Management of mangrove ecosystems for increasing fisheries production in Lubuk Kertang Village, North Sumatra, Indonesia

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Abstract. Mangroves play an important and valuable role in coastal and marine ecosystems, in particular acting as nursery grounds for coastal and offshore fisheries. Mangrove ecosystems in North Sumatra, Indonesia, have been lost through anthropogenic activities. The purpose of this study was to calculate the potential contribution of mangrove litter to fisheries and to design a dynamic model of mangrove management for optimal and sustainable fisheries utilisation using Powersim Software. This study used observations (mangrove characteristics including litter production and environmental parameters) and interviews (benefit values) to consider the link between mangrove area and fishery resources. The collected data were entered into the dynamic model, and scenarios were simulated for up to 75 years. Results showed that the estimated potential fisheries benefits amount to 1,202.282 kg ha^{-1} year^{-1} or IDR 22,663,023 (US$ 1,679) ha^{-1} year^{-1}. An increase in mangrove area of up to 10 ha year^{-1} is a minimum requirement for sustainable utilisation of fisheries. The species composition providing maximum value for coastal fisheries consisted of *Avicennia* spp. 15.2%, *Rhizophora* spp. 60.8% and *Sonneratia* spp. 24%.

Key Words: Mangrove, nutrient litter, economic value, dynamic model.

Introduction. Mangrove forests are distributed in the inter-tidal zone along the coast in most tropical and sub-tropical regions (Giri et al 2014), providing valuable ecosystems with significant production potential. Mangroves also play an important role in managing coastal and marine ecosystems (Blasco & Aizpuru 2002; Dahdouh-Guebas et al 2005; Duke et al 2007). For centuries, mangroves have contributed significantly to the socio-economic lives of coastal dwellers. Despite their enormous socio-economic value and ecological significance, mangrove ecosystems are under severe threat (Nagi & Abubakr 2013).

Mangroves in Indonesian coastal areas, including in North Sumatra, have been degraded through direct and indirect exploitation (Richards & Friess 2012; Basyuni et al 2015). Anthropogenic impacts (reclamation for aquaculture, farming and residential and industrial development) are causing the disappearance of mangroves at an alarming rate, the most significant losses occurring in Southeast Asia (Giri et al 2011; Satyanarayana et al 2011; Porwal et al 2012; Cornforth et al 2013). High population growth and migration into coastal areas have led to an increased demand for their products, and the situation is exacerbated by poor planning and uncoordinated economic development in coastal zones.

Perhaps the most crucial role played by mangroves is in the ecological support they provide to maintaining the productivity of fisheries in coastal and marine waters,

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acting as spawning grounds and nurseries for various fishery species (Able 2005). As primary producers in the food chain, healthy mangroves are the basis of diverse and plentiful fisheries, the foundation being high leaf production, leaf fall and rapid breakdown of the detritus. Litterfall has been estimated to account for 30% to 60% of total primary production (Abrantes & Sheaves 2009). The importance of mangrove leaf litter in the maintenance of detritus-based food webs in the coastal environment, and the significance of these food webs for coastal fisheries, has been previously reported (Baltz et al 1998).

Exploitation of mangroves invariably compromises their role supporting healthy fisheries, with social and economic aspects (e.g. employment for coastal dwellers) taking precedence over sustainable management. In this study, we wished to address the significant contribution of mangroves to the functioning of a healthy ecosystem, one that combines ideal coastal land use with sustainable fishing. Our aim was to estimate the potential benefits and value provided by mangrove litter and to design a dynamic model of mangrove management for optimal and sustainable fisheries.

Materials and Methods

Study sites. The study was carried out in Lubuk Kertang mangrove forest, North Sumatra, Indonesia. The Lubuk Kertang Village lies between latitudes 04°02′34.25″N and 04°05′27.11″N, and between longitudes 98°14′57.92″E and 98°18′37.87″E. Regionally it is located at Langkat Regency, and Brandan Barat district, North Sumatra province, Indonesia. The study was conducted at five different locations as shown in Figure 1. Stations 1 and 2 are areas of natural mangrove, station 3 is characterised by oil palm plantations, and stations 4 and 5 are rehabilitated mangroves. All stations were used by local fisheries for mangrove crab trapping.

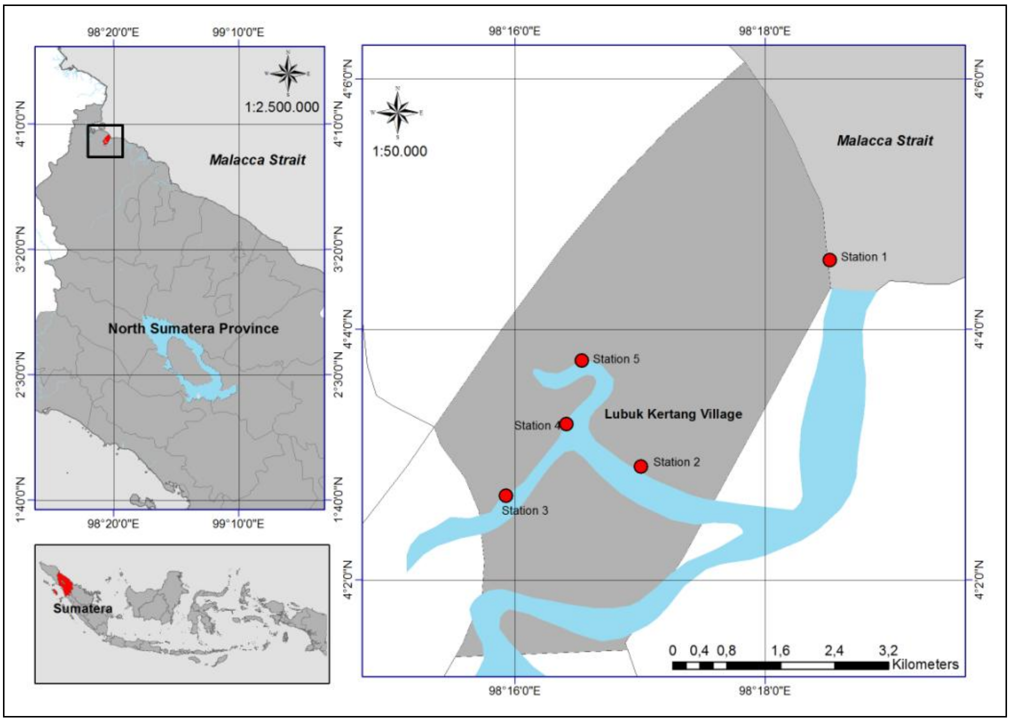

Figure 1. Study site location sat Lubuk Kertang Village, North Sumatra, Indonesia.

Data type and source. Primary data included the characteristics of the mangrove trees, physical and chemical parameters of the environment, the primary productivity of the mangrove ecosystem sand the socio-economic data of the fishermen utilising the mangrove ecosystems. Secondary data included fishery production data, number of fishermen, number of fish farmers and pond and mangrove area.

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Mangrove ecosystem characteristics. Mangrove density, type and stem diameter were measured, and these data were used to calculate the Importance Value Index (IVI) and Shannon–Wiener diversity index (H′) of the mangrove species. The methodology of IVI and H′ indexes calculation were performed as previously reported (Basyuni et al 2015). For sampling, quadrant transect observations were conducted by purposive sampling at five stations, two of which were considered to represent mangroves adjacent to the sea (stations 1 and 2), and three which were characteristic of upstream mangroves (stations 3-5). The mangrove data collection was done by extending a line transect of 100 m inland perpendicular to the coastline. At each station, three plots (replicates) of 10 × 10 m were examined, and the number of mangrove trees counted to calculate that station's mangrove tree density. The IVI and H′ were calculated to define mangrove condition. In each zone along the line transect, the specified environmental parameters were measured, and on each plot, the substrate types were observed and noted.

Measurement of physical and chemical parameters. At several points in each plot at a station, the substrate type, water temperature and salinity were measured.

Mangrove litter production. Production of mangrove litter was calculated using the litter trap method as previously described (Ashton et al 1999). Each trap consisted of a 1 × 1 m^2 of netting mounted beneath the tree canopy at a height of 1-1.5 m above ground level. Five traps were located at each station. The litter that fell into the nets was collected and put in a plastic bag biweekly (on days 14, 28, 42 and 56) and then separated on the basis of the components: leaves, twigs or fruit. The wet weight of each component was taken, after which the material was oven dried at 105 °C for the measurement of the dry weight.

Relationships between mangrove characteristics and environmental parameters. The relationships between mangrove characteristics and environmental parameters were analysed by agglomerative hierarchical clustering (AHC) in which grouping is based on classes having similar or adjacent characteristics (Dasgupta & Long 2005). Clustering was based on several criteria including optimal environmental conditions, fishing production, production of mangrove litter and prediction of mangrove vegetation future dynamic.

Primary productivity analysis. Estimation of fish production was done through a nutrient approach, whereby the nutrients released into water by the litter is then utilised by phytoplankton through photosynthesis as primary production. An estimate for fish production was determined on the basis of the production of nutrients (N and P) from the litter via the following steps:

- Σ Nutrient (g m^{-2}) = Σ (LLx × RNx) + (LLx × RPx), where LL = total leaf litter production; RN, RP = potential release of N and P; x = mangrove species,
- C:N ratio for protein production was taken as 17:1 (carbon:nitrogen). The amount of nitrogen that changes to dry weight (g C) is 1 g C = 2 g of dry weight (de Weir et al 2005). Proportion of phytoplankton (g) C: Nutrient (g) N = 17:1,
- Primary production is determined by decomposition of the litter, Σ PPL (g C m^{-2}) of nutrient production, namely, Σ PPL = Σ Nutrient × 2 × 17,
- Production of herbivorous fish (g wet weight of fish m^{-2}) is calculated from Σ PPL by using production conversion efficiency primary of Beveridge (1984), as follows: production of herbivorous fish (HF) = 10 × (b × ΣPPL), where b is the percent value of conversion into grams of fish carbon per square meter per day (g C^{-fish} m^{-2} day^{-1}). Fish weight evaluation depends on fish species and aquaculture conditions. The carbon content in fish is 10% of the weight of the fish, or in other words, the wet weight of the fish is equal to 10 times the carbon content of the fish,
- Production of carnivorous fish (CF) produced by the ecosystem. The mangroves were assumed to have an energy flow efficiency of 10%; CF was taken as10% of HF; Total fish production ΣFB = HF + CF.

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Value of fishery utilisation (consumer surplus). The benefits of mangroves for the community were identified from fishery utilisation activities (such as presence of fishermen) and habitat utilisation activities (such as exploitation of ponds). Data on income, fish prices, education, age, and the number of families of fishermen and fish farmers locally were obtained via interview using techniques previously described (Basyuni et al 2018). Selection of respondents was made by purposive sampling. The data were processed with Microsoft Excel and Maple 11 software (Poudyal et al 2009) to calculate consumer surplus and economic value of utilisation as previously reported (Salem & Mercer 2012).

Dynamic models of mangrove resource management. Modelling was performed through model simulation with the help of computer-based system dynamics software Powersim Studio (Lopes et al 2012) using input from related variables. Three scenarios were modelled relating resources and fishery production: the "business as usual" (BAU) scenario (i.e. conditions as they exist currently), the conservation scenario and the fish pond expansion scenario. The USD:IDR exchange rate was taken as 1:13,500.

Results

Mangrove ecosystem characteristics. Table 1 summarises the characteristics of the mangrove species found at the study sites. The most abundant mangrove species recorded was *Rhizophora apiculata* with a density ranging from 5 to 21 trees m^{-2}. The least abundant species was *Avicennia marina* with a density ranging from 2to 3 trees m^{-2}. *Avicennia* spp. were only found at stations 1 and 2.

Table 1

Mangrove species found at the study sites

No	Mangrove species	Station				
		1	2	3	4	5
1	*Avicennia alba*	3	2	0	0	0
2	*Avicennia lanata*	5	4	0	0	0
3	*Avicennia marina*	3	2	0	0	0
4	*Rhizophora apiculata*	11	5	21	16	6
5	*Rhizophora stylosa*	4	2	3	6	2
6	*Sonneratia alba*	3	4	2	5	9
7	*Sonneratia caseolaris*	0	2	0	3	2
Density (tree 100 m^{-2})		29	21	26	30	19
Diameter (cm)		10-14	10-22	10-17	10-15	10-15
Height (m)		2-5	2-7	2-4	2-5	2-7

Physical and chemical parameters. The temperature range was 22-31 °C and salinity ranged from21‰ to 31‰. The sediment substrate was dominated by sandy-clay (Table 2).

Table 2

Physical and chemical parameters at the study sites

Station	Temperature (°C)	Salinity (‰)	Sediment composition (%)		
			Dust	Sand	Clay
1	28-29	30-31	19	55	26
2	29-31	28-31	13	63	24
3	25-27	25-26	15	71	14
4	22-25	27-29	21	53	26
5	26-27	21-24	23	55	22

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Relationship between mangrove characteristics and physical and chemical parameters. Based on Agglomerative Hierarchical Clustering (AHC) analysis, the individual mangrove observation stations cluster into three groups based on physical and chemical parameters and mangrove characteristics (Figure 2).

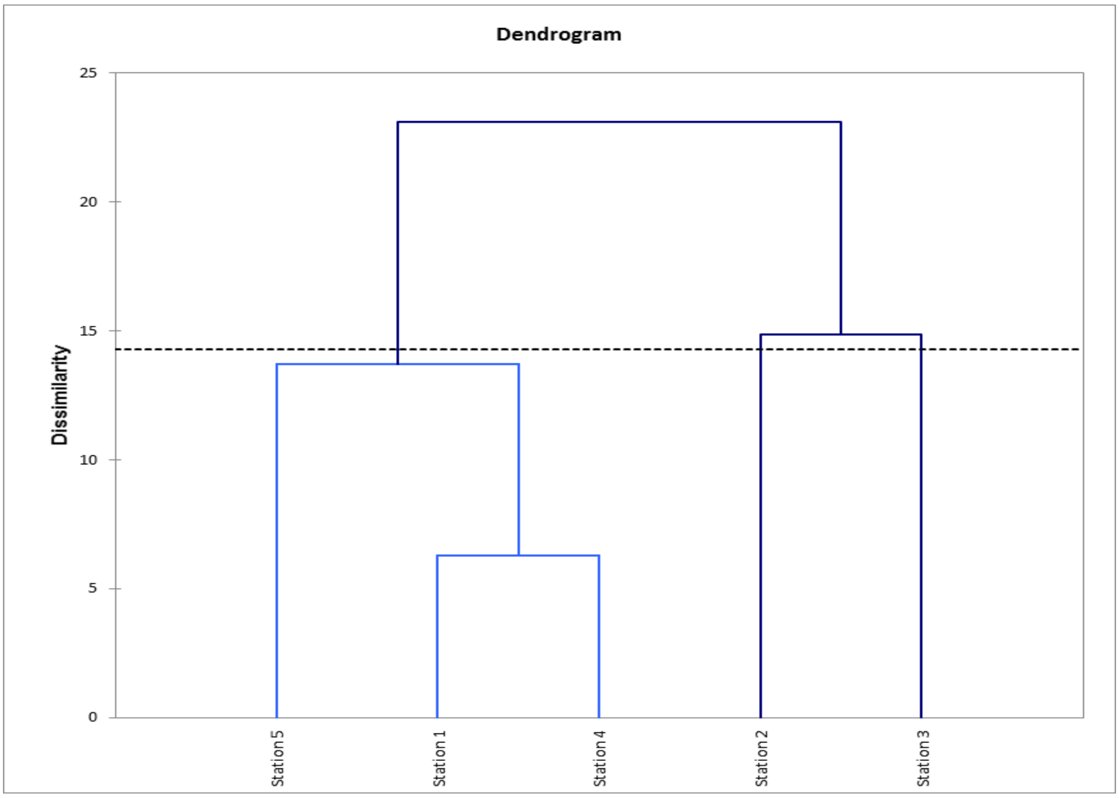

Figure 2. Dendrogram showing clustering of the five stations based.

The first group consists of stations 1, 4 and 5. This group was defined by the presence of *Rhizophora* spp., *Avicennia* spp. and *Sonneratia* spp. at high density, medium salinity and a sandy-clay substrate. The second group consists of station 2 with *Rhizophora* spp., *Avicennia* spp. and *Sonneratia* spp. at low density, high salinity and a sandy-clay substrate. Group three consists of station 3 populated with *Rhizophora* spp. and *Sonneratia* spp. at medium density, low salinity and a sandy-loam substrate. A summary of the data applicable to each grouping arising from the dendrogram is shown in Table 3.

Table 3

Stations classified on the basis of the dendrogram data

Group	T (°C)	S (‰)	Dust (%)	Sand (%)	Clay (%)	Density (tree m^{-2})	Tree diameter (cm)	Tree height (m)	Number of species
1	24	28	21	53	26	30	12.5	3.5	4
2	30	29	13	63	24	21	16	4.5	7
3	27	26	15	71	14	26	13.5	3	3

T = temperature, S = salinity.

Importance Value Index and diversity index. The species with the highest IVI value was *Rhizophora* spp. in group 3 (253.980%), whereas the species with the lowest value was *Avicennia* spp. in group 1 (37.420%). Results for H' show that the mangrove ecosystems in groups 1 and 3 have a low diversity (0.951 and 0.271, respectively) whereas those in group 2 have a medium diversity (1.092) (Table 4).

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Table 4

Importance Value Index (IVI) and diversity index (H′) at the sampling sites

Group	Species	Relative density (%)	Relative frequency (%)	Relative dominance (%)	IVI (%)	H′
1	*Avicennia* spp.	14.103	11.765	11.553	37.420	0.951
	Rhizophora spp.	57.692	52.941	56.226	166.780	
	Sonneratia spp.	28.205	35.294	32.221	95.720	
2	*Avicennia* spp.	38.095	28.571	43.751	110.418	1.092
	Rhizophora spp.	33.333	42.857	28.776	104.966	
	Sonneratia spp.	28.571	28.571	27.473	84.616	
3	*Rhizophora* spp.	92.308	75.000	86.672	253.980	0.271
	Sonneratia spp.	7.692	25.000	13.328	46.020	

Fish biomass estimation. The estimation of fish biomass in the mangrove ecosystem was calculated on the basis of nutrient release from mangrove litter. The average production of the fish sensor was 1,248.762 kg ha^{-1} year (Table 5).

Table 5

Estimation of fish biomass at the sampling sites

Species	Average weight (g)	N (%)	P (%)	Nutrient total (g m^{-2})	PP (g C m^{-2})	HF (g m^{-2})	CF (g m^{-2})	Fish total (g m^{-2})
Avicennias pp.	3.375	0.056	0.007	0.063	2.146	0.217	0.022	0.238
Rhizophora spp.	5.325	0.128	0.012	0.140	4.761	0.481	0.048	0.529
Sonneratia spp.	2.825	0.063	0.005	0.069	2.332	0.236	0.024	0.259
Average of fisheries production (g m^{-2} day)								0.342
Average of fisheries production (kg ha^{-1} year)								1,248.762

N = nitrogen, P = phosphorus, PP = primary productivity, HF = herbivorous fish, CF = carnivorous fish.

Value of fishery utilisation (consumer surplus). The results of the questionnaire showed that capture fishing yields an average production of 2543.41 kg year^{-1} and an average income of IDR 25,418,102 (US$ 1,883) year^{-1} per person. Aquaculture activities produce an average output of 813.5 kg year^{-1} and an average income of IDR 57,226,350 (US$ 4,239) year^{-1} per person. The average price of each fish is IDR 18,849 (US$ 1.40) in marine fisheries and IDR 34,792 (US$ 2.58) in aquaculture fisheries. The socio-economic characteristics of the fishermen are shown in Table 6.

Results of data processing with Maple 11 software showed capture fishing activity produced a consumer surplus of IDR 214,127,349 (US$ 17,861) person^{-1} year^{-1} and an economic value of IDR 107,990,988.6 (US$ 8,000) ha^{-1} year^{-1}. Aquaculture activities provided a consumer surplus IDR 19,349,333 (US$ 1,433) person^{-1} year^{-1} and an economic value of IDR 26,726,437.76 (US$ 1,980) ha^{-1} year^{-1}. The predictions for consumer surplus and the economic value are displayed in Table 7.

Table 6

Socio-economic characteristics of fishermen and fish farmers

Activity	Production (kg year^{-1})	Price (IDR kg^{-1})	Age (year)	Education	Family members (person)	Income (IDR person^{-1})
	Q	X1	X2	X3	X4	X5
Capture fishing	2543.41	18849	40	7	3	25,418,102
Aquaculture	813.5	34792	41	8	4	57,226,350

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Table 7

Estimations of consumer surplus and economic value

Activity	Large area (ha)	Average Q (kg ha^{-1})	Consumer surplus (IDR person^{-1} year^{-1})	Total economic value (IDR ha^{-1} year^{-1})
Capture fisheries	638.37	2,543,41	214,127,349	107,990,988.6
Aquaculture	63.71	813,5	19,349,333	26,726,437.76

Dynamic models of mangrove ecosystem management. The calculation of litter in this model took account of the composition of mangrove species because the production of each species differs and has different nutrient content. The composition of mangrove species and litter production were analysed from characteristic mangrove data at five stations in Lubuk Kertang Village. The mangrove composition comprises 15.2% of *Avicennia* spp. producing a litter dry weight of 12,318.75 kg ha^{-1} year^{-1}, 60.8% *Rhizophora* spp. producing a litter dry weight of 19,436.25 kg ha^{-1} year^{-1}, and 24% *Sonneratia* spp. producing a litter dry weight of 10,311.25 kg ha^{-1} year^{-1} (Table 8).

Further scenarios of mangrove management covering BAU, conservation and fish pond expansion are shown in Table 9.

Table 8

Composition of mangrove species and weight of mangrove litter

No	Species	Total (tree)	Percentage (%)	Litter (kg ha^{-1}year^{-1})
1	*Avicennia* spp.	19	15.2	12,318.75
2	*Rhizophora* spp.	76	60.8	19,436.25
3	*Sonneratia* spp.	30	24	10,311.25
	Total	80	100	

Table 9

Scenarios of mangrove ecosystem management

No	Scenario	Mangrove addition (ha year^{-1})
1	BAU	-5.8
2	Conservation	10
3	Fish pond expansion	3

(BAU) = "business as usual" scenario

Existing mangroves add to the primary productivity in aquatic ecosystems and provide a food source for fisheries. There is the potential for fisheries activity to be increased and therefore to raise the income of fishermen. However, altering land use to fish ponds reduces land occupied by mangroves in equal proportion, lowering also the contribution made by mangroves to supporting marine fisheries. Income arising from both capture fisheries and aquaculture will be of economic value for fisheries (Figure 3).

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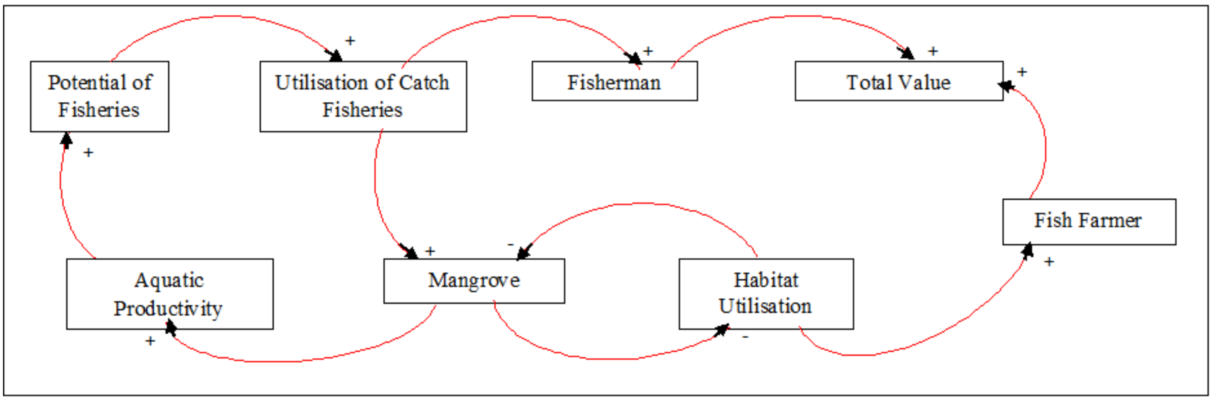

Figure 3. Relations from both capture fisheries and aquaculture (causal loop model).

The simulation used in this study involved eight variables: mangrove area, fish pond area, litter, nutrient, primary productivity, ecological value, fish consumer surplus and economic value without reference sources on the mangrove vegetation impact on the future fishing activities in the Indonesian coastal area. The chosen scenarios are then simulated using the dynamic model illustrated in Figure 4.

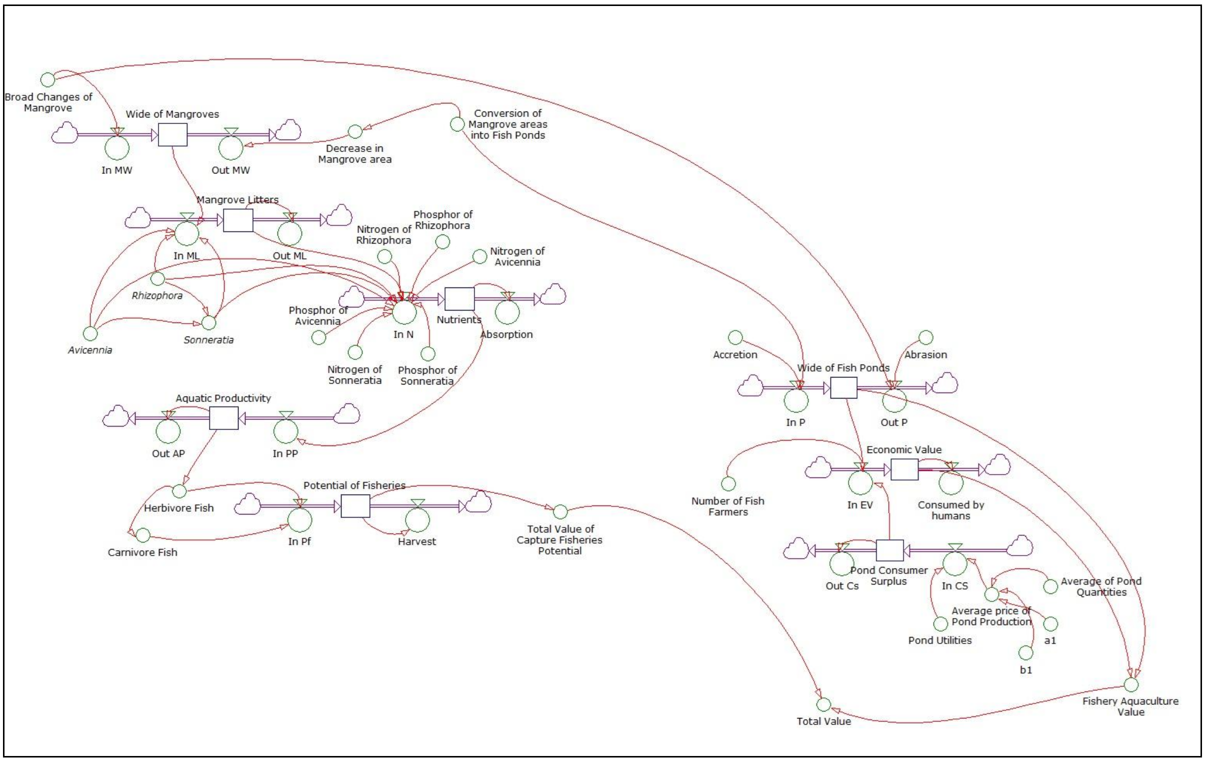

Figure 4. Dynamic model illustrating how mangrove ecosystem management supports fisheries production.

When the simulation was run for a period equating to 75 years, using three different combinations of the three mangrove species occurring in the study areas, the fisheries total value increased in scenario 2 (conservation), and decreased in scenarios 1 (BAU) and 3 (fish pond expansion). These simulations are depicted in Figures 5-7. The simulations indicated that the planting of a predominance of *Rhizophora* spp. (specifically a composition of *Avicennia* spp. 15.2%, *Rhizophora* spp. 60.8% and *Sonneratia* spp. 24%) yielded higher total values than other compositions. The simulations are summarised in Table 10.

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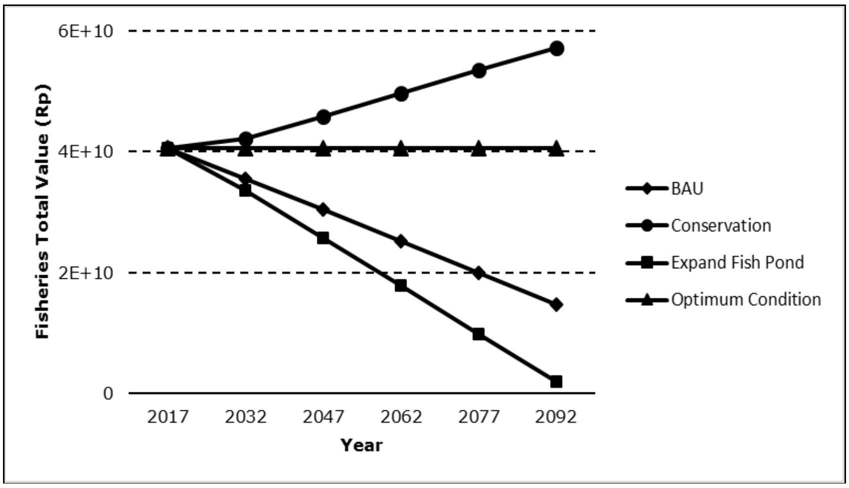

Figure 5. Dynamic model simulation result with mangrove composition of *Avicennia* spp. 15.2%, *Rhizophora* spp. 60.8% and *Sonneratia* spp. 24%.

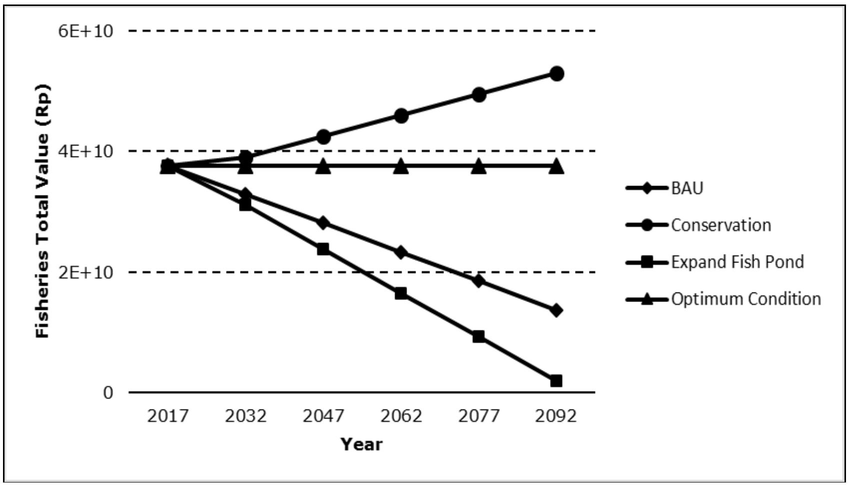

Figure 6. Dynamic model simulation result with mangrove composition of *Avicennia* spp. 30%, *Rhizophora* spp. 50% and *Sonneratia* spp. 20%.

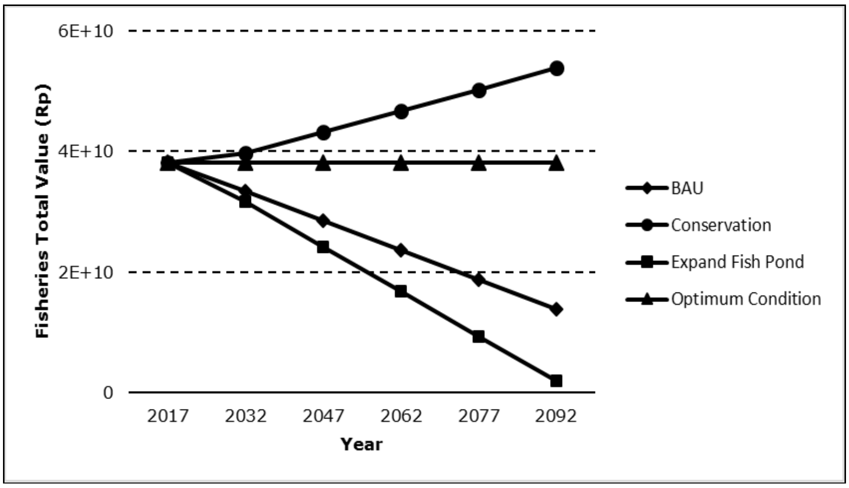

Figure 7. Dynamic model simulation result with mangrove composition of *Avicennia* spp. 20%, *Rhizophora* spp. 50% and *Sonneratia* spp. 30%.

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Table 10

Total value of fishery utilisation with different mangrove compositions simulated for the year 2092

No	Scenario	Total value (IDR)		
		A	B	C
1	BAU	14,712,505,643	13,680,565,509	13,884,883,229
2	Conservation	57,202,705,417	52,936,985,456	53,781,571,444
3	Fish pond expansion	1,961,267,805	1,899,461,619	1,911,698,859
4	Optimum condition	40,532,817,939	37,625,285,505	38,200,958,821

Note:
A = *Avicennia* spp. 15.2%; *Rhizophora* spp.60.8%; *Sonneratia* spp. 24%
B = *Avicennia* spp. 30%; *Rhizophora* spp.50%; *Sonneratia* spp. 20%
C = *Avicennia* spp. 20%; *Rhizophora* spp.50%; *Sonneratia* spp. 30%.

Discussions. The present study examined the dissemination of mangrove species in five stations showing differing species densities. *Avicennia* spp. was found only in stations 1 and 2. Species in the genus *Avicennia* are pioneer plants on sheltered coastal land, capable of occupying and growing in saline locations (Borkar et al 2009). *Rhizophora* spp. were distributed evenly across all stations. Their ubiquity may be due to their high adaptation to the surrounding environment, but they also possess a shorter and more slender hypocotyl than other species, allowing them to be more easily transported by seawater to grow elsewhere. *Sonneratia* spp. were found at almost all stations. These species, in particular *Sonneratia caseolaris*, are able to grow in areas receiving fresh water input (Kathiresan & Bingham 2001), though *S. alba* is often found in more saline areas receiving seawater intake. In this study, the *Sonneratia* spp. observed were more often found upstream.

The lower salinity of the upper river might be caused by higher input of freshwater compared with seawater. Therefore, stations 1 and 2 have a relatively high salinity, with salinity decreasing upstream of station 5. Salinity levels ranging from 10‰ to 30‰ are appropriate for mangrove survival, the figure varying according to the species (Ball 1998; Khan & Aziz 2001; Paliyavuth et al 2004). In mangroves, growth is stimulated at low salinity (25% seawater/5‰ salt concentration) or moderate salinity (50% seawater/15‰salt concentration) but declines with further increases in salinity (Ball 1998; Khan & Aziz 2001; Basyuni et al 2012 a, b), suggesting that mangroves have adapted to tolerate salinity at varying degrees. Sediment texture composition was dominated by sandy-clay substrate due to the river channel receiving substantial sediment input from the river flow. Sandy clay is a suitable substrate for mangrove growth. According to Marchand et al (2004), who conducted correlation analysis between sediment characteristics and mangrove vegetation density and species, a mud substrate shows a positive or perfect relationship; where the percentage of mud substrate is high, then density will be higher and species diversity will also be greater.

Litter production at the study sites was dominated by *Rhizophora* spp., followed by *Sonneratia* spp. The high production of *Rhizophora* litter reflected the dominance of these species in this study. Tree density affects litter production (Woodroffe 1985); higher tree density leads to higher litter production.

The primary productivity of the mangrove ecosystems in this study varied from the infertile to the very fertile category. This finding is very closely related to the nutrient levels resulting from litter decomposition in the mangrove ecosystem. The primary production value of 870-1747 g C m^{-2} yr^{-1} plays a significant role at the beginning of the estuary food chain. According to Ronnback (1999), a grazing food chain with high primary production shows the role of mangroves as feeding grounds for herbivorous fish and, at tropical latitudes, carnivorous fish. Therefore, through its litter production, a mangrove forest significantly influences fish production in the surrounding waters. The increase of N at the early stage of decomposition is quite common because of immobilisation (Domisch et al 2006). Both N and P have been shown to be actively involved in translocation and in microbial growth and metabolite production, resulting in

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increasing levels during decomposition (Parsons & Congdon 2008), an effect showing positive linear correlation in most of the sites in the present study.

Within the mangrove ecosystem, there is at least one life cycle stage of various species of fish and invertebrates that utilise the mangrove ecosystems as feeding places, owing to the abundance of food produced through the production of litter. The carrying capacity of a mangrove ecosystem begins with the production of organic material derived from mangrove litter (detritus) and continues with that energy being transferred up the food chain (Abrantes & Sheaves 2009).

On the basis of our results (Table 10), if significant benefits for fisheries are to be realised, the management of mangrove ecosystems is necessary, a finding that confirms a previous study (Sitorus et al 2017) showing how mangrove ecosystems contribute to fisheries. Foley et al (2010) reported that the direct threat from humans to the mangrove ecosystem through the creation of ponds and other changes in land use caused huge losses not only to fisheries but also to fish farming following environmental damage.

Conclusions. This study estimates the potential production of fisheries supported by mangrove litter in Lubuk Kertang Village at 1,202.282 kg ha^{-1} $year^{-1}$, equivalent to IDR 22,663,023 (US$ 1,679) ha^{-1} $year^{-1}$. The mangrove ecosystem in Lubuk Kertang Village provides economic benefits to capture fisheries of IDR 107,990,988.6 (US$ 8,000) ha^{-1} $year^{-1}$ and to fishery aquaculture of IDR 26,726,437.76 (US$ 1,980) ha^{-1} $year^{-1}$. A BAU scenario decreases mangrove area by 5.8 ha $year^{-1}$ and also reduces the total value of fishery utilisation. An increase in mangrove area by 10 ha $year^{-1}$ is the minimum necessary to maintain sustainable fisheries. The composition of mangrove species affects the total value of fisheries utilisation; a composition of *Avicennia* spp. 15.2%, *Rhizophora* spp. 60.8% and *Sonneratia* spp. 24.0% yields the highest overall value.

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