Designing management of sustainable shrimp cultivation area in East Lingga, Lingga District

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Abstract. Shrimp production has decreased in the coastal area of East Lingga District for 20 years, and this is an indicator of environmental biophysical degradation and of coastal natural resources. High population growth with limited natural resources, results in a shift in land use that leads to environmental degradation, including ecological, social, and economic aspects, which ultimately impact shrimp farming. Various efforts need to be made to increase shrimp production on the one hand and to preserve the environment on the other. For this reason, this research is important in order to obtain the best scenario in the design of sustainable shrimp farming in East Lingga, Lingga District. The research took place from May to June 2020 in East Lingga, Lingga District. The research was conducted with a dynamic systems approach. The research results were categorized as the pessimistic scenario, where it is found that there is an increase in production of 582.83 tons per year, the moderate scenario which can increase shrimp production by 941.86 tons per year and the optimistic scenario which can increase shrimp production to 1,560.40 tons per year. However, a 70% increase in effort in the optimistic scenario will result in high environmental impacts, especially pond waste.
Key Words: causal loop, dynamic, modeling, scenario.

Introduction. The development and utilization of the coastal areas of East Lingga Sub district, Lingga Regency are much faster than development in other land areas. Various industrial activities, housing, ports, and rapid population growth cause coastal areas to degrade in regard to social, economic, and environmental aspects, and can cause conflicts in their utilization (Weeks et al 2014). This is as stated by Daris et al (2019), that natural resources must be managed in a sustainable manner so that conflicts do not occur in their use. Furthermore, Daris et al (2020) stated that the high pressure on the use of coastal resources can lead to conflicts and a decrease in the quality of the environment and resources.

Shrimp production has decreased in the coastal area of East Lingga District for 20 years, one of which is an indicator of environmental biophysical degradation and coastal natural resources. High population growth with limited natural resources, results in a shift in land use that leads to environmental degradation, including ecological, social, and economic aspects, which ultimately impact shrimp farming. For this reason, coastal management must be carried out comprehensively between sectors and stakeholders (Dalby & Mackenzie 1997). The management of the fisheries sector involves many parties, including fishermen, government, institutions, academics and fisheries actors (traders, fish processors, cultivators) (Wahyudin et al 2018).

The coastal area of East Lingga District has a very strategic role because it has a function as a buffer for the aquatic ecosystem. This area is influenced not only in the surrounding environment but far upstream because it is the site of the mouth of three major rivers, namely the Kerandin River, the Pinang River, and the Kudung River. These rivers carry all kinds of materials that are soluble or insoluble in water. In this area, there are a total of 15 industries in the northern region and about 2 industries in the eastern region that rely on the waters of the East Lingga District as their buffer (BPS of Lingga Regency 2019). In 2010 the area of aquaculture in the East Lingga Sub district had an area of 5,545 ha. Currently, the area has decreased due to conversion to industrial and residential areas, especially in the East region, so that it becomes 2,028 hectares. Shrimp cultivation area in 1995, was around 1,109 ha, but in 2015 survey results showed that as little as 50 ha could be operated (Agency of Marine Affairs and Fisheries 2018).

Good coastal development must implement sustainable aquaculture. Sustainable aquaculture is an adaptable aquaculture production technology system, whose ecological and economic viability is unlimited, which largely determines the ability of farmers (Marfai & King 2008). The components of sustainable shrimp pond aquaculture development consist of three components, namely economic, environmental, and social (Cicin-Sain & Knecht 1998). Further, Hung et al (2018) showed that social variables which can be used as benchmarks for sustainable shrimp pond cultivation include health, education, infrastructure, political participation, and poverty. To achieve the sustainability of fisheries management in particular and coastal areas in general, a system-based management approach is needed such as that conducted by Yusuf et al (2016) which is driven factors analysis on sustainable management of tallo watershed estuaries and that conducted by Massiseng et al (2020) is a dynamic simulation of mangrove ecotourism management in Lantebung Makassar City. Meanwhile, Sharp and Hall (2007) focused on the sustainability of shrimp pond culture which includes: 1) maintaining essential ecological processes, 2) availability of sufficient resources, 3) providing cultivation materials and tools. Based on the description above, the purpose of this study is to design a sustainable shrimp culture management model in the coastal pond area of East Lingga District, Lingga Regency.

Material and Method

Location of research. The research was conducted in the pond area located on the coast of East Lingga District, Lingga District stretching from the northern coordinates 0°08'37.01"S 104°44'35.27"E, western coordinates 0°14'03.36"S 104°41'20,34"E, eastern coordinates 0°18'12.86"S 104°55'22.42"E, and southern coordinates 0°21'57.89"S 104°54'27.60"E. The research took place from May to June 2020.

Data analysis techniques. The stages in conducting the research are: (a) research planning, namely this activity consists of compiling a proposal, determining the location and implementation strategy, (b) research preparation, consisting of the preparation of tools and materials, field officers, questionnaires, data collection, and laboratory tests, (c) primary and secondary data collection, which consists of interviews, discussions in the form of Focus Group Discussions (FGD), results of laboratory and field testing, and literature review, (d) analysis of land suitability of shrimp farming areas in the coastal area of East Lingga District, namely this stage consists of measuring water, soil and support parameters or infrastructure which are then analyzed by weighting and overlay using GIS, (e) carrying capacity analysis, namely this stage consisting of a comparison of land suitability and availability of shrimp culture (Shuba et al 2018; Jayanthi et al 2020), and (f) institutional analysis, namely activities starting with the identification of institutions that affect the management of shrimp farming areas using the basis of stakeholders (Brambor et al 2006). Then an analysis is carried out to determine the most influential institutions to achieve the goals and programs (Thornton & Ocasio 2008). At the sustainability analysis stage, the activity begins with the identification of environmental, social, economic, human resources, technology, and other parameters. Furthermore, analysis is carried out with output and input diagrams and causal loop. To determine the sustainable management of shrimp farming areas, an analysis was carried out using carrying capacity and business scale (Morcillo et al 2018). The results of the analysis can be seen from the traditional, semi-intensive, and intensive pond management systems. The stages of the system analysis process are needs analysis, problem formulation, system identification, modeling, model verification, validation and implementation (Raczynski 2019; Shivrudraswamy et al 2018).

Results and Discussion

The design of the shrimp pond cultivation area in East Lingga District, Lingga Regency is an effort to support the Lingga Regency government program in the development of the Marine and Fisheries sector towards the Fisheries industry. The choice of shrimp farming was because in the coastal area of East Lingga District previously there was an existing shrimp pond cultivation area of 312 hectares, but in terms of productivity, it had not been optimally utilized. The Lingga Regency Government has provided access to the surrounding community to utilize the coastal area for productive fishery business activities, as an effort to improve community welfare. To design a shrimp pond cultivation area, this can be done through 3 model scenarios, namely the pessimistic model scenario, the moderate model scenario, and the intensive scenario models.

Causal intersection. Analysis of the causal loop diagram of shrimp farming is needed to describe a feedback concept design on the structure in a dynamic. Evaluation of the sustainability of shrimp pond culture in an integrated manner in the marine sector can be processed using a dynamic system (ISA), by processing data from interviews, workshops, with stakeholders and processed using a causal loop (Sonnenburg & Bäckhed 2016). The cause-effect relationship is at the core of the system. There are two main characteristics that stand out from the dynamic system (Banovic et al 2016), namely (1) the cause-effect relationship between the variables, or the build of a model structure, and (2) feedback in response to the cause-effect relationship. The model-forming structure is a feedback structure expressed by closed circles that influence each other. The design of the causal loop diagram (CLD) here describes the interplay between variables.

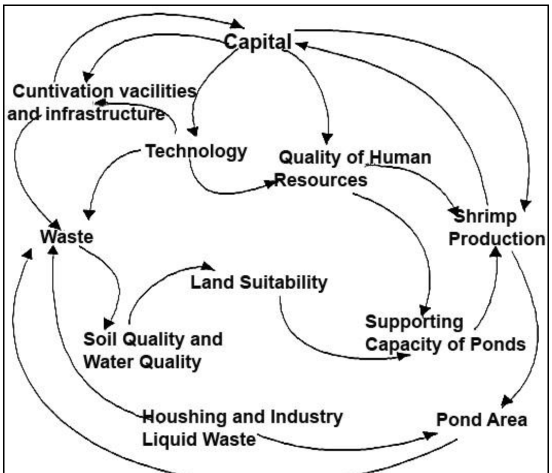

Figure 1. The causal intersection relationship between variables that affect the sustainability of shrimp farming areas.

The causal intersection relationship between variables it's ensuring the sustainability of the ecological, economic, and social functions of sustainable shrimp pond management in the coastal area of East Lingga District (Figure 1). The causal deviation relationship between shrimp farming is divided into 3 block groups (building block), namely, block 1 is production, block 2 is carrying capacity, and block 3 is land suitability. Based on the causal intersection relationship between variables of shrimp pond culture, it shows that production is influenced by capital, pond area, carrying capacity, and quality of human resources. The higher the production capital will increase, and vice versa. Greater land and carrying capacity will increase production and land reduction will reduce production in the hope that other variables will not change. In block 2, the carrying capacity is very much influenced by human resources, land suitability. Increased carrying capacity is determined by increasing human resources, capital, technology, facilities, and infrastructure as well as land suitability. Meanwhile, land suitability is influenced reciprocally by water quality, water quantity, and domestic waste caused by housing. Meanwhile, technology, infrastructure, and capital can reduce waste and increase the competence of human resources. The carrying capacity, suitability, and area of ponds are closely related to the capital and human resources that affect production. This is where the causal relationship is formed. Shrimp farming technology applied in the coastal area of East Lingga District consists of intensive, semi-intensive, and traditional. To manage the future, it is necessary to create a scenario for the three technologies.

Based on the results of the validation test of the shrimp pond culture model, it can be concluded whether the system model is a valid representative of the reality being studied conclusively (Lowry et al 2012). The validity test currently used is face validation, namely the validity test using the responses of experts. Based on the opinion of experts, the results of this simulation are quite realistic. The results of this test can be turned into a scenario model.

Intensive shrimp pond scenario model. This dynamic model is built based on the causal loop where this activity is useful for knowing models in conducting decision-making analysis (Burford & Lorenzen 2004), and this policy analysis issues appropriate and effective recommendations (Ponce-Palafox et al 2011). The design through the intensive pond technology scenario model is made into three interrelated scenarios, namely (1) a pessimistic scenario, (2) a moderate scenario, and (3) an optimistic scenario. The current condition is a condition that is considered a pessimistic condition and develops by changing the variables into a moderate scenario to an optimistic condition (Table 1). Furthermore, the relationship between variables in this condition is based on simulations and expected targets for the next 20 years (2020-2040). The scenarios for the development of intensive pond variables on simulation for 20 years with 3 scenarios, are presented in Table 1 and Figure 2 below.

Table 1

Scenarios for the development of intensive pond variables

No.	*Scenario*	*Human resources*	*Capital*	*Facilities and infrastructure*	*Technology*
1	Pessimistic	Existing	Existing	Existing	Existing
2	Moderate	30	30	30	30
3	Optimistic	70	70	70	70

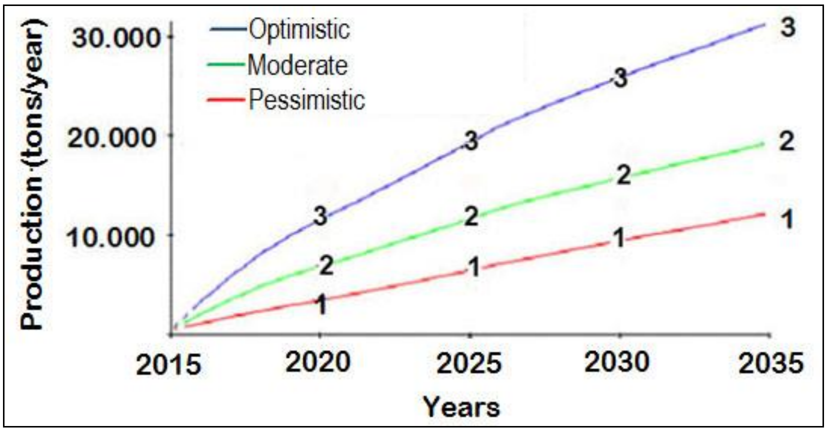

Figure 2. Scenario graph of intensive shrimp aquaculture pond production on the coast of Lingga District.

Production in a pessimistic, moderate, and optimistic scenario is depicted in a graph making it easier to compare between scenarios. These three scenarios are a simulation regarding the next 20 years, based on several key variables, namely: improvement of technology, improvement of human resources, suitability of land, and environmental capacity support.

Pessimistic scenarios of shrimp ponds. The pessimistic scenario is the management of shrimp cultivation areas based on current potential, assuming other conditions are the same or unchanged (Ruiz-Velazco et al 2010). Scenarios are made for 20 years (2020-2040). The orientation of this scenario is based on production and the area of the pond used for shrimp farming. The simulations used are land suitability, and carrying capacity with parameters of groundwater quality and quantity of seawater, waste or pollution, facilities and infrastructure, capital, technology, and human resources competencies. Based on the Agency of Marine Affairs and Fisheries in Lingga Regency (2018), it is known that the production of shrimp ponds in 2015 was 509 tons/year, with an operated pond area of 120 ha. From the simulation results, production in 2035 is predicted to increase by 12,165.57 tons/year with a pond area of 1200 ha. The increase in production occurred due to the increasing area of shrimp ponds, so this model is called an extensification model.

Moderate scenarios of shrimp ponds. The moderate scenario shows semi-intensive pond management by increasing input in the form of facilities and infrastructure, technology, human resource competence, and capital with an increase in the input of 30% (Cao et al 2011). The same is stated by Irvine et al (2020), that the moderate scenario is semi-intensive pond management by increasing inputs in the form of facilities and infrastructure, technology, human resource competence, and capital. The increase in input to the resulting production, after increasing the input by an average of 30%, increased production will be obtained (Table 1). Improvement of facilities and infrastructure is a form of improvement. The construction of road networks, water channels, electricity, and ponds so that they are stronger to hold water in the ponds are forms of improvement. This facility can provide convenience in shrimp farming operations. The use of environmentally friendly technology and its proven ability in shrimp farming is an increase, such as the use of probiotics. Competence in human resources has increased marked by increased professionalism in shrimp farming. Competency enhancement can be done through apprenticeship, education, and training activities, where these can be done, to improve the ability of farmers to solve problems. Then, the capital aspect is the nominal amount given to investment and fixed costs, variable costs, and other costs in shrimp farming operations.

The increase in input in this scenario is 30%, whereas currently the facilities and infrastructure in the form of roads, electricity, channels, and maintenance containers are rehabilitated by 30%. Then the maintenance container is replaced with mulch plastic and HDPE plastic. This plastic can last up to a dozen years, so it is very efficient. Although, the initial investment may seem expensive. The water reservoir is expanded, and the capacity is improved by deepening and expanding the area. Planting mangroves around the ponds can accelerate the process of breeding shrimp. Likewise, technology application, from research and development of universities that are oriented towards sustainability, is increased by 30%. Technology application for the western land, which has a high level of pollution due to industrial waste, and for the eastern region there is no other alternative except to improve the environment. The closed technology with the application of probiotics provides hope for successful cultivation. Participation capital for investment from financial institutions is increased by 30%, thus forming new businesses with the procurement of new land and the application of new technologies.

Based on scenario data after maintenance for 35 years, the production increase from pessimistic to the moderate scenario is 59%. With variable conditions unchanged. It’s increased production from moderate to optimistic by 63%. The sustainability of shrimp farming is determined by the level of implementation of technology, human resources, facilities and infrastructure, and capital. The more intensive it is, the more feed waste and medicines are wasted in the water. The application of environmentally friendly technology must be followed by sustainability policies such as environmental control and supervision, comprehensive problem solving, and the provision of integrated (comprehensive) infrastructure. Cultivation continues to develop as environmental, social, and economic conditions change. In a moderate scenario, the production in 2015 is 509 tons/year and after 20 years, namely in 2035, assuming there is an increase in human resources, capital, facilities and technology variables by 30%, it can produce shrimp production of 19,346 tons/year or an increase of 18,837.15 tons in over 20 years.

Optimistic scenarios of shrimp ponds. The optimistic scenario is the optimal ability of pond management related to the environment, society, economy, human resources, and technology to produce optimal production with input inputs increased by 70% from the original condition (Queiroz et al 2013). The scenario is optimistic that the production in 2015 is 509 tons/year and in 2035, after 20 years, assuming there is an increase in human resources, capital, facilities and technology variables by 70%, it can produce of 31,716.94 tons/year of shrimp or an increase of 31,207.94 tons in over 20 years.

The fluctuation of aquaculture shrimp production in ponds is caused by the carrying capacity, quality of human resources, pond area, and capital. Production will increase if the pond area, capital, technology, facilities, infrastructure and the quality of competent human resources (Primavera 1998). Cultivation on land that is suitable and it has the carrying capacity according to the carrying capacity of a sustainable shrimp pond. Production can decrease by decreasing natural resources with increasing time, along with exploitation which can lead to overshoot behavior. For example, the application of facilities and infrastructure includes drugs, waterwheels, pumps, and others. Based on this simulation, the development of products for the next 20 years can be seen. This production is very much determined by the area of the pond that can be used for intensive, semi-intensive, and traditional scale shrimp farming.

One of the failures of the aquaculture business that is negatively impacted by the environment is usually due to incorrect location determination which is not suitable for land suitability. A location permit for aquaculture must guarantee business actors the feasibility and sustainability of their business so that land evaluation for determining a suitable location for aquaculture must be developed (Farkan et al 2017; Ponce-Palafox et al 2011). The social variables, that can be used as benchmarks for sustainable aquaculture, such as health, education, infrastructure, political participation, and poverty (Ni et al 2020; Witoko et al 2019).

The development of a pond cultivation business must consider several factors, including water source, discharge and quality, tidal amplitude, topography, climate, and soil properties (Kautsky et al 1997). Environmental factors, namely soil and water quality, are factors that must be considered in determining the suitability of pond cultivation land (Gross et al 2013; Prussi et al 2014). The factors that are considered in determining the characteristics of land are topography and elevation, soil, hydrology, and climate (Lammers et al 2017). Spatial analysis with a Geographical Information System (GIS) was used to determine the suitability of pond cultivation land (Oliveira & von Sperling 2011). Land management is determined based on land characteristics that are adapted to technology and commodities that can be applied in the pond (Friedlander 2008; Kumar et al 2015). According to (Zhang et al 2015) the land suitability parameters are divided into two components, namely based on spatial suitability aspects including RTRW and land suitability based on physical and chemical aspects of pond waters.

Based on the results of observations, it is known that the criteria for the suitability of pond cultivation land in East Lingga District, Lingga Regency include: a) soil topographic parameters, including variables of slope, texture, drainage and peat thickness, b) physical parameters, including variables of water temperature, brightness and tidal amplitude patterns, c) chemical parameters, including dissolved oxygen, ammonia, pH, salinity and H2S variables, and d) climate parameters, measured variables are rainfall and rainy days. Meanwhile, land use parameters include: 1) the area of land utilized for tiger shrimp (*Penaeus monodon*) cultivation and the area of land designated for cultivation areas, 2) population pressure, which is the rate of increase in the level of resource use in the area as assessed by the surrounding population, 3) community perceptions of utilization of land, is the community's response to an area, and 4) parameters of economic aspects include the following variables: a) the level of production and revenue generated from shrimp farming during one production process in the last year, 2) production costs (fixed costs and variable costs) issued during one production process in the last year, 3) the level of profit generated during one production process in the last year, and 4) the feasibility level of cultivation from the economic aspect with the RCR value.

Conclusions. The design of sustainable shrimp pond culture management is described in the form of a traditional, moderate, and intensive model scenario. Based on the relationship between land suitability, carrying capacity, social and institutional arrangements, it is very close to support shrimp production. Production and sustainability of shrimp farming in the coastal area of East Lingga District can be increased by making scenarios under current conditions (pessimistic), moderate and optimistic. Through the pessimistic scenario, it is found that there is an increase in production of 582.83 tons per year, while the moderate scenario can increase shrimp production by 941.86 tons per year and the optimistic scenario can increase shrimp production by 1,560.40 tons per year. However, a 70% increase in effort in the optimistic scenario will result in high environmental impacts, especially pond waste.

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