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An Integrated Decision Support System (DSS) for the Management of Sustainable Mariculture in Indonesia

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ABSTRACT

Indonesia has great potential for aquaculture development but its expansion is often insufficiently focused in environmentally sustainable practice. For this reason, regarding an ecosystem approach to aquaculture (EAA),the aim of this paper is to demonstrate the application of decision support system for the management of sustainable floating net cage mariculture (SYSMAR DSS)in three selected regions in Indonesia: Talise Island, Galang Island and Ekas Bay.Through GIS spatial planning tools, SYSMAR DSS is used to perform site selection and assesses production and ecological carrying capacity. Economic analysis provides vital information on 18 cases, focusing on the economic viability of Tiger Grouper (*Epinephelus fuscoguttatus*), Humpback Grouper (*Cromoliptes altivelis*)and Leopard Coral Grouper (*Plectropomeus leopardus*) which utilizes various feed types and production scales.SYSMAR DSS shows that only Galang Island provides a substantialarea with a suited area of about 12,940 ha. The estimated maximum production carrying capacity is 51 – 366 tons/farm andecological carrying capacity is in the range 18,393 – 21,727 tons/year/suitable area. After a 5-year projection period, the economic evaluation highlighted that all studied culture developments are economically viable. These results confirm the SYSMAR DSS is able to determine potential sites which comply with environmental sustainability and socio-economic criteria.

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INTRODUCTION

As the stocks of wild fish decline worldwide and the human population increases, aquaculture is becoming one of the quickest increasing food production sectors and also important as protein food supplier to the world population [1,2,3]. On the other hand as a result of the increase in fish production and seafood mariculture, there is a growing concern about the impacts of such activities on the environment. Therefore, it is vital to improve aquaculture technology and to develop management tools that address the need for an eco-friendly production process and the concerns regarding food safety[4].

In 2010, an ecosystem approach to aquaculture (EAA) was introduced by FAO to promote sustainable development, equity, and the resilience of interlinked socio-ecological systems. Farhan and Lim [5]recommended the use of Decision Support Systems (DSSs) to meet the flexibility ofdynamic environments.In this paper the application of a DSS under development at the Research and Technology Centre Westcoast of the University of Kiel for the sustainable environmental and socio-economic management of floating net cage (SYSMAR) is assessed. The DSS utilizes high resolution hydrodynamic information concerning water depth, current velocities and wave heights obtained from hydrodynamic models. Through GIS as spatial planning tools, SYSMAR DSS is able to assist in estimating site selection, determine different types of carrying capacities (CC) such as production CC, as well as ecological CC to guarantee sustainable environmental development. Furthermore, a method for the economic analysis of mariculture investment is proposed. Financial indicators to enable an adequate economic assessment were identified[6,7,4].

The investigations were carried out at three priority sites in Indonesia namely Talise Island located in the northern most tip of Sulawesi; Galang Island which is part of the Riau Archipelago located opposite of

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Singapore and Ekas Bay located south of the Lombok Island(see Figure 1). The development focuses on the most common high value finfish species nurtured in FNC in Indonesia[8,9,10,11]. Thus, Tiger grouper (*Epinephelus fuscoguttatus*), Humpback grouper (*Cromoliptes altivelis*), and Leopard Coral grouper (*Plectropomeus leopardus*) are considered.

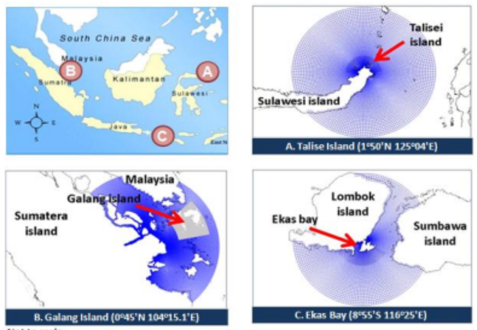

Fig. 1: Research Areas.

MATERIAL AND METHOD

Hydrodynamic and wave models:

In order to provide flow and wave information, hydrodynamic models for the three selected regions were set up using the open source Delft3D modeling suite. Curvilinear grids covered the region with increasing resolutions of up to 40 meters in the areas of interest as indicated in Figure 1. Bathymetric information was taken from the GEBCO database [12]. Additional bathymetric information for the near shore was provided by the national surveying agency[13]. Tidal driving forces were specified along the open model boundaries in the form of astronomical constituents[14]. Wave models were set up using maximum wind magnitudes and directions for the period 2005 to 2009 from the NCEP/NCAR reanalysis database[15].

Site Selection:

A comprehensive site suitability and capability map which integrates all of the selected criteria was edited using thirty two parameters identified in Table 1. In order to assess the relative impacts of each category of parameters (e.g. physical, chemical, and ICZM) on the DSS result, the suitability maps of the three applied categories are presented. The parameters considered in SYSMAR were taken from FAO, Cross and Kingzett, Kapetsky and Agullar-Manjarrez and Szuster and Albasri [16, 17, 18, 19].

Production Carrying Capacity:

Production carrying capacities have been defined by the emission of particulate carbon governed by the amount of waste and physical characteristics, and deposited beneath FNC farms[20]. A simplified footprint approach considers particle settling velocities, carbon flux, current velocities, water depth and dispersion constants to provide an approximation of the carbon deposition footprint and derived deposition rates around the farm as described in Gilibrand and Van der Wulp [21, 6]. Gilibrand [21] identified a breakdown rate of 0.7 kg C $m^{-2}y^{-1}$, which is equivalent to 1.9 g C $m^{-2}d^{-1}$ and adopted by Rachmansyah [22], while Krost [23] proposed a slightly more conservative threshold value of about 0.5 to 2 g C m^{-2} d^{-1} on the basis of measurements carried out in fish farms in Indonesia. Thus in order to ensure practical sustainability in Indonesia, we adopt the threshold value criteria of 1 - 2 g C m^{-2} d^{-1} for determining local/production carrying capacity.

Ecological Carrying Capacity:

In this paper, the ecological carrying capacity for FNC finfish farms within a domain is set to be equivalent to the production rates of total dissolved nitrogen (TDN) which do not contribute more than 1% of the TDN flux of the domain[24,25,6].

Economic Analysis of Mariculture Investments:

Economic decision tools in mariculture aim to assist farmers, potential investors, and decision makers (stakeholders) in understanding the economic requirements, costs and benefits, and risks involved in production.

Economic sustainability is maintained when environmentally sustainable production rates remain profitable [26]. In this paper, the discount cash flow analysis methodologies facilitate the justification of an investment in cases in which the net present value (NPV) is greater than 0, the benefit cost ratio (BCR) greater than 1 and the internal rate of return (IRR) greater than each benefit cost value [27,28]. Required information of the main economic properties of grouper at Galang Island was collected from various institutions in 2012 and 2013 as shown in Table 2 (1 € = 12.500 IDR).

Table 1: Site selection of groupers grown in floating net cages.

Description	Parameters	Indicators	Units	Unsuitable	Allowable	Optimal
Physical Process	Min. water depth	water depth	m	< 6	≥ 6	> 8
	Max. mooring	water depth	[illegible]	> 25	≤ 25	< 20
	Flushing	mean current	m/s	<0.01	≥0.01	0.2 – 0.5
	Currents	mean current	m/s	> 1	≤ 1	0.2 – 0.5
	Exposure to waves	significant wave	m	> 1	≤ 1	< 0.6
	Exposure to wind	max wind speed	m/s	> 15	≤ 15	< 10
	Water temperature	water temperature	°C	<20 or >35	20 – 35	27 – 31
	Salinity	salinity	ppm	<15 or >35	15 -35	26 – 31
Water Quality	Dissolved oxygen	dissolved oxygen	mgO_2/l	< 4	≥ 4	> 5
	Acid-base balance	pH	$-log(H^+)$	<6 or >8.5	6 – 7.8	7.8 – 8.5
	Water transparency	Secchi depth	m	< 2	≥ 2	> 4
	Turbidity	suspended matter	mg/l	> 10	≤10	< 5
	Ammonium	ammonium	mg NH_4-N/l	> 1	≤ 1	< 0.5
	Nitrate	nitrate	mg NO_3-N/l	> 200	≤ 200	< 200
	Nitrite	nitrite	mg NO_2-N/l	> 4	≤ 4	< 4
	Phosphate	total phosphate	mg P/l	> 70	≤ 70	< 70
ICZM	Villages	thematic map	m	< 200	≥ 200	> 500
	Towns	thematic map	m	< 200	≥ 200	> 500
	Cities	thematic map	m	< 200	≥ 200	> 500
	Harbours	thematic map	m	< 200	≥ 200	> 500
	Industry	thematic map	m	< 200	≥ 200	> 500
	Tourism	thematic map	m	< 200	≥ 200	> 500
	Streams	thematic map	m	< 200	≥ 200	> 500
	Rivers	thematic map	m	< 200	≥ 200	> 500
	Erosive shoreline	thematic map	m	< 200	≥ 200	> 500
	Semi intensive hatcheries	thematic map	m	< 200	≥ 200	> 500
	Intensive hatcheries	thematic map	m	< 200	≥ 200	> 500
	Ponds	thematic map	m	< 200	≥ 200	> 500
	Sewage discharges	thematic map	m	< 200	≥ 200	> 500
	Traffic lanes	thematic map	m	< 200	≥ 200	> 500
	Coastal usage	thematic map	m	< 200	≥ 200	> 500
	Environmentally protected area	thematic map	m	< 200	≥ 200	> 500

Table 2: Economic properties of grouper cultures at Galang Island

Economic Properties		10 FNC	600 FNC
Investment , including home base, guard house, storage,	Floating net cages 3x3x3m	11,908€	504,000€
FNC, operational equipment, electric , contingency, etc	Lifespan (years)	5	
Indonesian Bank, 2012	Discount rate (%)	13	
Progressive Tax , Law No.17, 2010[29]	Tax rate (%)	25	
Food convertion ratio[30,6]	Trash fish	7.78	
	Pellets	2.64	
Grow out period (day) [6]	Tiger Grouper	300	
	Humpback Grouper	500	
	Leopard Coral Grouper	180	
Seed price(€/kg)[31]	Tiger Grouper	0.6	
	Humpback Grouper	0.96	
	Leopard Coral Grouper	2.72	
Feed price(€/kg)[31]	Trash fish	0.32	
	Pellets	1.04	
Production (kg)	Tiger Grouper	3,285	197,100
	Humpback Grouper	1,380	87,782
	Leopard Coral Grouper	5,475	328,500
Commodity Value (€/kg)[31,32]	Tiger Grouper	11.20€	
	Humpback Grouper	28.00€	
	Leopard Coral Grouper	21.60€	
Wages (€/year)	Total wages	4,612€	44,688€

RESULTS AND DISCUSSION

Site Selection:

After classifying, the physical information from hydrodynamic and wave numerical models give an insight into the spatial distribution of areas which are suited for the development of floating net cage mariculture. The first location for the application of SYSMAR DSS site selection is in the vicinity of Talise Island. The concluding outcome of the wave parameter analysis showed that all the area is defined as unsuitable (see Figure 3a). As can be seen in Figure 3b, the final result of site selection in Ekas Bay shows no potentially suitable area for development of floating net cages (FNC) grouper culture. It is affected by incopatible wave height

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parameter, current and flushing which are considered too weak or low for FNC activities. Conditions are more feasible in Galang Island. The final result of the suitability map from all parameters in the vicinity of the Galang Island can be seen in Figure 3c. It shows about 12,940 Ha (40.3%) of the seawater area in Galang Island are interpreted as suited area. The areas are spread over the vicinity of the Galang Island. Regarding the results of site selection carried out on three areas, we conclude that Galang Island is a suitable location for further development of FNC grouper culture in Indonesia.

Production Carrying Capacity:

There is a large area available for the development of FNC grouper culture in Galang Island. The SYSMAR DSS is applied to recognize the best locations for a limited number of farms. The selection is carried out for all potential farms based on the production carrying capacity. Thus, suitable and potential locations for all farms with a minimum distance of 500 meters between individual farms were selected for each of the locations as shown in Figure 3d. We consider large scale farms (over 100 cages) made up of cages with the size of 3m x 3m x 3m, with a distance between cages of 1 m [33,34].

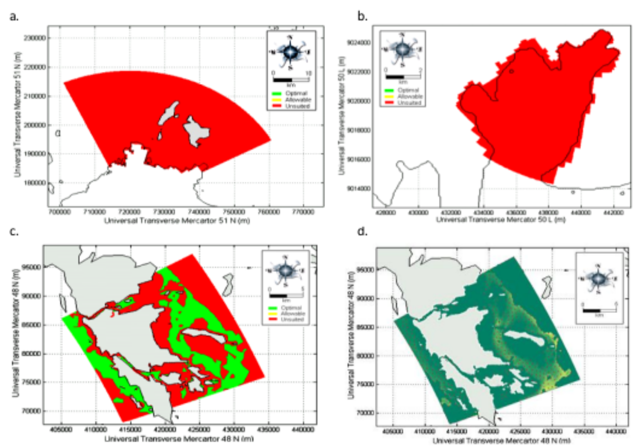

Fig. 2: Results of site selection for Talise Island (a), Ekas Bay (b), Galang Island (c) and Production carrying capacity including proposed potential farm locations as red dots (d).

In Galang Island, prediction based on maximum deposition and feeding with trash fish indicated that about 51 – 125 tons/year/farm can be produced, but when feeding with mixed trash fish and pellet or feeding just pellet about 73 to 196 tons/year/farm and 115 to 366 tons/year/farm, respectively can be sustained (see Table 3). Discrepancies of the production carrying capacity are obtained by feeding type and also physical models which are influenced by currents and maximum water depth parameters as dominant factors and responsible for the indicated ranges.

Ecological Carrying Capacity:

The ecological carrying capacity for FNC finfish farms within a domain is proposed to be equivalent to emission rates of total dissolved nitrogen (TDN) not exceeding 1% of the TDN flux of the suitable domain. The maximum daily TDN load is calculated with respect to the flushing rate and TDN background concentration of the suited region, which is recorded in the order of 0.31 mg N l^{-1}[35]. As can be seen in Table 3, the ecological carrying capacities are in the range of 18,393 - 21,727 tons per year in the vicinity of Galang Island.

Since the estimation of the total maximum production CC does not exceed the ecological carrying capacity [36], the estimation of the maximum allowable production in the vicinity of Galang Island is 21,727 t/a. Regarding the estimation of production carrying capacity in the vicinity of Galang Island, this total production is achieved by 206 fish farms with an estimated production CC in the range of 32.5 t/a/f to 366 t/a/f.

Economic Analysis of the SYSMAR DSS:

The aim of the Indonesian government is to expand fish farming activities, especially through small family owned businesses. Therefore, it is necessary to consider small scale farms (10 cages or less) and large scale farms (100 cages or more).Table 4 presents a ranking of the 18 cases studied of 10 cages and 600 cages

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according to the indicators of financial viability of FNC grouper culture projects in Galang Island. The project ranking shows that the highest net present value (NPV) amounts to 9,961 million Euros that the highest internal rate of return (IRR) amounts to 590% and that the payback period is shorter than 1 year in the case of a large farm of 600 cages in which the variety Leopard Coral Grouper is fed trash fish. On the other hand, the lowest NPV is obtained from a small farm of 10 cages in which the variety Tiger Grouper is fed pellets (NPV: 34,089 €, IRR 107% and payback less than 1 year).

Table 3: Results of the estimation of site selection and carrying capacity, A) Site Selection, B) Production CC based on the dissipation of particulate organic matter in the vicinity of a particular farm, C) Ecological CC based on the maximum POM load and TDN surplus.

Type of Carrying Capacity	Feedstock	Grouper species		
		TG	HG	LG
Site Selection Ha			12,940	
Production Carrying Capacity: Deposition threshold 1g C $m^{-2}d^{-1}$				
t/a/fish farm	TF[a]	0.5-59	0.5-85	0.5-51
	P[b]	0.5-158	2-400	0.5-115.5
	M[c]	0.5-90	0.5-153	0.5-73.5
Deposition threshold 2g C $m^{-2}d^{-1}$				
t/a/fish farm	TF	0.5-155.5	1-277	0.5-125.5
	P	3-624	20-1000	2-366
	M	1-268	2.5-650	1-196
Ecological Carrying Capacity[d] based on a limitation by particulate organic matter:				
t/a/entire domain	TF	3,959-9,972	5,371-15,503	3,493-8,410
	P	10,478-35,993	22,162-128,071	7,942-23,795
	M	6,014-16,729	9,152-33,467	5,308-13,050
based on a limitation by Total Dissolved Nitrogen:				
t/a/entire domain	TF	18,393	18,393	18,393
	P	21,727	21,727	21,727
	M	20,116	20,116	20,166

Remarks: [a] trash fish, [b] Pellet, [c] Mix 70% trash fish and 30% pellet [d] The calculation considers an acceptable bed load of 1-2g organic carbon $m^{-2}d^{-1}$

Surprisingly, the results for the 18 cases show strongly positive levels of NPV, very large values of internal rate of return, well above the discount rate value of 13% and an extremely short payback period below one year. It is apparent that the economic analysis for the sites in Galang Island clearly indicates the economic feasibility of FNC grouper culture projects.

The research shows that FNC finfish culture developments are economically viable as a whole, because after a 5-year projection period, positive cumulative cash flow and net present value, internal rate of return at rates above the bank rates, and a payback period far below the 5 year projected lifetime of the project are evident.

The use and implementation of a DSS for sustainable aquaculture development in Indonesia, with respect to the EAA concept of various carrying capacities which was introduced by FAO in 2010, is very complex and a number of concerns should be taken into account. We find that the dissimilarity of the definitions of carrying capacity in the different contexts, along with its development is a complex problem. On the other hand, this DSS is able to present the integration of all key components of detailed site selection, determination of carrying capacity along with an economic appraisal.

Table 4: Ranking of economic analysis of the FNC finfish culture.

No.	Type of Floating Net Cages Grouper	NPV (1.000 €)	IRR (%)	PP year
	600 Cages			
1	Leopard Coral Grouper feed with trash fishes	9,961	590	0.19
2	Leopard Coral Grouper feed with trash fishes and pellets	9,837	583	0.17
3	Leopard Coral Grouper feed with pellets	9,739	577	0.17
4	Humpback Grouper feed with pellets	4,062	257	0.39
5	Humpback Grouper feed with trash fishes	4,025	255	0.39
6	Humpback Grouper feed with trash fishes and pellets	3,994	253	0.39
7	Tiger Grouper feed with trash fishes	3,159	204	0.49
8	Tiger Grouper feed with trash fishes and pellets	3,054	200	0.50
9	Tiger Grouper 600 cages feed with pellets	2,996	197	0.51
	10 cages			
10	Leopard Coral Grouper feed with trash fishes	150	387	0.26
11	Leopard Coral Grouper feed with trash fishes and pellets	148	382	0.26
12	Leopard Coral Grouper feed with pellets	146	378	0.26
13	Humpback Grouper feed with trash fishes	51	149	0.66
14	Humpback Grouper feed with trash fishes and pellets	51	148	0.67
15	Humpback Grouper feed with pellets	50	147	0.67
16	Tiger Grouper feed with trash fishes	36	112	0.87
17	Tiger Grouper feed with trash fishes and pellets	35	109	0.89
18	Tiger Grouper feed with pellets	34	107	0.91

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