# Improving Silvofishery Management Through Seedling Growth-Environment Quality Dynamic Relation Analysis

*by* Endah Dwi Hastuti

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# Improving Silvofishery Management Through Seedling Growth-Environment Quality Dynamic Relation Analysis

**Endah Dwi Hastuti, Rini Budi Hastuti**

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Faculty of Science and Mathematics, Universitas Diponegoro, Indonesia

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Correspondence Author:
Jl. Prof. Soedarto, SH, Tembalang, Semarang, Central Java, 50275
E-mail: endah_pdil@yahoo.com

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## INTRODUCTION

The interaction between mangrove and environment dynamics has been explained in many researches (Berger *et al.*, 2008; Hastuti *et al.*, 2016; Orchard *et al.*, 2015). Mangrove plants are sensitive to the environment condition (Gilman *et al.*, 2008). There are various ecosystem components and processes linked each other within mangrove ecosystem (Berger *et al.*, 2008). Mangrove ecosystems are dominated by water inundation which is frequently changed due to tidal activities or seasonal dynamics (Krauss *et al.*, 2009). The changes of environment, especially water quality might affect the growth of mangrove seedling.

Mangrove forest plays an important role in influencing the environment parameters (Hastuti *et al.*, 2012). Physically, mangrove plants provide a physical barrier for tidal dynamics and canopy for the ecosystem beneath it (Krauss *et al.*, 2014). Mangrove stands generates slow water movements which improve the sediment settling, resulting a lower turbidity level and TSS concentration in the water (Balke *et al.*, 2013). Mangrove canopy provides protection for its floor from direct sun light, hence water warming could be decreased resulted in lower water temperature (Nagelkerken *et al.*, 2008). While, the DO is affected by photosynthesis process by phytoplankton and mangrove stands (Knight *et al.*, 2013). Even though, the availability of nutrient and pollutants in the water also affect the concentration of DO in mangrove floor (Shukla *et al.*, 2008). The long-term effect of mangrove includes the variability of nutrients concentration such as organic matter, nitrogen and phosphorus (Feller *et al.*, 2010). Slow water movement in the mangrove floor increase the rate of sediment accumulation (provided by TSS) which contains some nutrients (Mackenzie *et al.*, 2016). The dynamic of nutrients within mangrove ecosystem is defined by the accumulation rate and the uptake rate by mangrove stands, since mangrove needs quite large amount of nutrient to grow well.

Mangroves require suitable environment condition to grow optimally. Various factors such as temperature, salinity, turbidity, sedimentation rate and nutrient concentration are considered to play important roles to the growth of mangrove (Balke *et al.*, 2013). Temperature range is the main factor affecting the mangrove distribution (Quisthoudt *et al.*, 2012). Mangrove require warm area to grow, even though the temperature range is limited. According to Krauss *et al.* (2006), seasonal temperature affects the annual diameter growth of mangrove. Salinity also plays important role in controlling mangrove distribution. Several mangrove species are found in the saline zone, while the others are in the low salinity and even fresh water zone (Jayatissa *et al.*, 2008). Turbidity and sediment play an important role in seedling settlements. Turbidity affects mangrove's photosynthetic capability, while sedimentation rate also affects the seedling burial (Hastuti & Budihastuti, 2016a). In addition, the concentration of nutrient definitely affects the nutrient supply for mangrove growth (Osman & Abohassan, 2010).

Both environment factors and growth of mangrove are dynamically change over time (Hastuti *et al.*, 2016). The changes of environment factors are usually driven by seasonal variables (Agunbiade *et al.*, 2010). Even though, the growth of mangrove also plays a significant role in the changes of environment variables (Hastuti & Budihastuti, 2016b). Mangrove stand itself changed over time. Mangrove plants are continuously growing which would change its dominance over the environment condition (Nazim *et al.*, 2013). The growth rate of mangrove depends on its environment condition (Hastuti *et al.*, 2012). The dynamic of environment condition such as the one as the effect of seasonal pattern might affect the growth rate of mangrove. Thus, the growth of mangrove stands and the changes of environmental factors have linked each other, forming a dynamic relationship which last forever.

The dynamic linkage of environmental factors and growth of mangrove might be formulated. Various variables such as the existing environment condition, changes of environment condition, existing stand condition and growth of mangrove stands might have linked each other, forming a dynamic environment-growth relationship. However, to formulate the dynamic linkages of environment factors and the growth of mangrove require controlled treatment to observe the changes of environment conditions and growth rate of mangrove stands. Those treatments should be conducted in a quite long period to observe the periodic change of observed parameters.

Silvofishery pond canal is one potential structure to apply the treatments. The canals have a controlled water input and output which is the main factor in mangrove ecosystem dynamic. Experiment conducted in the silvofishery canal also provides a more homogenous mangrove condition since the mangrove have existed from the very beginning of pond development. Hence, the development of mangrove and the dynamic of environmental factors could be observed appropriately. *Avicennia marina* is one pioneer mangrove species which lives in the inundated area in the coastal zones. Application of silvofishery ponds often use *A. marina* as the integrated mangrove. Even though, the reciprocal system of *A. marina* and the environment variables has not well understood.

The linkage of mangrove growth and environment dynamics provides a structured relationship in form of a model. To verify the linkages of both variables, a simulation is required to prove that the model is valid. This research aimed to analyze the linkages between mangrove growth and environment dynamics and to estimate the growth of mangrove along with the environment dynamics. This research was expected to provide a more advanced information on ecosystem complex relationship and to provide an information to the society regarding the best management of silvofishery pond application. The benefits achieved from this research included initial development of complex ecosystem modeling in purpose of further understanding on the multiple simultaneous effect of environment factors on seedling growth as well as the effects of mangrove development on environment changes which were not much studied. Thus, applicative benefit of the research would be its potential to better manage silvofishery pond ecosystem to achieve more effective management regarding environment quality improvement in order to optimize pond productivity.

## METHODS

This research was conducted through field experiment in the silvofishery pond for 2 years. The field was located in Mangunharjo Village, Tugu District, Semarang City, Central Java. Observation was conducted from March 2015 to June 2016. Observation was conducted periodically every 3 months. Experiment design applied in this research included the variation of canal width. The mangrove seedling was planted in a consistent space of 1 x 1 m. Thus the population of mangrove seedling varied with canals width. The width of the canals utilized in this research were 1 m, 2 m and 3 m. The silvofishery observed in this research applied plantation of *A. marina* in the pond canals.

Observation was conducted to the environmental factors including water quality i.e. temperature, salinity, turbidity, pH, DO and TSS and to sediment quality including organic matter (OM), nitrogen and phosphorus concentration. Seedling measurement such as stand height and diameter was observed to analyze the periodic growth rate of mangrove. Data processing was conducted to calculate the average value and value changes between observations. While data processing for mangrove growth was conducted to calculate daily growth of mangrove seedling.

Data analysis involved two steps. First data analysis was conducted to analyze the regression functions of linked variables. Regression analysis was conducted to understand the effect of environment parameters on the growth rate of mangrove seedling and vice versa. Next analysis was modelling analysis using Powersim Studio 2005. Variables which were significantly linked were used as a model building. The simulation was run for 1 year to estimate the changes of *A. marina* growth rate and the changes of environment parameters. Variables which were not significantly affected by other variables occupied random number generator based on the observation data.

## RESULTS AND DISCUSSION

The analysis showed that there were 6 environment variables affect the growth rate of *A. marina* seedling i.e. dissolved oxygen, temperature, salinity, turbidity, pH and TSS. The pattern of the environmental variables effect on the growth rate of mangrove seedling were varied. Detailed regression analysis result is presented in Table 1.

**Table 1**. Effect of environmental variables on the daily growth rate of *Avicennia marina* seedling

| Variable | Equation (Effect Pattern) |
|---|---|
| Height Growth | |
| DO | (-1.8597-0.4944*DO_Old-0.2515*DO_Ch + 2.8688*LN(DO_Avg)) |
| Temperature | E^(5.2775-0.2095*Temp_Avg + 0.1905*ASINH(Temp_Ch)) |
| Salinity | E^(-13.1486 + 3.3782*LN(Salin_Avg)) |
| Turbidity | E^(-7.6994-0.0044*Turb_Avg + 3.1037*LOG(Turb_Old)) |
| pH | E^(-3.6768 + 0.2061*pH_Old-0.5280*pH_Ch + 0.9221*ASINH(pH_Ch)) |
| Diameter Growth | |
| TSS | E^(-5.7734 + 0.0033*TSS_Ch) |

Notations: DO_Avg= Average DO concentration within growth period; DO_Ch= Changes of DO concentration within growth period; DO_Old= Initial DO concentration within growth period; pH_Ch= Changes of pH within growth period; pH_Old= initial pH within growth period; Salin_Avg= Average salinity value within growth priod; Suhu_Avg= Average temperature value within growth period; Suhu_Ch= Changes of temperature within growth period; TSS_Ch= Changes of TSS concentration within growth period; Turb_Avg= Average turbidity value within growth priod; Turb_Old= Initial turbidity value within growth period

The analysis showed that height growth of *A. marina* was affected by initial DO concentration, changes of DO concentration, average DO concentration, average temperature, changes of temperature, average salinity, average turbidity, initial turbidity, initial pH and pH change, while the diameter growth was affected by TSS change. There were multiple transformation patterns applied, including logarithmic, log natural (ln), and asinh (inversed hyperbolic sine) which indicate that the effect pattern of environment variables was not completely linear. It indicates that environment variables affect the dynamic growth rate of mangrove through several correction patterns.

The growth of mangrove significantly affected the environmental changes. The affected parameters included N, OM and temperature. Growth parameters which affect the environment dynamics included seedling height, average height, average diameter and daily growth rate of diameter. Detailed regression function of *A. marina* growth on the environment variables is presented in Table 2.

**Table 2**. Effect of *Avicennia marina* seedling growth on the environment parameters

| Variable | Equation (Effect Pattern) |
|---|---|
| N_Ch | SINH(1.5381-0.7633*LOG(H_Am_Avg) + 0.2124*LN(D_Am_Avg)) |
| OM_Ch | (1.9927 + 0.6578*LOG(Gr_D_Am))³ |
| Temperature | (38.6561-3.2386*LOG(H_Am)) |

Notations: OM_Ch= Changes of OM concentration within growth period; N_Ch= Changes of N concentration within growth period; H_Am= Height of *Avicennia marina* seeling; H_Am_Avg= Average height of *Avicennia marina* of the initial and final growth period; D_Am_Avg= Average diameter of *Avicennia marina* of the initial and final growth period; Gr_D_Am= Daily diameter growth rate of *Avicennia marina* seedling

**Figure 1**. Pond setting: mangrove plantation side to side with pond embankments

**Figure 2**. Morphometric measurement activities

Table 2 showed that the changes of N concentration was affected by the average height growth and average diameter growth of *A. marina*. The organic matter change was affected by diameter growth of *A. marina* and the temperature was affected by seedling height. The analysis has proven that the growth of mangrove as well as its final measurement also contribute to the changes of environment dynamics. The regression analysis result was then applied to build diagram constructor for dynamic modelling. The diagram indicates the linkages among observed variables achieved from the research. Figure 3 and Figure 4 showed the diagram constructor of the dynamic interaction of environment variable and mangrove growth.

The diagram constructor as shown in Figure 3 and Figure 4 verified the dynamic linkages of environment variables and the growth rate of mangrove. The diagram shows that only temperature had the reciprocal effect over seedling growth. Simulation was then conducted to estimate the possibility of growth rate and changes of environment variables. Since not all of the environment variables were affected, only the changes of affected parameters are presented. The simulation result of the affected parameters is shown in Table 3.

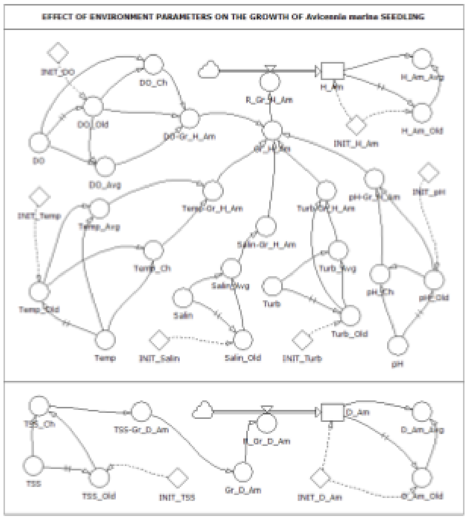


**Figure 3**. Relationship diagram of the effect of environment variables on the growth rate of *Avicennia marina* seedling

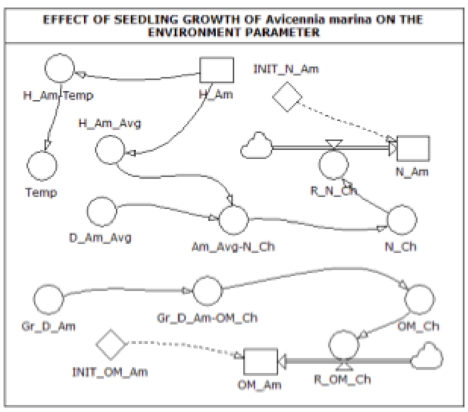


**Figure 4**. Relathionship diagram of the effect of *Avicennia marina* seedling growth on environment dynamic

Table 3 shows that the growth rate of mangrove seedling as well as the environment variables change dynamically. According to Table 3, the effect of environment variables on the height growth rate of *A. marina* seedling was ranged from 0.115024 to 0.282294 cm/day, while the diameter growth rate was ranged from 0.001287 to 0.006031 cm/day. The effect of seedling height on the temperature resulted in the temperature dynamic from 31.30 to 33.47 °C. The concentration of organic matter and nitrogen showed an increase among period. It indicated that the growth of *A. marina* seedling increases the accumulation of nutrients.

**Table 3**. Simulation result of *A. marina* and environment variables dynamic interaction model

| Height Growth (cm/day) | Diameter Growth (cm/day) | Temperature (°C) | BO (%) | N (%) |
|---|---|---|---|---|
| 0.119780 | 0.004223 | 33.22 | 1.70 | 0.55 |
| 0.213057 | 0.004204 | 32.69 | 1.73 | 0.55 |
| 0.195274 | 0.003993 | 33.26 | 1.75 | 0.56 |
| 0.143456 | 0.002568 | 33.47 | 1.78 | 0.58 |
| 0.219029 | 0.002771 | 32.27 | 1.78 | 0.59 |
| 0.214514 | 0.001287 | 31.30 | 1.79 | 0.61 |
| 0.115024 | 0.003048 | 33.37 | 1.80 | 0.62 |
| 0.212545 | 0.003604 | 32.70 | 1.81 | 0.64 |
| 0.282294 | 0.006031 | 31.89 | 1.83 | 0.65 |
| 0.192658 | 0.002205 | 31.52 | 1.88 | 0.66 |
| 0.223346 | 0.001894 | 31.58 | 1.88 | 0.67 |
| 0.258952 | 0.002574 | 31.55 | 1.89 | 0.68 |

The effect of DO on the growth of *A. marina* seedling was corrected by its changes. Generally, increasing DO concentration alter the growth rate of mangrove seedling. DO is an important variable for mangrove growth. Alongi *et al.* (2008) stated that the growth of mangrove is significantly related to oxygen metabolism. The concentration of DO also drive the nutrient availability in mangrove ecosystem. DO is required in mineralization of organic materials which are required for mangrove growth. It is proven by Vovides *et al.* (2011) which showed that the DO concentration decreased along with the N fixation processes.

Temperature is the main factor affecting the global distribution of mangrove. Gilman *et al.* (2008) stated that the change of temperature might affect the species composition, which means increasing the mortality risk of certain mangrove species and the chances of some other mangrove species. Further effect for the sustaining mangrove would be the change of phenological pattern, increasing productivity and change of mangrove coverage. The effect of temperature change on the physiological processes of mangrove includes the increasing photosynthetic rate and increasing autotrophic respiration rates (Lloyd & Farquhar, 2008). Sudden change of temperature might cause stress on the mangrove metabolisms which affect the growth of mangrove.

Salinity is an important variable affecting the photosynthetic process of mangrove vegetation. Biber (2006) stated that increasing salinity lead to the decrease of photosynthetic activities. Further effect of salinity stress was explained by Kanai *et al.* (2014) which showed a decreasing growth rate of mangrove under salinity stress. High salinity decreased the leaf half-life of mangrove (Suárez & Medina, 2008). Thus, it can be concluded that mangrove which grows in the saline environment has a lower growth rate compared to mangroves in the less saline environment. Even though, the salinity might be the driving factor of mangrove's high litter production.

Turbidity is a linked variable in the mangrove ecosystem. Kang (2012) showed that turbid water contain nutrient particles which is required by plankton. Genkai-Kato *et al.* (2012) stated that the abundance of phytoplankton also defines the turbidity of water. Hence, the turbidity of the water also indicates its fertility. Turbid water contains more nutrient than clear water. But, high turbidity could provide negative effect as well. According to Tanaka & Kodama (2007), high concentration of suspended sediment might accumulate which cause decreasing oxygen concentration and lead to hypoxia.

pH is the driving factor for nutrient availability. Oxmann *et al.* (2010) stated that the availability of phosphorus in the sediment and mangrove leaf are affected by sediment pH. While Rahaman *et al.* (2013) stated that pH regulates the occurrence of different forms of ammonia in the water. pH also defines the mobility of pollutants (Imo *et al.*, 2012). Hence, pH plays an important role in driving the availability of essentials compound in the mangrove ecosystem.

TSS concentration define the turbidity level of the water. TSS is the mean of nutrient transport in the aquatic ecosystem. According to Fabricius *et al.* (2014), nutrient always move altogether with the sediment. Hence, sedimentation always followed by the accumulation of nutrient. Cerco & Noel (2016) showed that TSS contain particulate nitrogen and particulate phosphorus which are needed for the growth of mangrove. Thus, without nutrient supply provided by TSS, mangrove ecosystem might be lack of nutrient.

The mangrove stands height and diameter significantly affect the nitrogen concentration in the sediment. Rivera-Monroy *et al.* (2007) stated that tidal activities is the main source of nitrogen in mangrove ecosystem. The accumulation of nitrogen in the mangrove ecosystem occurred along with the sedimentation. Sediment transport various minerals such as nitrogen and phosphorus (Sohel & Ullah, 2012). Negative effect of height was considered as the result of nitrogen uptake by mangrove stands, while the positive effect of diameter was considered as the result of decomposition of organic matter or the increased sediment trapping.

The accumulation of organic matter increases as the growth of mangrove seedling. A research conducted by Kristensen *et al.* (2008) showed that the as the forest age, the amount of fresh organic matter increased. Development of roots was considered as the affecting factor of increasing organic matter accumulation (Holstein & Wirtz, 2010). Another source of organic matter would be the decomposition of mangrove litter by microorganism associated with mangrove roots. Sanders *et al.* (2014) also noted that the enhanced organic matter accumulation rate was not only supported by litter decomposition and sediment trapping. Various microorganisms which lived in the mangrove roots also become the source of organic matter in the mangrove ecosystem. As mangrove grows, it provides more spaces and supports to those organisms.

The temperature was affected by seedling height. According to Nagelkerken *et al.* (2008), mangrove provides canopy which protects the forest ground from direct sunlight. Thus, the warming of surface water temperature could be hindered. The concentration of $CO^2$ also affects the temperature (Shakun *et al.*, 2012). The development of mangrove improves its photosynthetic capability, which means that there are more $CO^2$ be converted to $O^2$. This is considered as one of the mechanisms of temperature cooling by mangrove.

According to the result, the concentration of organic matter and nitrogen tend to increase over time. This risks to nutrient accumulation which might cause eutrophication while the nutrient concentration is over saturated. Best management practice to avoid the risk would be mangrove pruning or the integration of additional aquatic plants such as algae to decrease the nutrient accumulation rate and existing organic matter concentration.

The result indicates that the growth of mangrove seedling and its environment quality dynamically affect each other forming a specific pattern. The developed model could be considered as the main pattern of the complex relationship among parameters. Variation on the parameters input value might cause a different effect such as growth rate or environment suitability changes. Thus, this model could be used to estimate the effect of certain occurence of water environment phenomena to the growth of mangrove seedling. Hence, through this information, the management of mangrove planting as well as water quality control of the pond could be improved in a limited time interval. This contributes to a more advanced scientific understanding on how ecosystem works which was mostly studied based on a partial relationship model, which is insuitable to the real condition.

This research initiated a model development to achieve a deeper understanding on ecosystem researches. This research showed that there might be a chance to a model of ecosystem locally or globally. Through ecosystem modeling, a complex ecosystem relationship could be understood such as multiple impact of parameter changes or direct and indirect effect of a parameter on other parameters. The advantages of this research are including local utilization for resources management such as silvofishery pond and coastal rehabilitation and globally for the estimation of global environmental changes and its impact on the ecosystem. The benefit for local society from this research would be the better application of resource management by knowing the risk of certain ecosystem condition which could be followed by an appropriate handling act. Thus, resource management should work more effectively, especially on silvofishery management as expected to provide a better environment condition and pond productivity.

## CONCLUSION

The dynamic linkage showed that seedling growth of *A. marina* was defined by dissolved oxygen, temperature, salinity, turbidity, pH and TSS, while the growth of mangrove affected the water temperature, changes of sediment organic matter and nitrogen concentration. The simulation showed a dynamic growth rate of mangrove seedling and temperature, while the organic matter and nitrogen are accumulated over periods.

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# Improving Silvofishery Management Through Seedling Growth-Environment Quality Dynamic Relation Analysis

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