, such as national (islands), provinces and districts/cities, as well as for activities or sectors. The difference is that the unit of analysis of the ecosystem services model is based on ecoregions and land cover. In terms of analysis technique used, the ecological footprint model uses mathematical formula to calculate consumption and capacity of natural resources embodied in global hectares. The ecosystem services model uses a geographic information system. This analysis produces a map of ecosystem services types within a region, which has an index or score of certain ecosystem services. The scoring method is based on expert valuation, i.e. assessment by an expert panel on the roles of land cover and ecoregions in relation to the types of ecosystem services. Furthermore, the assessment results are analyzed using pairwise comparison as part of the analytic hierarchy process (AHP) method to produce an index or weight of variables in the decision making process [11]. Assessment by experts tend to be subjective, so there is the possibility of differences in ratings between them.

5.3. Output of calculation and usage

The ecological footprint model produces values for natural resources demand (ecological footprint), natural resources availability (biocapacity), and status of environmental carrying capacity realized in global hectare units. The output of the ecological footprint model implies a threshold of resource consumption, which is not allowed to exceed the capacity of natural resources. The status of the environmental carrying capacity becomes a deficit if the ecological footprint total is greater than its biocapacity. Meanwhile, the status of the environmental carrying capacity becomes a surplus if the total ecological footprint is smaller than its biocapacity. Based on the National Footprint Account, Indonesia has had an ecological deficit since 2002. This means that per capita consumption of Indonesian society exceeds the carrying capacity of the natural environment, as shown in Figure 3.

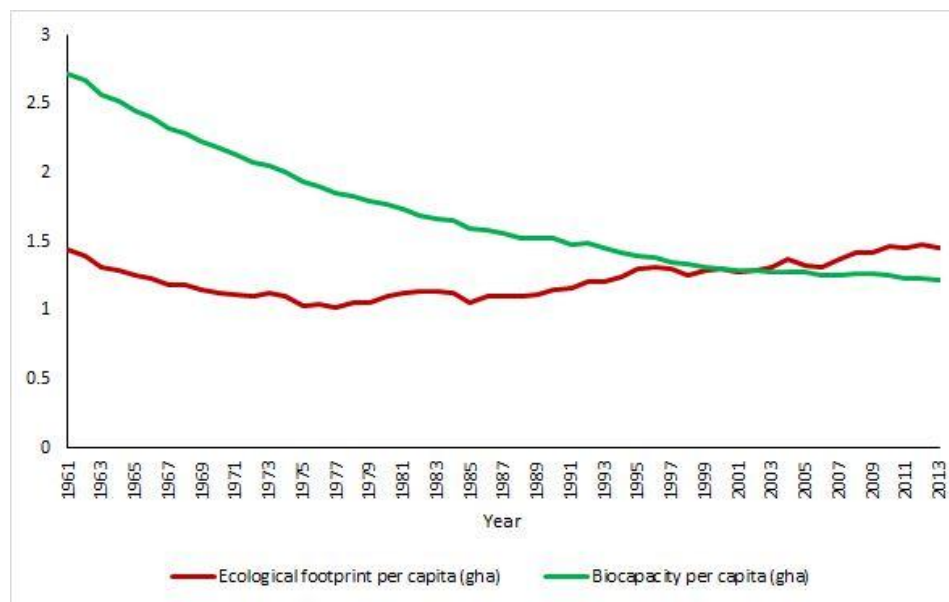


Figure 3. Graphic of Indonesia's per capita ecological footprint and biocapacity 1980-2013 [17]

In terms of information consistency, ecological footprint output can change each year, because the input data on production, exports and imports for each demand sector and the population change annually. The ecosystem services analysis produces a map of ecosystem services types. Specific ecosystem service maps show each ecoregion class with scores or an index range of particular ecosystem services, ranging from low to medium to high, as shown in Figure 4. However, the ecosystem services model is not able to set a resource consumption threshold because it uses an ordinal scale. The output of the ecosystem services model covers relatively long time periods, because the data input, including ecoregions and land cover information, change over a relatively long time period.

Based on the regulations, environmental carrying capacity calculation is carried out in the framework of spatial planning [8,9], natural resources utilization, and implementation of strategic environmental assessment (SEA) [9]. Ecological footprint output can be utilized in such cases. For example, when there is an ecological deficit, development planning should be fixed in accordance with SEA recommendations. These recommendations can be seen in terms of supply and demand. From the supply side, allocation of space utilization must be provided and maintained, both allocation of cultivation areas and protected areas. Area allocation must be adjusted to the demand or resource consumption of the average population in the region. In the ecosystem services model, the most dominant information within a region will determine the level of management. For example, water supply as an ecosystem service in a region is dominant because of vast forests in good condition. Therefore, allocation of land uses should emphasize forest areas maintained in protected areas. Because the ecosystem service model is based on ecoregions, water supply functions must be seen in ecoregion perspective across administrative boundaries. This implies a need for coordination and

cooperation between provinces or district/cities. Between both models there is a difference in use. Firstly, the ecological footprint model can provide more scalable information than the ecosystem services model. Secondly, the ecosystem services model can see geographic distribution of ecosystem service types within a region.

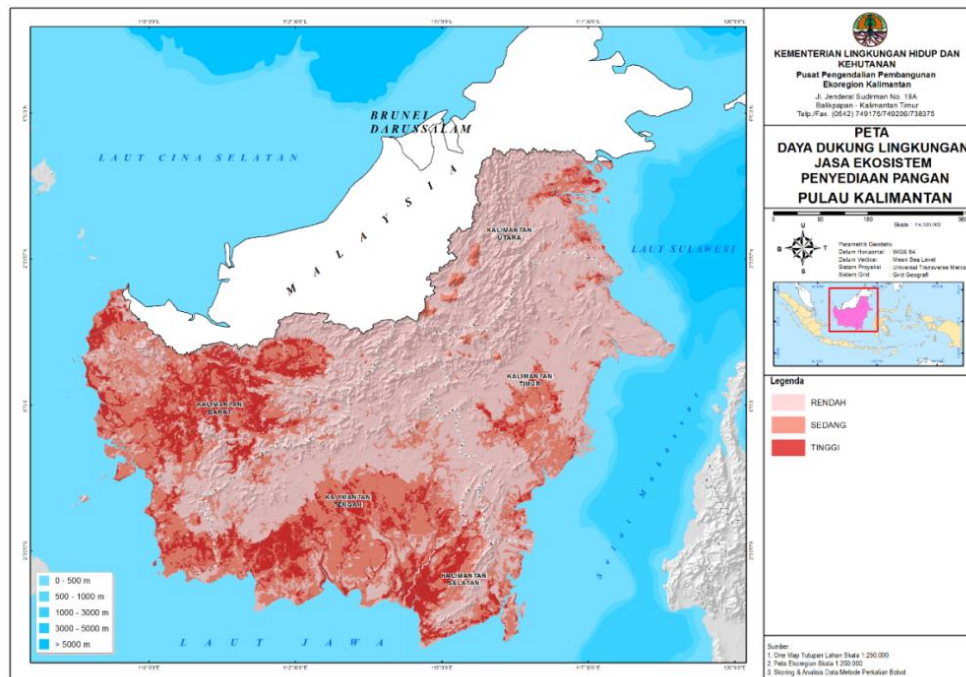


Figure 4. Map of food type services in Kalimantan [11]

5.4. Data availability

Ecological footprint calculation requires certain data, specifically statistical data in terms of production, exports and imports of commodities related to agriculture, forestry, animal husbandry and fishery. At the national level, the data can be obtained from world institutions such as FAO, IEA and UN Comtrade. But at province and district/city level these data are not necessarily available. Subekti [11] conducted a survey on the availability of data and found that data on export and import of agricultural products, fishery and forestry are generally unavailable, as well as trade data of other commodities. Referring to Borucke et al. [14], ecological footprint calculation of a particular commodity uses net consumption, i.e. the actual consumption influenced by trade (exports and imports).

The data needed for an ecosystem services model are maps indicating ecoregion, land cover, and land use. The map type must consider the scale, as it relates to the unit of analysis, such as national (island), province or district. Map availability for such units can be seen in Table 3. According to Law of the Republic Indonesia No. 32 Year 2009 on Environmental Protection and Management, each province and district has the authority to set ecoregions and environmental inventory [9]. Therefore, mapping of information on ecoregions is part of the government's tasks.

Table 3. Map availability used in ecosystems services model

Unit of analysis	Information scale	Type of map	Map availability
1. Island ecoregion (national)	Macro (1:1.000.000 to 1:500.000)	1. Ecoregion	Available, from KLHK
2. Crossprovincial ecoregion (province)	Meso (1:250.000)	1. Ecoregion (detailed)	Available, from KLHK

Unit of analysis	Information scale	Type of map	Map availability
3. Land use/ecosystem (ditrict)	Micro (1:100.000 to 1:50.000)	2. Land cover 1. Ecoregion (detailed) 2. Land cover 3. Land use	Differs in each district/city

6. Conclusion

The ability of a region to support human activities such as natural resource consumption and waste discharge can be determined by calculation of its environmental carrying capacity. When development activities exceed resource capacity and waste absorbtion capacity, it means that the development is not efficient and reduces the quality of the environment, i.e. the development is unsustainable. Therefore, environmental carrying capacity has a close relationship with sustainable development.

Calculation of environmental carrying capacity can be done with different approaches. Proper approach selection will determine the success of the establishment and implementation of environmental carrying capacity. Two relatively new calculation approaches of environmental carrying capacity can be considered for use, i.e. the ecological footprint model and the ecosystem services model. The aim of comparing both models was to know their respective application possibilities in Indonesia. From this comparison, advantages and disadvantages of each model can be taken into consideration in applying either model.

The ecological footprint model has advantages, i.e. conceptually it describes demand and supply resources, including supportive and assimilative capacity, and measurable output through threshold of resource consumption. However, this model also has weaknesses, such as not considering technological change and resources beneath the earth, as well as the necessity to provide trade data between regions for calculating at the provincial and district/city level. The ecosystem services model also has advantages, such as being in line with strategic environmental assessment (SEA) in assessment of ecosystem services, using spatial analysis based on ecoregions, and a draft regulation on calculation guidelines formulated by the government. Meanwhile, the weaknesses are that it only describes supply of resources and that the outputs of the calculations are without resource consumption threshold.

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