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A System Dynamics Model for Analyzing the Eco-Aquaculture System with Policy Recommendations: Case Study on Integrated Aquaculture Park (*i*-Sharp), Setiu Terengganu, Malaysia

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Abstract: The sustainability of aquaculture industry strongly dependence on numerous factors such as environmental, ecology, economics, industry, human behaviour, policy and many other factors. The interdependence of this factors is called as eco-aquaculture. However, eco-aquaculture field has not been widely studied, especially in Malaysia. Therefore, to fundamentally enhance the sustainable development capacity of an eco-aquaculture system, the integrated simulation and analysis of the material-energy flow processes and the trends of process generates the ecological and economic positive-negative effects should be addressed. Thus, we build a system dynamics model of the eco-aquaculture system named "SD-AQEP" to simulate quantitatively material and energy flow in the local eco-aquaculture industry chain, evaluate and analyse the integrated effects of the ecological-economy and their long-term evolution trends, identify the defects of the system and then make recommendations to improve system performance until 2025. This model is divide into three parts: aquaculture, policy and effects and also the interaction and material-energy flow mechanism among each part as the logical framework of modeling. In this study, we focus on the eco-aquaculture system particularly at Integrated Aquaculture Park (*i*-Sharp), Setiu, Terengganu; Malaysia. The results from the simulation revealed that the potential risks which are the negative effects of the system are identified. Then, the system improvement especially policies are made in order to reduce, eliminate all the risks as well as negative effects and at the same time bring and expand the ecological and economic to the positive effects. The systems also can diagnose scientifically the potential short-comings and defects in the system, provided the basic improvement policies as well as checking the effectiveness of the improvement policies. Hence, this system is potential to revealing the internal structures in the complex system with ecosystem and other systems such as economy, environment, human activity, etc.

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INTRODUCTION

Aquaculture industry recently, especially shrimp farming on a large scale growing rapidly. It is driven by the rapid increase protein based diet demand from universal population identified among the factors that led to increase this figure. it's exacerbated by a decline in the total catch and landings of fish are also seen recent improvements contributed to this figure. However, the opening of shrimp ponds in large scale seem to impact directly on the environment. This is because the industry is seen very closely and interact with the environment, such as for the assimilation of wastes, furnishing seeds, the production of feed pellets, etc [1, 2, 3]. Therefore, effective control should be established so that a direct impact on the global environment is maintained. To achieve a balance between ecological and economic benefits to human development as a result of an increase in the aquaculture industry, creating a dynamic system that comprehensive and is seen as a long-term solution appropriate and should be considered.

The sustainability of the aquaculture industry depends strongly on a number of important elements such as environment, ecology, economy, industry, human behavior, the police, as well as some other factors [4]. Dependence on the diversity of these factors are known as eco-aquaculture. It is an approach in aquaculture studying a balance between ecological and economic interests to promote sustainable development in both. However, eco-aquaculture is not widely explored, especially in Malaysia. The core of this system is the process of material production, energy production that can effectively generate all the impacts on the ecological and economic processes. If the production of energy materials and their use cannot continue to grow, the eco-aquaculture systems will decline. Therefore, to increase the capacity of the system where it can be used to analyze comprehensively all the relevant factors in the development of eco-aquaculture must be developed. For that purpose, dynamic system model is the most suitable model

STUDY AREA

This particular paper study focus area on integrated Shrimp Aquaculture Park (*i*-Sharp), Setiu, Terengganu, developed by Blue Archipelago Bhd. for shrimp farming in an orderly and controlled manner. *i*-Sharp has been identified as one of the High Impact Project by YAB Prime Ministry of Malaysia that represents a unique private and public partnership. This particular area consists of is proposed to be a fully integrated 1,000 ha aquaculture industrial park equipped with a Seawater Intake System. Consists of pumping station and 1. 2 km long 1, 500 mm diameter submarine pipe, and the necessary infrastructure to support 638 grow–out ponds, processing plant, a feed mill, a hatchery, office, staff accommodation, utility building and other support buildings. This project divided into two phase: Phase 1 covering an area of 432 ha and Phase 2 of 568 ha. Phase 1 of *i*-Sharp comprising of 216 ponds has started operations with a production capacity of 3,100MT per annum. Phase 2 on the other hand will have 400 ponds capable of producing another 5,600MT per annum. *i*-Sharp will be complemented by a dedicated processing plant with a capacity of processing 20MT per day and a hatchery slated to produce 1.5 billion PLS per annum. *i*-Sharp is targeted to employed 465 locals by 2015 which contribute to the growth of income of the population in Setiu.

FIGURE 1. The *i*-Sharp Map

FIGURE 2. The current *i*-Sharp projects

METHOD AND MODEL DESCRIPTION

Objectives and Modeling Requirement

In the ecological aquaculture system, it's brings two effects. The first effect brings a positive effects which are good and benefits for us. However, the second effect brings some negative effects as well potential risks. Thus, a systems analysis model is important to build to analyze the reasons for the risks and negative effects. Besides that, it's also can identify the controlling and influencing factors so that the improvement policies will be make in order to reducing its negative effects, enhancing the positive effects and more depth it will promoting the sustainable development of the systems.

Method of System Dynamics

In order to realize the objectives and its requirement as mention above, we build an eco-aquaculture systems analysis model using a systems dynamics method developed by Forrester [5]. After going through some process of development and improvement in the last few decades, dynamic system model has been widely used, especially in the economic, society, ecology and more specifically in many complex systems [6, 7, 8]. The advantage of these systems for instant it can reveal the dynamic changes; give a feedback, information of delay and many others. Besides that, it characterized by quantifiability as well as controllability. According to Tao [9], these systems have a few advantages particularly in analyzing, improvement and managing the system characterized through complex feedback effects as well as long development cycle. With this advantages and the requirement need in our study, the systems dynamics method is used.

Logical Framework of the Modeling

One of the purpose of this study is to increase the positive effects, and at the same time reduce the negative effects. With that effects, the policy makers (the decision-makers) will take a necessary action in order to improve existing policies or introduced a new policies based on the interaction between "effect subsystem" and "aquaculture subsystem" and constitute the "policy subsystem". It can be done by modifying the "effect subsystem" and ultimately it can promote the sustainable development of the entire eco-aquaculture system (Fig. 3A and 3B). Thus, we built a system dynamics model called as "System Dynamics-Aquaculture Effect Policy" or "SD-AQEP" based on the interaction between aquaculture, effects and policy.

Data Sources

In order to get a complex relationship between aquaculture, the effects and policy, we need and used data from primary and secondary data. Primary data such as waste and environment scenario, we get from field investigation, observation and face to face interview in local areas. While, secondary data are mainly come from *i*-Sharp and Department of Fishery by year 2011 and 2012.

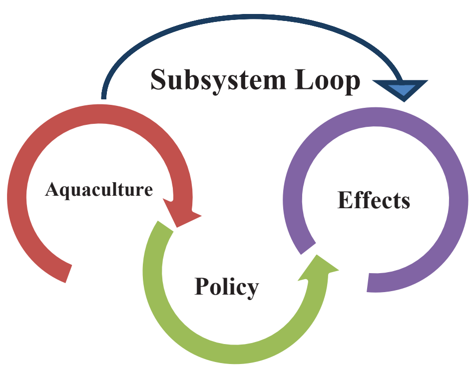


FIGURE 3A. Subsystem Loop of SD-AQEP.

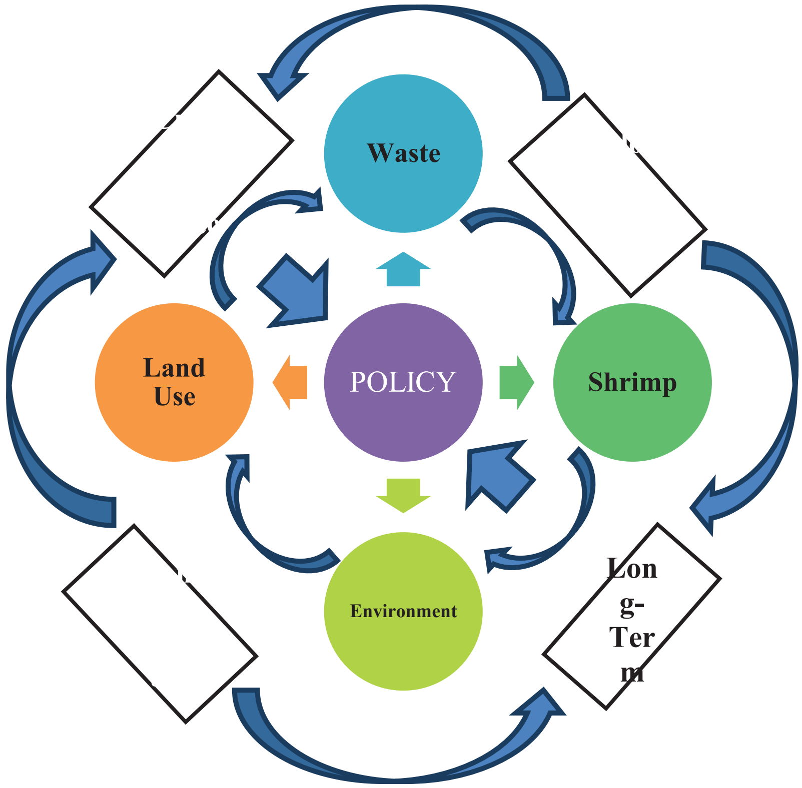
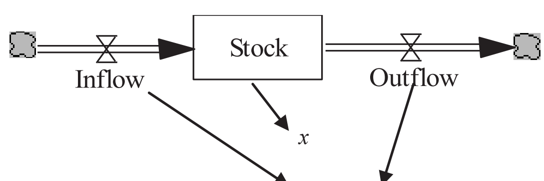


FIGURE 3B. Logical framework of SD-AQEP.

PROCESS MODELING FOR SD-AQEP

Stock-flow Diagram

The related mathematical equation in the mathematical model of system dynamics as shown in Equation 1:



$$\frac{dx}{dt} = \overset{\circ}{x} = net\ \ flow = inflow\ \text{-}\ outflow$$

$$\left(\frac{dx}{dt}\, comes\ \ from\, \frac{\Delta x}{\Delta t} = \frac{change\ in\ x}{change\ in\ t}\right) \tag{1}$$

According to Fig. 3A and Fig. 3B, the stock flow diagram of the SD-AQEP model is designed and become the core of SD-AQEP model. In this study, the differential equations built by stock flow diagram, the whole eco-aquaculture system is stimulated quantitatively and dynamically using Vensim software format as Fig. 4 and Fig. 5.

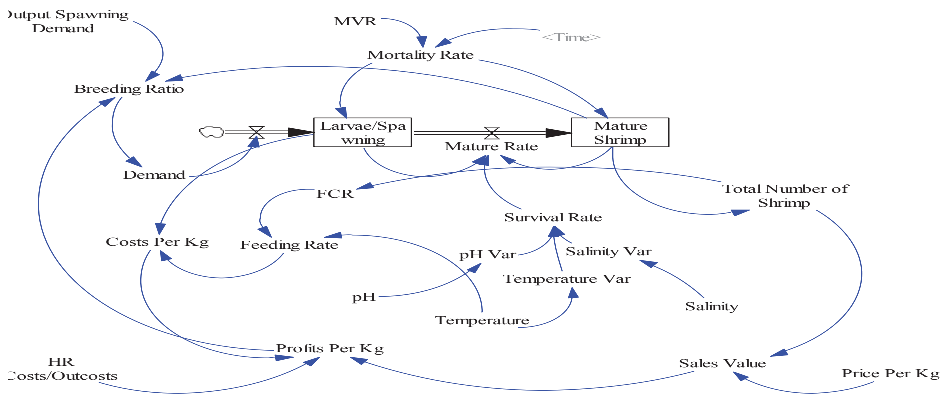


FIGURE 4. The stock –flow diagram of shrimp

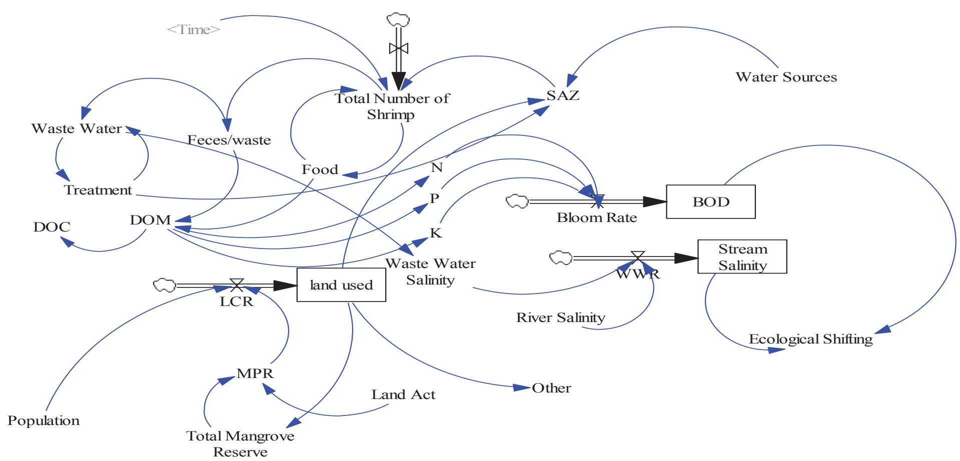


FIGURE 5. The stock –flow diagram of land used, BOD and salinity

ANALYSIS OF THE MODEL SD-AQEP

Land Use for Aquaculture Practice

According to the SD-AQEP model, the probable evaluation trends of the eco-aquaculture system between 2015 until 2025 are simulated and analyzed in i-Sharp, Setiu, Terengganu. The graph name as the "Base" is the graph simulation without altering basic variable that control the system. Using simulation, based on previous Shrimp Mature Production, a sufficient amount of land needed to be used for developing shrimp

Farms to fill up the demand quota for shrimp markets worldwide.

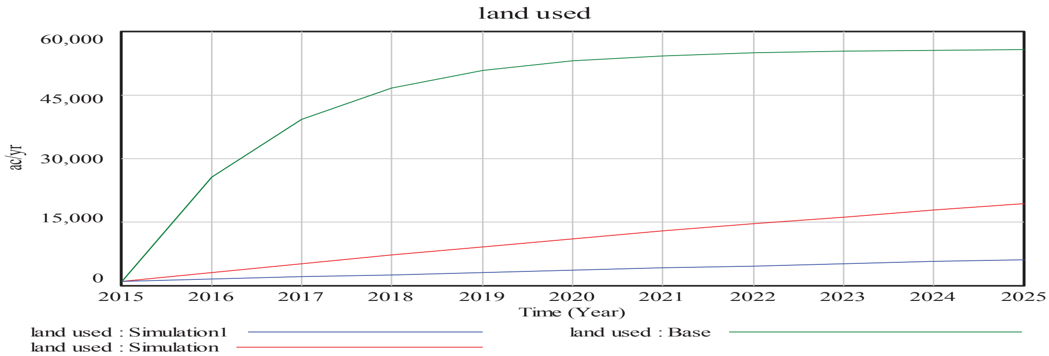


FIGURE 6. Land Used for Shrimp farms

This particular practice prove to be fatal towards the native ecosystems by changing the native landscape towards an aquaculture park. The deforestation of *Gelam Wetland* that are unique towards this costal wetland area will upset the ecosystem balance and promoting more natural disasters. Hence by obeying towards land regulation and law, could reduce the deforestation and land conversion rate and provide balance towards native ecosystems and produce a sufficient amount of shrimp for 70-80% of current demand

Hence by promoting an efficient law of land regulation, this particular wetland will be safe from the total elimination and conversion into an aquaculture farm. Thus this particular places could provide a safe place for native species and keep its function for years to come.

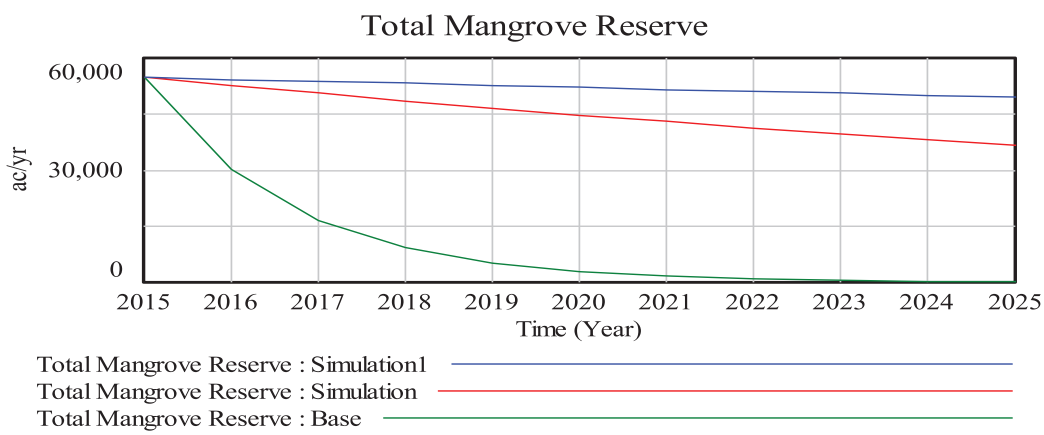


FIGURE 7. Total Mangrove Reserve

Salinity and Biological Oxygen Demand (BOD) from Local Sources of Fresh Water

In 2010, this particular aquaculture farm practice unethical waste management. Due to its humongous activity, the total of water circulation and recycling are keep barely at minimum. Hence they took an initiative to discard the waste water into a local river stream and causes an uproar among the local live nearby to this aquaculture area. This resulted in a banning of discharged waste water from local authorities in early 2011. Hence using SD-AQEP, we predict the effects of this particular practice and evaluate it over time:

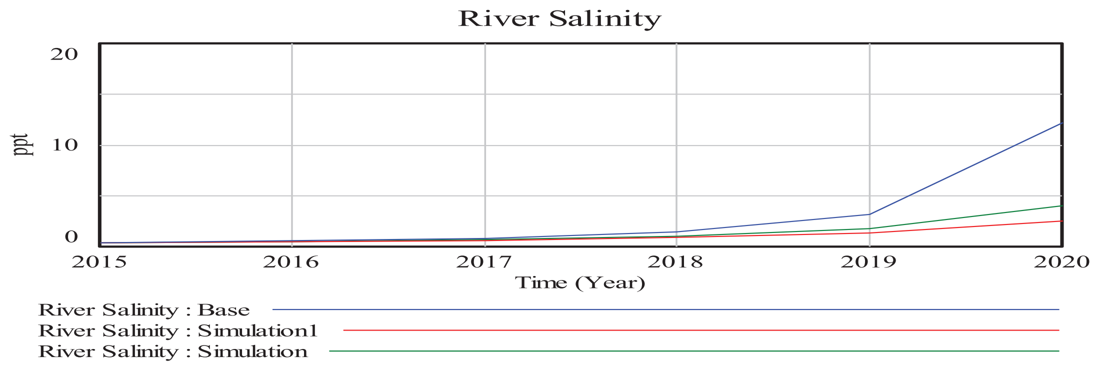


FIGURE 8. River Salinity

Practice of discharged pond water into local fresh water stream, it could be fatal over time. The simulation shows that this particular practice increase the river salinity level from .1 ppt to 15.0 ppt in early 2020. Note that a natural amount of salinity in local river are kept at .5 ppt, this particular shifting of salinity could be devastating towards native species in this river. Hence the effect could be vary from fresh land water towards the fresh reserve ground water as this particular area are a wetland that provide the recharge of ground water towards its ecosystems. Apart from salinity incensement, this particular water discharged also carry excessive Nitrogen, Potassium and Phosphorus (NPK) that resulted from shrimp waste and excessive feeds that dissolved in water. This particular nutrient initially exists in natural ecosystems in certain amount to provide nutrient for microbe and algae. Due to the excessive existence of NPK in river, the rate of algae bloom exponentially increase until $5.0\times e^{21}$ mg/L in 2020. By this time, the algae bloom will consume majority of oxygen in the water and promote native species towards migration or extinction.

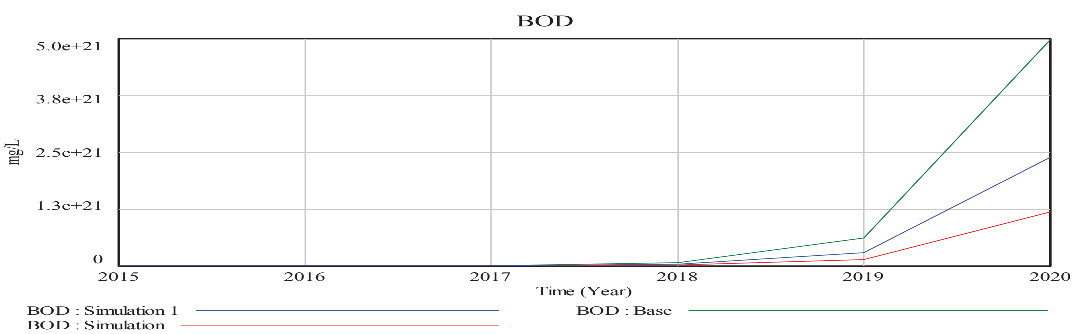


FIGURE 9. Biological Oxygen Demand (BOD)

Simulation of shrimp production shows positive growth alongside the years to come. Based on company expansion rate, supply and demand for fresh shrimp production, the company capacity of shrimp production shows positive growth. By 2025, total production of shrimp could exceed 80% total mature shrimp exceed previous production until 2015 (Fig. 10). By supporting the demand for shrimp for international capacity, the simulation capacity exceeds the basis capacity by 10% starting the 18th year onwards. Hence by 2050, we could conclude that the markets for shrimp industry are exceedingly well and should reach their threshold on years to come

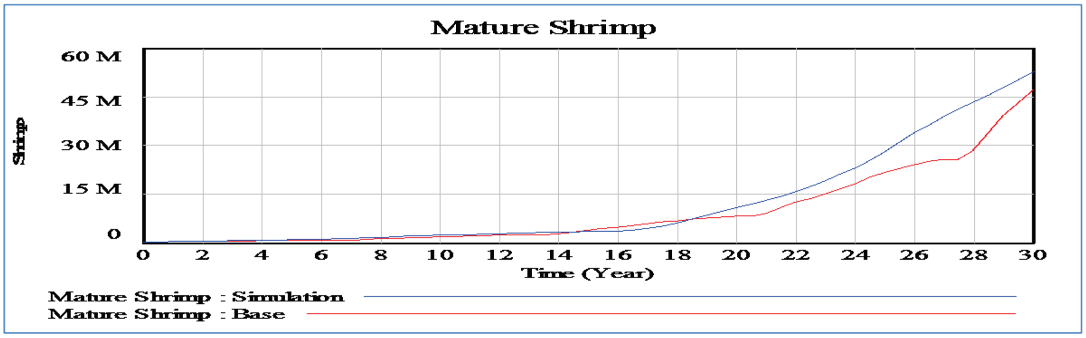


FIGURE 10. Shrimp Mature Production Rate

Subsequently, the feeding rate will increase based on the incensement of total maturing rate. This particular Feeding Changing Ratio provides an understanding about how will the feeds affects the total gram of the maturing shrimp. The normal ratio of Feed Conversion Rate is at the best of 1.4 to 1.7 means for a gram of feed will increase total of 0.6 to 0.8 gram of shrimp. Through observation on Feed Changing Ratio per gram of shrimp (FCR/g) the total rate of change whopping up into an absurd amount of 100g of feeds to 45g of shrimp. Hence, the production foods surely costs lots towards improving production for maturing shrimp. This particular change maybe resulted onto using low protein feeds, low amount of green algae in pond ecosystem from extensive aquaculture practice or probably lacking men power for inspecting the total gram for the shrimp.

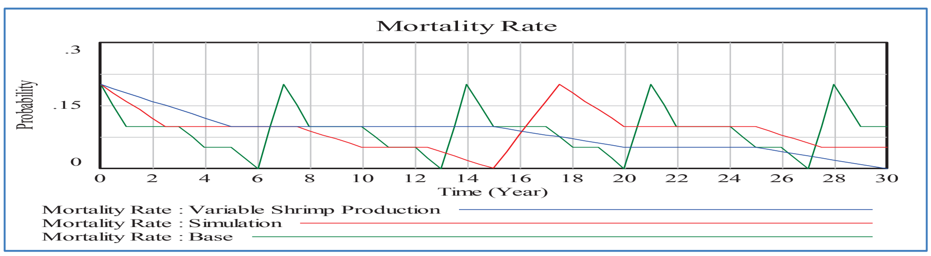


FIGURE 11. Shrimp Mortality Rate

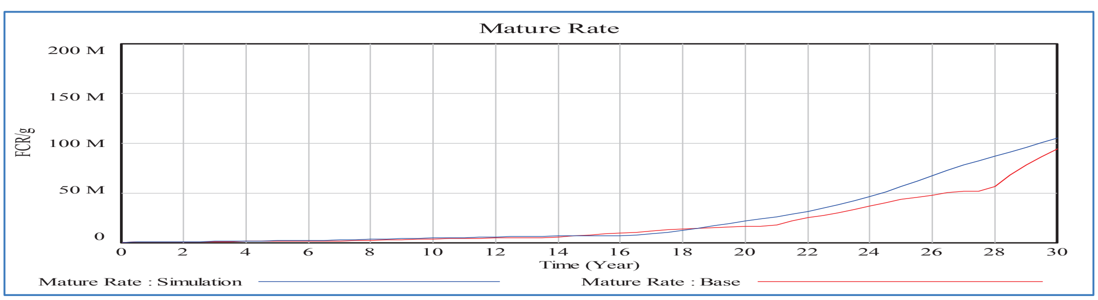


Figure 12. Shrimp Mature Rate

IMPROVEMENT POLICY FOR *i*-Sharp USING SD-AQEP

Improvement Policy for Current Aquaculture Practices

The improvement objective are to eliminating potential risks and sharply reduce current arising problems. This particular improvement focus on certain aspects such as management, environment, waste management and altering surrounding or existing variable.

Improve Policy Towards Land Uses and Act

Government should act to improve the current land act to provide more protection towards *Gelam Wetland* in Setiu. By promoting stricter act and law, this particular area will be conserved and thrived to its former glory and provide natural barrier towards upcoming natural disaster. By 2020, we could maintained 59,800 acre wetland area that been conserved for research and conservation of natural resources and increase the amount of renewable natural resources for local people.

Improve Policy for Water Usage and Waste Water Management

Government should impose banning direct discharged conduct by farm or industrial and promote an entity that responsible to impose a monthly checkup upon discharging treated water into freshwater stream. Hence, subsidies should give towards industry to promote maxima water recycling and reuse.

Improve Material for Shrimp Foods Production

In order to expend their business horizon, *i*-Sharp should consider to use more nutritious diet for shrimp production and impose more microbe rich environment in the prawn ponds. This could produce a more excellent harvest and rich microbe environment could cut FCR up to 20% per culturing period.

Improve Aquaculture Pond Water System

A standard operating procedure for better management for pond could be applied onto business environment. By using a better SOP for managing aquaculture activity, *i*-Sharp management could boosts up worker productivity and increase harvesting yield. The new increase variable for water recycle could cut the percentage of water discharged. Hence by adding direct discharged into the sea mechanism, could 100% cut the increase of salinity in nearby freshwater stream? Advance technology for separating waste from water could be beneficial in terms of making sub-product from aquaculture. This particular method can generate fertilizer for agricultural uses.

CONCLUSIONS

By utilizing the SD-AQEP model, the eco-aquaculture system in *i*-Sharp, Setiu District, Terengganu is simulated, analyzed and improved and some conclusions are drawn as follows: (i) In this study, a system dynamic model called SD-AQEP is built and use to simulate and analyze an eco-aquaculture system. The results from the simulation revealed that the potential risks which are the negative effects of the system are identified. Then, the system improvement especially policies are made in order to reduce, eliminate all the risks as well as negative effects and at the same time bring and expand the ecological and economic to the positive effects. (ii) The systems was developed can proved specifically the interaction and material flow mechanism among aquaculture, policy as well as effects subsystems of industry. In addition, the systems can diagnose scientifically the potential short-comings and defects in the system, provided the basic improvement policies as well as checking the effectiveness of the improvement policies. (iii) The core contributions of this study is the model itself, which is SD-AQEP model. This model is divide into three parts: aquaculture, policy and effects and also the interaction and material-energy flow mechanism among each part as the logical framework of modeling. Hence, this system is potential to revealing the internal structures in the complex system with ecosystem and other systems such as economy, environment, human activity, etc.

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