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SUSTAINABILITY OF INTEGRATED AQUACULTURE DEVELOPMENT PROJECT USING SYSTEM DYNAMIC APPROACH

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Abstract: Integrated aquaculture projects in shrimp farming inflict tremendous effects, especially on the socioeconomic and natural environment. In order to evaluate the effects, this study introduces a simulation system known as System Dynamic Aquaculture Effect Policy (SD-AQEP) that was developed to simulate the probable effects of *Integrated Shrimp Aquaculture Park* (ISHARP), Setiu Terengganu Malaysia. The simulation system analyzes various selected sectors using dynamic approach. Hence, the dynamic simulation for aquaculture model (SD-AQEP) that has been developed could be used as an exploratory platform for policy analysis and decision analysis based on the probable effects of ISHARP. The baseline simulation is from 2010 to 2040 and the simulated results were used to suggest several policy recommendation for aligning the countermeasures with the resultant consequences.

Keywords: Integrated aquaculture, sustainability, system dynamics, ISHARP.

Introduction

The number of shrimp farms in Malaysia have increased rapidly due to the success experienced by neighbouring countries likes Thailand, Indonesia and Philippines. Malaysia production of shrimp is ranked third back in 2001 after Taiwan and Thailand (Raman, 2001). More plans for intensification and expansion have been drawn up. Forecasted production of marine shrimp in the year 2020 based on the the Food Production Action Plan (Fisheries Sector) will be 250,000 metric tonnes (MT). Since 2004, 40,000 hectares of land have been reserved for aquaculture development by the government (FAO, 2003). *Integrated Shrimp Aquaculture Park* (ISHARP) located in the East Coast of Peninsulas Malaysia, it occupies 1,200 hectares of mangrove forest in the Setiu Wetland managed by the Blue Archipelago Berhad since 2009 (Figure 1). The project is divided into two phases: phase 1 covers an area of 432 hectares and phase 2, an area of 568 hectares. Phase 1 consists of 216 ponds with a production capasity of 3100 MT per year. Phase 2 will have about 400 ponds that can produce 5,600 MT per year (Nyan *et al.*, 2013). The main purpose of ISHARP is to provide sufficient shrimp production and to promote sustainable shrimp aquaculture in Malaysia. To achieve the production of shrimp with zero effect onto the environmnt, the shrimp farm uses biosecure recirculating systems with biofloc technology. ISHARP's goal was to utilize biosecure recirculating systems with biofloc technology for its 600 ponds and reservoirs in order to cultivate Pacific white shrimp, *Litopenaeus vannamei* on 1,000 hectares of land (Nyan *et al.*, 2013). ISHARP will revolutionize not just the economy of this sleepy coastline district, but also the entire seafood industry in Malaysia (Muhamad-Safiih *et al.*, 2016).

The geography of Setiu Coastal (Latitude 5.572770, Longitude 102. 805685) particularly consists of area that is ideal for shrimp farming. The area is located at the edge of South China Sea provide access to abundance sea water for shrimp pond usage and posses a suitable type of soil for marine aquaculture. This coastal area covers approximately 31,672.9 hectare or around 23.305% of Setiu district. (UPEN, 2015, pers. Comm). Although this particular area represent more than 30,000ha of Setiu district, the current population is only 16,616 people (Council, 2013). Uniquely, this area holds a much more valuable abundance of natural resources and invaluable mangrove species. (WWF, 2009; Nakisah & Fauziah, 2003). Consequently, the existence of ISHARP poses a threat to the environmental quality of the mangrove and the valuable resources within. (Asche & Khatun, 2006).

Therefore, in order to protect the Setiu mangrove environment while promoting the development of the shrimp farm industry; it was essential to build a System Dynamic Model for sustainability of integrated aquaculture. The model simulates quantitative and qualitative assessment of aquaculture practices in order to analyze trends in economics, ecosystem changes and spillover towards its community. Hence, this model is named "System Dynamics model-Aquaculture Effect Policy" (SD-AQEP).

Scope and Purpose of System Dynamics Model

SD-AQEP model is built to simulate quantitatively the material and energy flow of the integrated aquaculture chain, evaluate and analyze the integrated effects of the ecological-economical long term trends, then identify the defects of the system and make recommendations. The time line horizon of the model is 30 years, from 2010 to 2040.

The model asks strategic questions such as: how the evolution of future shrimp crop patterns and their respective production levels will effect the availability of land, water quality, market conditions and local population. Traditionally, the practice of aquaculture was driven from filling the needs of the masses (Smith & Philips, 2001). However, along the line of development in aquaculture, considering the dynamical interaction concept between all component based on producing feedback, a brief discussion of some basic interrelationships should be helpful.

Methodology

System Dynamic Model

This study applies the system dynamic simulation model in order to analyze the case study of ISHARP. System dynamic approach that was used in this study was introduced by Professor J.W. Forrester in the mid 1950s (Forrester, 1968) and has been widely applied in the study of economy, society, ecology and many complex systems. Complete description of the methodology was given in Forrester (1958, 1968) and Sterman (2000). System dynamic methodology basically consists of three major variable; stock, rate and auxiliary, while flows have two; ultimately create an interaction between physical/material and information (Forrester, 1958; Shen *et al.*, 2009; Muhamad-Safiih *et al.,* 2016). System dynamic has been use in many areas including universal environmental sustainability (Forrester, 1968; Meadows *et al.*, 1992; Shen *et al.*, 2009; Muhamad-Safiih *et al.,* 2016), regional viable development issues (Saeed, 1994; Bach & Saeed, 1992), environmental management (Mashayekhi, 1990), water resource planning

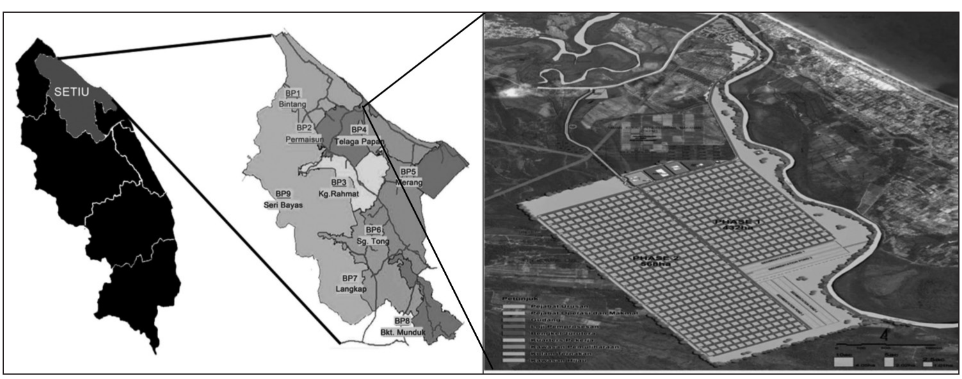

Figure 1: The location map of ISHARP in Setiu, Terengganu, Malaysia
Adapted from Muhamad-Safiih *et al.* (2016)

(Ford, 1996) and ecological model (Wu *et al.,* 1993). This model development process was executed using Vensim PLE for Windows Version 6.3D software developed by Ventana System, Inc.

The methodology focuses on understanding of how the physical processes, information flows and managerial policies interact so as to create the dynamics of the variables of interest. Entire homogeneity between elements construct the system's '*structure*'. Performing over time, the structure generates '*dynamic nature*' S-shaped growth, exponential growth or decline, oscillations or collapse. The typical purpose of a system dynamic study is to understand how and why the dynamics of concern are generated and then search for policies to improve the situation. The policy improvement asscioated to the longterm, macro-level decision rules used by stakeholders and upper management. Basic system dynamic consist of three types of variable in the model which are *Converter*, *Stock* and *Flow*. *Stock* are the core variables representing the principle accumulations in the system. *Flow* variables are the rate of change in *Stock* and they represent the activities which fill in or drain the stocks. Converters mediate variables using miscellaneous calculation and finally, the connectors or simple arrow diagrams exist in the model represent the cause and effects links within the structure (HPS, 1996). The corresponding system development first undergo preliminary data collection through a series of interviews and questionnaires before the actual model's developed. Secondary data obtained from local authorities and reports were analyzed and compiled. The SD-AQEP model must then be test using pseudo-data and zero initial value to determine the reliability of the simulation.

Model Description

The SD-AQEP stratum of models and their corresponding interactions are illustrated in Figure 2. Detail description for dynamic component are given in this section. Aquaculture subsystem mainly content of the shrimp feeding, production and maturing of *Litopenaeus vannamei.* This makes a circular industry chain with feeding-production-maturing. Aquaculture practices dynamically produce some positive impact mainly in economic growth and stock demand, however, this industry promotes negative feedback onto environmental aspects such as production of waste water and abrasive land use. These effects show the "*effect sector*" and its existing interaction in the "*aquaculture sector*" by influencing ecology, economy, society and other factors. Based on the framework, serious waste water may cause ecological degradation which can also effect aquaculture development. The decision maker will improve policies according to increase positive effects and reduce the negative effects based on the interaction between "*effect sector*" and "*aquaculture sector*". These policies can be describe as the "*policy sector*". It can adjust the "*effect sector*"and also promote the sustainable development of the whole aquaculture system. These interactions among aquaculture, effect and policy was used as a framework that leads to the production of a system dynamic model named SD-AQEP (System Dynamics-Aquaculture-Effect-Policy).

Aquaculture Industry Sector

Aquaculture industry in SD-AQEP is the core model, which dynamically influences all other sectors. The aquaculture sector represents the process of shrimp growth. Shrimp life cycle goes through different stages till maturity. The first stage for *vannamei* are the eggs; the *vannamei* eggs hatch within 16 hours after fertilization. The larval stages are comprised of *Nauplius* (6 stages in 1 day and 20 hours), *Protozoea* (3 stages in 6 days), Mysis (3 stages in 9-10 days) and 1st day post larvae (PL) (10-11 days) *megalopa* (6-35 days). The *megalopa* and early juvenile are called PL. Transition from juvenile to sub-adult takes 135-255 days and subsequent completion of sexual maturity occurs within 10 months (Bailey & Moss, 1992).

The causal loop diagram (CLD) of the shrimp development and growth model is

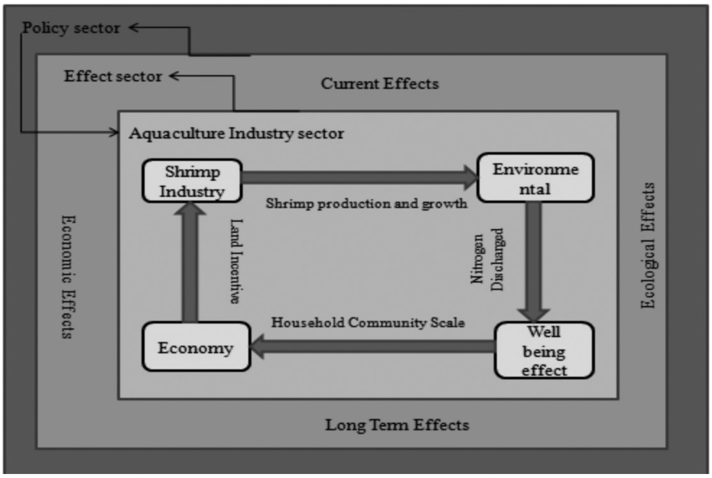

Figure 2: SD-AQEP model overview

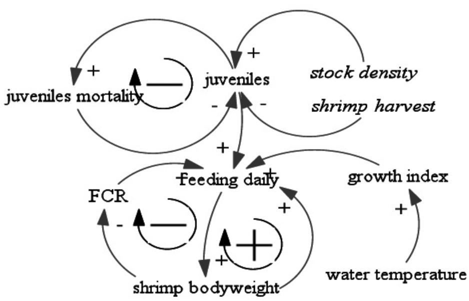

Figure 3: CLD of shrimp production and growth

illustrated in Figure 3. "*Positive loops are self-reinforcing*" are a simplified representation as more feed given to the shrimp, make more shrimp growth, causing continuous feeding to shrimp. Negative feedback loops are self-correcting. In this CLD if shrimp growth is faster, then feed conversion ratio (FCR) decrease, which means less shrimp feed is given than is required and shrimp growth declines (Sterman, 2000). The shrimp production sector shows the evolution of the shrimp life cycle (i.e. from juveniles to mature). The CLD in Figure 3 is a simplified representation of shrimp production and growth. The shrimp growth process generally started from juveniles towards maturity.

The aquaculture production sector can be describes as the increase of shrimp weight from stocking time to harvest time. The CLD (Figure 3) above describes the *L.vannamei* life cycle using two negative feedback loops (NFL) and one positive feedback loop (PFL). The two remaining loops describe shrimp growth. One negative feedback loop accounts for the mortality occurred during the juvenile stage. The second NFL represents the relationship of shrimp weight to feed conversion ratio (FCR).

The PFL represents the relationship between shrimp stock and daily amount of feed given. The daily amount of feed given depends on the average shrimp weight and water temperature. An increase in daily feed will occur when shrimp weight and water temperature increase.

Effect Sector

The effect sector represents the positive and negative side effects caused by ISHARP development. The effect sector is divided in to environmental, well-being and economic sub sectors.

Environmental

The environmental subsector consists of three main variables: land use, ecosystem loss and water quality. The land use variable is the process of how the conversion or conservation of land effects the livelihood of all parties involved in the study area. The ecosystem loss variables evaluate damage caused by shrimp farming to natural resources such as the mangroves and forestry in the study area. The water quality variable evaluates the process and impact of related water in the integrated shrimp pond and towards the surrounding water bodies. However, this study will only focus to the nitrogen cycle in the shrimp ponds.

The positive loop (Figure 4) provides feedback from the relation between stock density in the pond to the total juvenile growth rate and back to the stock density quantity. If stock density increase, then juveniles' growth rate decreases. The first negative loop represents the relationship between shrimp mortality and water quality. Higher water quality is one of the main factors that reduce the stock mortality rate. Lower mortality rates contributes towards more yields. However, efforts to produce more yields and increase harvest rates effect water quality negatively. Hence, increase in stock density will lower water quality, causing an increase in mortality rate and a decrease in the shrimp harvest rate. The second negative loop represents the effect of water quality on the juvenile growth rates. As water quality increases towards optimal levels, the juvenile growth rate will increase. Higher juveniles' growth rates lead to more shrimp harvest in the system, which will have a negative impact on water quality. According to Bunting (2001), despite the importance of water quality for development of shrimp growth, upkeep of environmental are important and cared with effluents that can affect the sustainability shrimp farm. Negative effect can occur on the surrounding environment when the influents are containing abundance of phosphates, nitrogenous compounds and organic matter (Clark, 1996). According to Burford *et al.* (2003), the increase of nutrients can make phytoplankton flourish, accelerate eutrophication processes and promote hazardous environment. The nitrogen loop model includes all processes of nitrogen discharged: ammonia concentrations, nitrites and nitrates, chlorophyll and dissolved nitrogen organic. It provides a comprehensive and general description of the long-term effects of nitrogen accumulation in shrimp ponds.

Well Being Effect

Figure 5 shows the CLD of well being effect. The sub sector of well being is classified into three variables.

Population represents the population living in Setiu Wetland and was categorized by male and female with age cohort. The population module dynamically estimates factors effecting the populations fertility rate and birth rate. Additionally, the module indicates how of environmental, social and economic factors also effect the population.

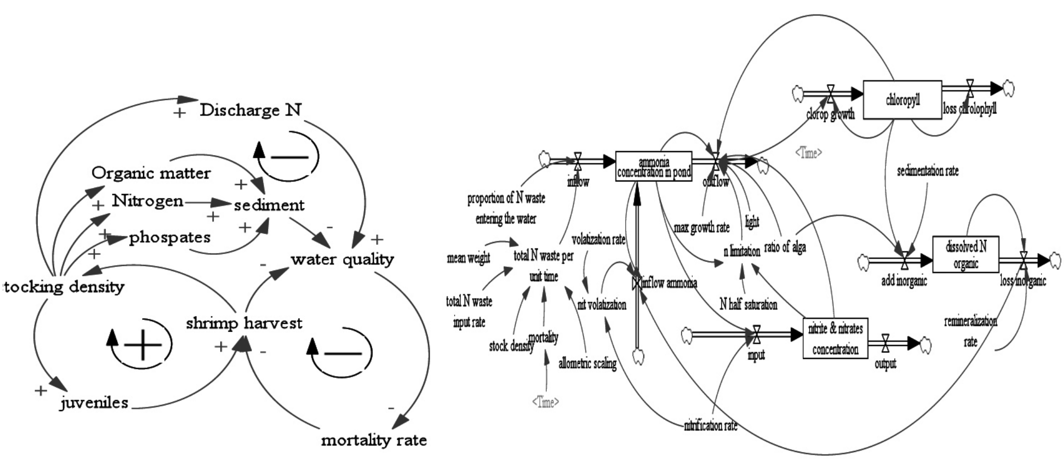

Figure 4: CLD and stock diagram of nitrogen discharged from shrimp ponds

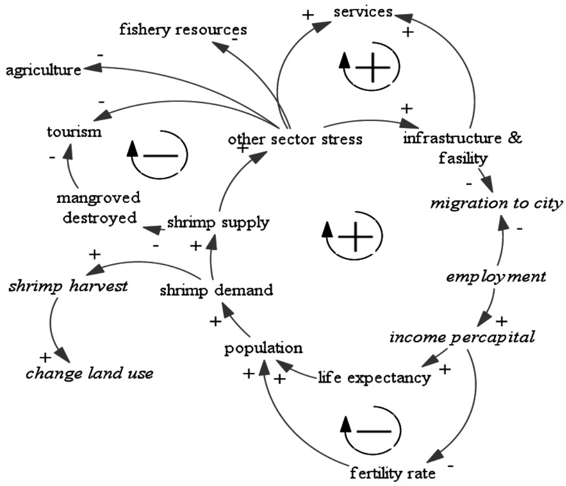

Figure 5: CLD of well-being effect

Clearly, population expansion increases the demand for shrimp, which in turn increases the total shrimp harvest. When demand for shrimp rises, so does production of shrimp which inevitabily puts stress on other industry sectors (agriculture, tourism and fisheries resourse) and effects the GDP. In turn, the GDP effects the fertility rate and life expectancy which determines the population of an area. The variables of infrastructure and facilities are derived from infrastructures supporting road networks and transport.

Economy

The economy sub sector shows that shrimp farming has bloomed when there are changes in agricultural priorities and incentives for shrimp farming. Figure 6 illustrates the positive and negative effects from land use for the integrated aquaculture development project. This modules describes how the shrimp farming creates employment. According to Neiland *et al.* (2001), shrimp farming creates employment as labor along the whole supply chain, includings production of shrimp stock, daily upkeep cleaning and processing. Most shrimp farms are located in the rural areas which cause local employment opportunities to increase (Huitric *et al.*, 2002). When employment increases, it will

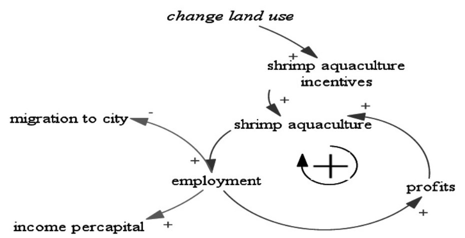

Figure 6: CLD of economy (land based aquaculture and employment)

hinder the population for shifting to the cities in order to seek employment. Furthermore, it will increase the average income of the rural poor (Danish Fisheries Consultant, 1997; Neiland *et al.*, 2001). Clearly, an abundant harvest will lead to an increase of profits and in time, will promote more investment, resulting more land that will be converted to shrimp ponds.

Result and Discussion

The Base Run of the SD-AQEP

In this section, the base run of SD-AQEP is summarized in terms of the dynamics of shrimp production and growth, nitrogen recycling and land use. The base run used as a base for evaluation of the alternative scenario and policy analysis. The time frame used in this study is 30 years starting from 2010 to 2040.

Shrimp Growth and Production

The shrimp biomass bodyweight increases dramatically based on the increase of daily feed amount into the pond (refer Figure 7). Overtime, the feed conversion ratio (FCR) decreases as the total weight of shrimp increases. Additionally, shrimp biomass and shrimp harvest will both increase in the next 30 years.

Nitrogen Recycling

In the environmental model, nitrite and nitrates increase corrosponding to the level of ammonia concentration (Figure 8); the relation between corresponding variables are the higher the concentration of ammonia, the higher the nitrate and nitrates increase. The disolved organic level (DO) composed two negative feedback loops representing phytoplankton and shrimp farm. Figure 8 shows the discharged of Total Ammonia and Nitrogen (TAN).

Land Use

The total available land (Figure 9) is expected to decreasing dramatically corresponding to the increase of demand for land to be used for agriculture and aquaculture. This due to the demand of shrimp production, food production and other related production sector. Subsequently, more demand mean more production and more land used for shrimp farming. However, as the shrimp farm activity reach its peak and total development stagnant, the total investment will gradually reduce and

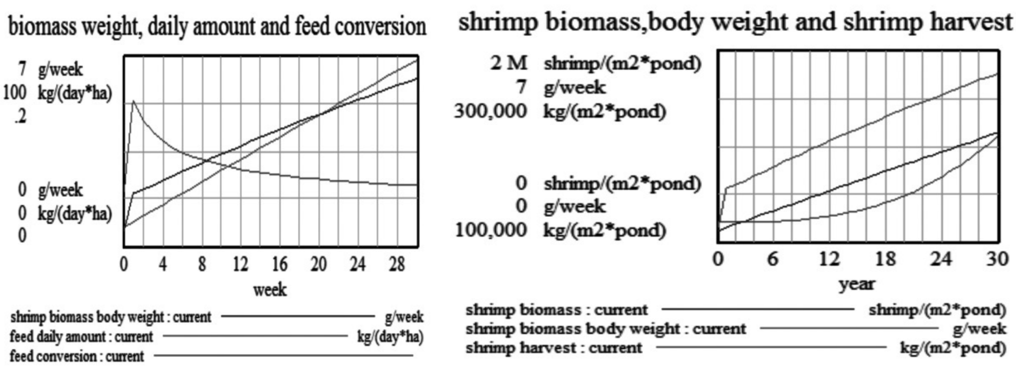

Figure 7: Shrimp biomass bodyweight, daily amount, feed conversion and shrimp harvest

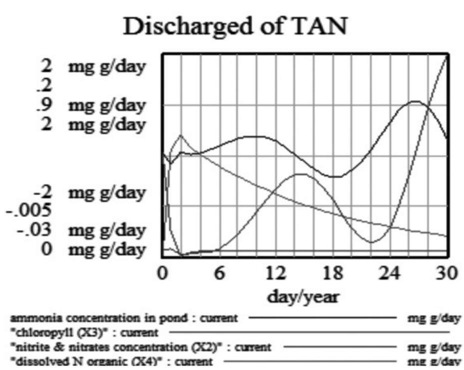

Figure 8: Discharged of Total Ammonia and Nitrogen (TAN)

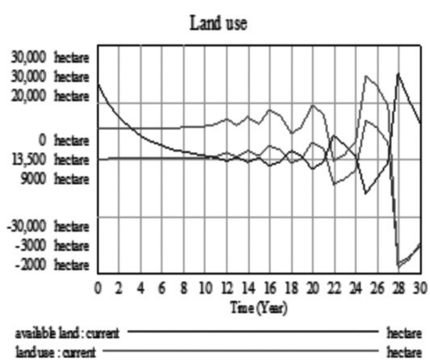

Figure 9: Land use

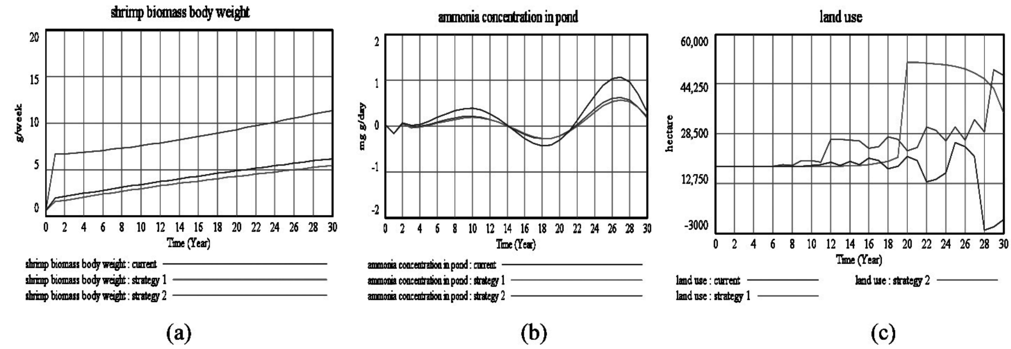

Figure 10 (a), (b), (c): Simulation under the condition of policy implementing, (a) Biomass of Shrimp, (b) Ammonia concentration and (c) Land use

the amount of investment only exist to sustain the existing business.

Integrated Policy Analysis and Effects Prediction

Improvement Policies to Lower Food Conversion Ratio (FCR) in Ponds

In order to expand their business horizon, the company should consider using a more nutritious diet for shrimp production and creating a more microbe rich environment in the shrimp ponds. This could produce superior harvest and the rich microbe environment could cut FCR up to 20% per culturing period (refer Figure 10 (a)). Lower FCR might be more related to retain nutrients in the ponds system. Otherwise higher FCR implies that less protein derived N^2 is retained from the shrimp population biomass.

Improvement Policies Better Management Strategies in Shrimp Ponds System

The assimilation of the applied N^2 in feed more efficient in using zero water exchange system than daily water exchange system. Based on Figure 10 (b) zero water exchange system are used to increase shrimp growth in such that ammonia concentration was in a manageable level. Hence, the growing shrimp process are more efficient if stock density or shrimp growth coefficient increase. Two alternatives stocking strategies are used in this simulation. The result showed a decrease of ammonia concentration in strategy 1 with a lower stock density than stock density in strategy 2.

Improvement Policies the Lands Reserved

Government should act to improve the current land act to provide more protection towards Gelam Wetland in Setiu. By promoting stricter law, this particular area can be conserved and returned to a healthy state and able to provide a natural barrier against a possible natural disaster. From Figure 10 (c), by 2020, 59,800 hectares of wetland area could be conserved for research and increase the amount of renewable natural resources for the local people.

Conclusion

In this study, prolonged sustainability of an integrated shrimp aquaculture project (ISHARP) is analyzed using a system dynamics approach. The model SD-AQEP serves as an experimental platform towards the questions related to growth of shrimp, water quality, land use, employment, population and other variables. SD-AQEP model reveals that the dynamics of the shrimp industry, with the effect and policy can be improved by an integrated policy. The development of SD-AQEP through academic research can give insight on this generated structure for use on similar studies as well. The research plan to build a smaller of the model to give the essence of the dynamic theory.

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