



## Decision Support System for Selection of Suitable Mariculture Site in the Western Part of Java Sea, Indonesia

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**Abstract.** Mariculture (marine aquaculture) has been intensified and has created essential employment opportunities over the last two-decades in Indonesia, as well as many other countries in the world. This development has negative impact to the environment. Considerable amounts of nutrient waste in dissolved and particulate form were released by intensive fish farming into the environment through feed excess, soluble fish excretion and faeces production. One of the first steps to avoid the dangerous environmental impacts is careful site selection to minimize environmental impacts arising from the farming activities (sustainability) as well as to guarantee adequate conditions from the operational point of view (suitability).

The paper focuses on the development of a Decision Support System (DSS) as a tool for the appropriate selection of mariculture site location. The DSS is based on physical, chemical and sediment criteria as well as on data of conflicting coastal use. The GIS analysis results in a map indicating the suitable areas for the improved method of offshore cage mariculture. In this study, emphasis was placed on finfish species; however the methods and results may be employed for other species as well following some modifications.

The DSS was applied for the western part of Java Sea, Indonesia. The data were acquired from direct field measurement, numerical modeling and existing information from particular agencies. Numerical modeling was used to obtain spatial and temporal distributions of hydrodynamic parameters (i.e. current velocities and water levels). The Delft3D modeling system (Delft Hydraulics, The Netherlands) was employed for this purpose. The DSS was developed under GIS application of ESRI® ArcGIS™ using weighted overlay method. The results showed the adequacy of the system for supporting governmental authorities in the implementation, environmental controlling, and estimation of overall carrying capacity for environmental sustainable marine fish farming.

**Keywords:** *Decision Support System; Geographic Information System; mariculture; suitability; sustainability; numerical model.*

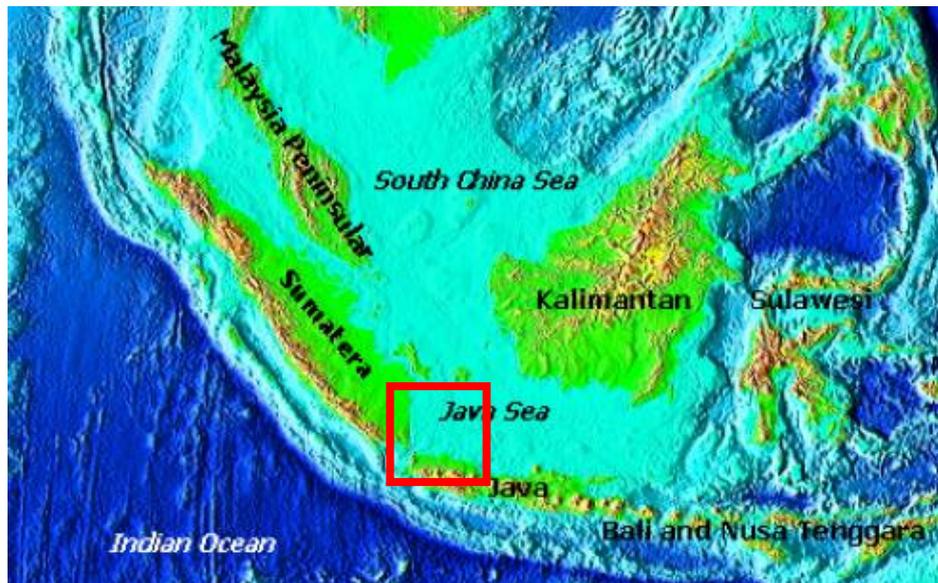
## 1 Introduction

Aquaculture is a form of bioproduction that involves the propagation, cultivation and marketing of aquatic animals and plants in a human controlled environment. Mariculture is a specialized branch of aquaculture since it is defined as the cultivation of marine organisms for food, either in their natural environment, or in seawater in ponds or raceways. An example of the latter is the farming of marine fish, prawns, or oysters in saltwater ponds. Cage mariculture is the most commonly used method of raising marine dwelling fish to maturity. It utilises a readily available resource, seawater, to provide a substrate for culture and a renewable supply of good quality water with the necessary conditions for growing fish.

The rapid growth of mariculture in Indonesia and worldwide has led to increased concerns about its environmental sustainability. The management of mariculture development inherently has a spatial component because of the differences among physical, chemical, biological and socioeconomic characteristics varying from location to location. This paper describes the strategy for mariculture site selection based on several properties that need to be accounted for and introduces the use of Decision Support System as a tool to realize the strategy.

Decision Support System is an interactive computer-based system or subsystem using communications technologies, data, documents, knowledge and/or models to identify and solve problems and thus to help decision makers to decide on complex tasks [1]. Academic research involves designing and studying Decision Support Systems in their context of use. In general, Decision Support Systems (DSS) are a class of computerized information systems that support decision-making activities.

The DSS was applied for the Java Sea which lies on the Sunda Shelf with an average depth of around 40 meters. Water masses from/to Java Sea are exchanged through the Karimata Strait, which is the passage between the Java and South China Sea; the Sunda Strait, which is the passage between the Java Sea and Indian Ocean; and the eastern part of Java Sea, which is the passage between the Java Sea in the east and Banda Sea or Makassar Strait (Figure 1). Following the patterns of sea surface circulation in the Southeast (Figure 5.4), the Java Sea is strongly influenced by the semi-annual reversing between the northwest and southeast monsoon. During the northwest monsoon, the surface current flows to the east with a velocity around 0.25 – 0.38 m/s and during the southeast monsoon to the west with a velocity about 0.12 – 0.25 m/s [2]. The tidal type in the sea around Seribu Islands region is mixed diurnal with a tidal range of about 0.8 meters [3].



**Figure 1** Map of Indonesian Archipelago (Western Part) and the study area of Java Sea (in the red box).

## 2 Site Selection Strategy

Site selection is an important factor of mariculture business to avoid undesirable impact on the environment, ensure the profitability of the operation as well as to avoid competing demands for coastal space. Mariculture cage installations have to fulfill some requirements in order to maintain a good compatibility with the natural environment and must take the physicochemical characteristics of the environment into consideration.

Assessment of a single mariculture site location in the simplest case can be done by direct observation of physicochemical, sediment and social characteristic of the coastal area in question. When required data are available and critical values are known, the location can be classified as suitable for farming or not.

Recently, mariculture activities are no longer subjects of concern of only fish farmers and managers; it involves all other users of the coastal zone. As a result, mariculture can no longer be considered an isolated activity, but should be considered in the general context of Integrated Coastal Zone Management (ICZM).

There are also needs for governmental agencies, which are involved in mariculture management, to perform spatial analysis in an area envisaged for

mariculture development in order to assess the potential environmental, economic and social impacts of the future mariculture activities. The decision-making process to manage the development of mariculture should be supported by an expert system in order to provide proper decisions.

These conditions have led to augmented interest in the development of an interactive tool for evaluation, presentation and communication of all site selection parameters. This tool includes Geographical Information Systems (GIS) to store spatial information in a way that can be easily accessed, processed, displayed and presented. GIS-based Decision Support System (DSS) provide scientific advice in a form that can readily be understood and evaluated by managers and stakeholders without profound scientific skills. Consequently there is interest in finding simplified ways to represent data in a way that can easily be grasped but which preserves the original information without bias. In the following sections, the application of Decision Support System to the mariculture site selection problems will be described.

### **3 Development of Decision Support System**

In general, development of GIS applied in the Decision Support System includes seven phases, which are (1) identification of requirements, (2) formulation of specifications, (3) development of analytical framework, (4) locating data sources, (5) organization and manipulation of input data, (6) data analysis and verification, and finally (7) evaluation of output [4]. Iteration within Figure 2 shows the process in the development of GIS for DSS. In the following sections, the development of GIS for mariculture site selection in this study is described.

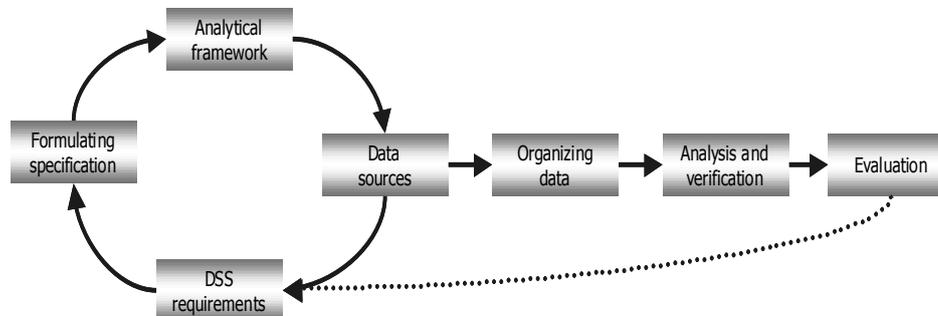
#### **3.1 Identification of Requirements**

The first process of development of DSS is identification of requirements. In this stage the list of questions, which should be answered by the DSS are listed. Discussions of DSS development objectives and how GIS tools can address the needs are the main tasks of this stage. As discussed before, the development of DSS in this study is intended to support the decision makers in order to identify the best locations of offshore cages mariculture.

#### **3.2 Formulation of Specification**

Required data and GIS-infrastructure, as well as cost and time constraints, in order to answer the particular questions are formulated in this second stage. The list of data requirements based on several parameters and its classification for best selection of offshore cage mariculture have been discussed previously in Chapter 2. Because of the lack of data for the study area some of the parameters

will not be included in the calculation. The selected parameters are shown in the Table 1. The DSS for offshore cage finfish mariculture site selection is developed on the base of the Desktop GIS using ArcGIS software.



**Figure 2** Development of a GIS process [4].

### 3.3 Analytical Framework

The next stage of DSS development is to develop the analytical framework, which is intended to formulate the integration of all data into a useful format for analysis and decision-making. There are several methods in the formulation of data integration that can be used either alone or in combination. The methods are arithmetic operators, classification, simple overlay, weighted overlay, neighborhood analysis, connectivity analysis, hierarchical models, and multi objective land allocation [4].

Since the parameters used in the development of DSS for site selection mariculture do not have the same level of importance, the weighted overlay method is chosen. In this method, each selected parameter is assigned a weight that is proportional to its importance. Each source layer is first reclassified onto a common scale and then multiplied by a weighting factor. The resulting values are used in further overlay operations to obtain an integrated result.

Reclassification of a particular thematic map in GIS can be made as a function of the initial value, position, contiguity, size or shape. Each reclassification operation involves the simple repackaging of information on a single map and results in no new boundary delineation. Such operations can be thought of as *recoloring* of maps [5].

Selected parameters, their classification and weight are presented in Table 1. In this research, the parameters for offshore cage mariculture site selection are reclassified into four classes (0 – 3), which represents unacceptable (=0) to good condition (=3) based on their specific suitability criteria. Based on the literatures and interview with some mariculture experts some parameters are not

classified for some classes (indicated by empty cells in Table 1). An example of a reclassification process is presented in Figure 3. In this figure a bathymetry map was reclassified based on scoring of suitability as shown in Table 1. All parameters are reformatted into raster format, with the same resolution as that of the numerical model. One layer of database represents one selected parameter and a final analysis map is obtained from overlaying method of all parameters.

Weighting of the map layers is achieved using the *Analytical Hierarchy Process* (AHP). AHP is a quantitative method designed in the early 1980's by T. L. Saaty as a systematic method for comparing decision criteria [6]. The procedure involves mathematically summarizing paired comparisons of the relative importance of the map layers. The results are a set of map layer weights that serves as input to a GIS model.

A scale from 1 (equally important) to 9 (extremely important) (Table 2) is used to record the relative level of importance for the pair wise combinations of the decision parameters. Parameters are compared to each other and recorded in a comparison matrix as shown in Table 3. The number of matrix elements as number of pair wise combinations is equal to  $(N*(N-1)/2)$ , where N is the number of decision parameters. The responses from the pair wise comparisons are entered into the importance table (comparison matrix). The order of statement determines where in the table the importance value is placed. The reciprocal is computed and placed in the reverse statement position.

In the case of mariculture site selection in this study, fifteen parameters are compared with one another. The complete list of the pair wise comparisons is presented in Table 3. The last row of the table indicates the summarized values of each column.

Table 4 presents the normalized value derived from Table 3, where the summarized value of each column is set to be 1. The weight of each parameter is presented in the last column of Table 4. The weight is the average value of the normalized weights.

The *weighted linear combination* was employed for the overlaying method. Using this method, weights of relative importance are assigned to each parameter (as they are presented in Table 4) and a weighted average is then obtained for each by multiplying the weight assigned by the scaled value for that parameter, and summing the products over all parameters as it is shown in Equation 1. An example of conceptual computation is presented in the Figure 4

$$TS = \sum_{i=1}^n w_i \cdot x_i \quad (1)$$

where  $TS$  = total score of each pixel  
 $w_i$  = weight of parameter  $i$   
 $x_i$  = score of parameter  $i$

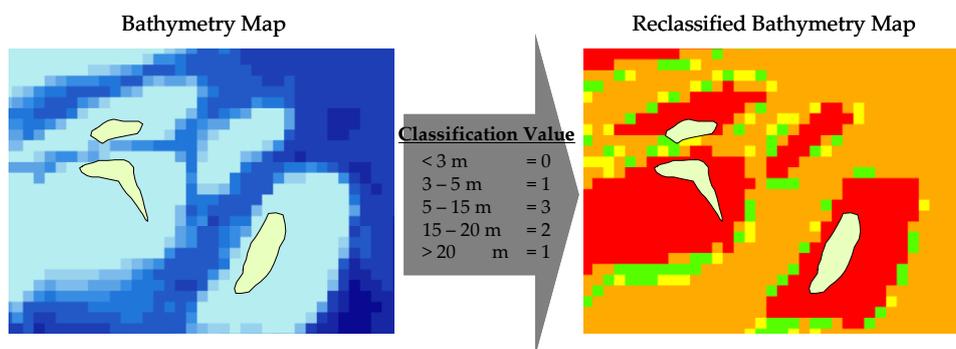
**Table 1** Selected parameters with their weight and classification [3].

Parameter	Unacceptable	Poor	Fair	Good
Score	0	1	2	3
Depth at Spring Tide (m)	< 3	3-5 or > 20	15-20	5-15
Maximum Current Velocity (m/s)	< 0.05 or > 1	0.05-0.2	0.5-1	0.2-0.5
Maximum Wave Height (m)	>1.5	1-1.5	0.6-1	≤ 0.6
Entrainment of Seabed Sediment by Wave (Dean Number)	< 2.4	2.4 – 3.2	3.2 – 4.0	4.0
Water Temperature (°C)	< 15 or > 35	15-20 or 33-35	20-27 or 31-33	27-31
Salinity (psu)	< 10	10-15	15-25 or > 35	25-35
Dissolved Oxygen (mg/l)	< 4	-	4-5	≥ 5
Ammonia (mg/l)	0.5	-	-	≤ 0.5
Water Ph	< 3 or > 14	-	3-7.8 or 8.6-13	7.8-8.6
Nitrate (mg/l)	> 200	-	-	≤ 200
Phosphate (mg/l)	> 70	-	-	≤ 70
Bottom sediment type	-	Mud	Coral	Sand
Distance to harbour (km)	< 0.2	-	0.2-0.5	≥ 0.5
Distance to navigation line (km)	< 0.2	-	0.2-0.5	≥ 0.5
Distance to industrial area (km)	< 1	1-2	2-5	>5
Distance to tourism area (km)	< 0.5	-	0.5 – 1.5	≥ 1.5

Since the overlaying results may derive from one or more parameter with the score of zero (unacceptable), a filter has to be made in the computation for the overlaying. If the scoring value of one parameter is equal to zero, than the overlaying results will be classified as unacceptable. The purpose is to prevent the elimination of an unacceptable value by the higher scoring value from the other parameters. The classification for the overlaying results is based on natural breaks. In this classification scheme, classes are based on natural groupings inherent in the data. The GIS software identifies break points automatically by picking the class breaks that best group similar values and maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively large jumps in the data values.

**Table 2** Scales of relative level of importance (modified after [7]).

Scale	Importance Level
1	Equally important
2	Equally to moderately more important
3	Moderately more important
4	Moderately to strongly more important
5	Strongly more important
6	Strongly to very strongly more important
7	Very strongly more important
8	Very strongly to extremely more important
9	Extremely more important



**Figure 3** Reclassification of minimum water depth.

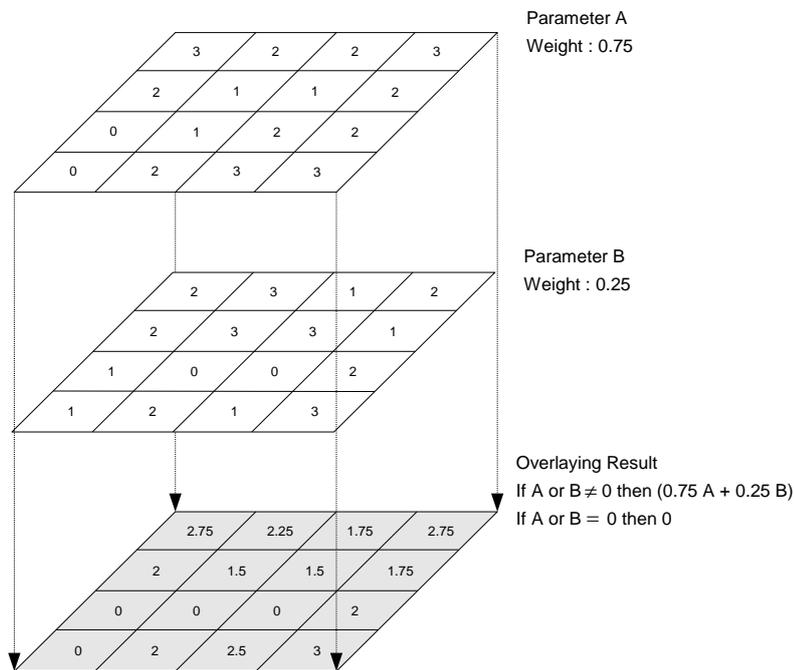
**Table 3** Relative importance of parameters for site selection (Comparison matrix) [6].

	DP	VL	WV	SE	TM	SL	DO	AM	PH	NI	PO	SD	HR	NL	IA	TA
DP	1.00	1.00	3.00	5.00	7.00	7.00	3.00	3.00	3.00	3.00	3.00	9.00	9.00	9.00	1.00	9.00
VL	1.00	1.00	3.00	5.00	7.00	7.00	3.00	3.00	3.00	3.00	3.00	9.00	9.00	9.00	1.00	9.00
WV	0.33	0.33	1.00	3.00	5.00	5.00	1.00	1.00	1.00	1.00	1.00	7.00	7.00	7.00	0.33	7.00
SE	0.20	0.20	0.33	1.00	3.00	3.00	0.33	0.33	0.33	0.33	0.33	5.00	5.00	5.00	0.20	5.00
TM	0.14	0.14	0.20	0.33	1.00	1.00	0.20	0.20	0.20	0.20	0.20	3.00	3.00	3.00	0.14	3.00
SL	0.33	0.33	0.20	0.33	1.00	1.00	0.20	0.20	0.20	0.20	0.20	3.00	3.00	3.00	0.14	3.00
DO	0.33	0.33	1.00	3.00	5.00	5.00	1.00	1.00	1.00	1.00	1.00	7.00	7.00	7.00	0.33	7.00
AM	0.33	0.33	1.00	3.00	5.00	5.00	1.00	1.00	1.00	1.00	1.00	7.00	7.00	7.00	0.33	7.00
PH	0.33	0.33	1.00	3.00	5.00	5.00	1.00	1.00	1.00	1.00	1.00	7.00	7.00	7.00	0.33	7.00
NI	0.33	0.33	1.00	3.00	5.00	5.00	1.00	1.00	1.00	1.00	1.00	7.00	7.00	7.00	0.33	7.00
PO	0.33	0.33	1.00	3.00	5.00	5.00	1.00	1.00	1.00	1.00	1.00	7.00	7.00	7.00	0.33	7.00
SD	0.11	0.11	0.14	0.20	0.33	0.33	0.14	0.14	0.14	0.14	0.14	1.00	0.33	0.33	0.11	0.33
HR	0.11	0.11	0.14	0.20	0.33	0.33	0.14	0.14	0.14	0.14	0.14	3.00	1.00	1.00	0.11	1.00
NL	0.11	0.11	0.14	0.20	0.33	0.33	0.14	0.14	0.14	0.14	0.14	3.00	1.00	1.00	0.11	1.00
IA	1.00	1.00	3.00	5.00	7.00	7.00	3.00	3.00	3.00	3.00	3.00	9.00	9.00	9.00	1.00	9.00
TA	0.11	0.11	0.14	0.20	0.33	0.33	0.14	0.14	0.14	0.14	0.14	3.00	1.00	1.00	0.11	1.00
TOT	6.12	6.12	16.30	35.47	57.33	57.33	16.30	16.30	16.30	16.30	16.30	90.00	83.33	83.33	5.93	83.33

Notes:

DP = Water Depth  
 VL = Current Velocity  
 WV = Wave Height  
 SE = Sediment Entrainment  
 TM = Water Temperature  
 SL = Salinity  
 DO = Dissolved Oxygen  
 AM = Ammonia  
 PH = Water pH  
 NI = Nitrate  
 PO = Phosphate  
 SD = Bottom Sediment Type  
 HR = Distance to Harbour  
 NL = Distance to Navigation Line  
 IA = Distance to Industrial Area  
 TA = Distance to Tourism Area  
 TOT = Total (Sum Value)





**Figure 4** Parameter overlaying method

### 3.4 Data Sources

It is necessary to identify data sources for the selected parameters in the analytical framework stage. It is generally both costly and time consuming to collect field (primary) data first hand. Therefore, all GIS practitioners attempt to allocate the data they need from existing secondary sources, either in paper or digital form. The initial consideration is identifying what data are needed for the overall analysis. This is followed by attempts to source the data, and to assess their age, scale, quality and relative cost. Different data types are often developed in different geographic coordinate systems, and must be re-projected onto a common coordinate system. Other common issues are ensuring that features common across multiple layers are spatially coincident, and understanding the resolution, constraints and uncertainty associated with the data. For these reasons, data collection and pre-processing are typically the most expensive and time-consuming component of an analysis.

As it is described in the previous section, all of the parameters have to be reclassified based on their criteria and weighted based on their importance. Therefore, the parameters are presented in the raster form, with their original

value and then reclassified (Table 1). In this study, data for the selected parameters are taken from previous field measurements data and numerical modeling results.

### **3.5 Organization and Manipulation of Data**

Once the datasets have been collected, it is necessary to organize and manipulate them for use in the GIS. The main activities in this stage are verification of data quality, data consolidation and reformatting. Database construction is another set of activities that is typically undertaken in this stage. Designing an appropriate database is important both in terms of ensuring that the information can be readily accessed for the target application and is available for re-use at a later time.

The development of GIS in this study is based on raster format. All parameters are reformatted to raster with a certain resolution depending on the original data resolution. All databases are presented in shape file (shp) format, which are easily readable by any GIS software and mapping.

### **3.6 Analysis and Verification**

This stage represents the culmination of efforts that have been expended, particularly on part of the GIS analysts, to develop the analytical framework, allocate data sources and organize data for the analysis. Field verification as part of any GIS work is absolutely essential, both for quality control of certain data sources and for testing the outcomes of models. Fieldwork as part of a verification exercise is frequently referred to as ground-truthing. The general approach to such work is similar to any field survey, and standard techniques for survey and environmental measurements can be used. The main difference is in the sampling plan and verification exercise, which typically has to be based on a sampling strategy designed to cover the entire area.

## **4 Results**

A comprehensive Mariculture Site Suitability Map, which integrates all of the selected criteria, is the final output of the developed DSS. Locations are selected based on the suitability and sustainability consideration of each weighted parameter. In order to evaluate the relative impact of each parameter category (e.g. physical, chemical, sediment, and coastal use) on the final DSS result, suitability maps of the four applied categories are presented in the following.

Figure 4a presents the suitability map based on physical parameters. The main dominant parameters in this group are water depth and current velocity, while

both parameters have a higher weight compared to wave height and Dean number (Table 1).

Considering the physical parameters, only 9.90 % of the area is defined as *unacceptable* for mariculture activities. The locations are mainly close to the islands where the depth is not sufficient (less than 3 m) and the current magnitude is minor (less than 0.05 m/s). Areas up to 7 km seaward from the north coast of Java and the east coast of Sumatera are included in this category. About 14.26% of the area is classified as the most suitable area (*good*). The most suitable area for mariculture is located about 8 – 15 km north from Java, 10 – 30 km seaward from the east coast of Sumatera, as well as in the Seribu Islands area.

Most of the areas exhibit *poor* and *fair* conditions, respectively 29.36% and 46.48% of the total study area. In the area where the water depth is deeper than 20 m and the current velocity is less than 0.2 m/s, the area is categorized as *poor*. Areas with *fair* conditions are mainly located in the deep water with current velocities up to 1 m/s.

With respect to chemical criteria, the entire area is categorized as suitable (*good*) (Figure 4b), since most of the chemical parameters indicate favorable conditions for mariculture. Only with respect to dissolved oxygen concentrations, which are in the range of 4 – 5 mg/l, is the area categorized as *fair*.

The sea bottom sediment of the Java Sea is characterized by muddy sediments in the eastern part as well as in the area close to Java and Sumatera Island (Figure 4c). Coarser sediment prevails in the higher current velocity areas where the main flow between the Java Sea and Indian Ocean, through the Sunda Strait, is taking place. More than half of the total area (55.87%) is categorized as poorly suited, 7.51% is categorized as fair and 36.61% as most suitable. Unacceptable conditions with respect to sediment parameters did not occur in this study.

The mariculture should be located at some distance from these areas, hence a buffer zone is required. Results of the suitability analysis based on coastal use parameters (harbors, navigation line, industrial and tourism) are presented in Figure 4d.

There are four main harbors in the study area (Tanjung Priok, Sunda Kelapa, Merak, and Bakauheni) included in the analysis of coastal use parameters for mariculture site selection. About 20 km northwest of Seribu Islands, lay some offshore oilrigs. The rigs are categorized as an industrial area and the

mariculture should be located at least 1 km away from that area. Tourism areas are mostly located in the Seribu Islands and Jakarta Bay.

As a final result, a comprehensive mariculture suitability map for the Java Sea area is presented in Figure 5. Most suitable (*good*) locations for mariculture account for 12.87 % of the entire area, which almost equals to the area classified as *unacceptable* (11.68%). Almost half of the area (43.78%) is categorized as *fair*. *Poor* locations for mariculture prevail in 31.67% of total area.

It is obvious that the comprehensive suitability map for fish farming is very similar to that of suitability with respect to physical parameters (Figure 4a). Minor differences are due to the extent of areas classified as unacceptable, which increases in the comprehensive analysis by 1.78% due to the integration of coastal use criteria. In turn, the percentage of most suitable area (*good*) decreases from 14.26% in the physical suitability map to 12.87% in the final results, as do areas classified as *fair* from 46.48% to 43.78%. The Seribu Islands area itself does not differ much from the physical results; only several tourism sites in the northern part reduce the extent of most suitable locations for mariculture.

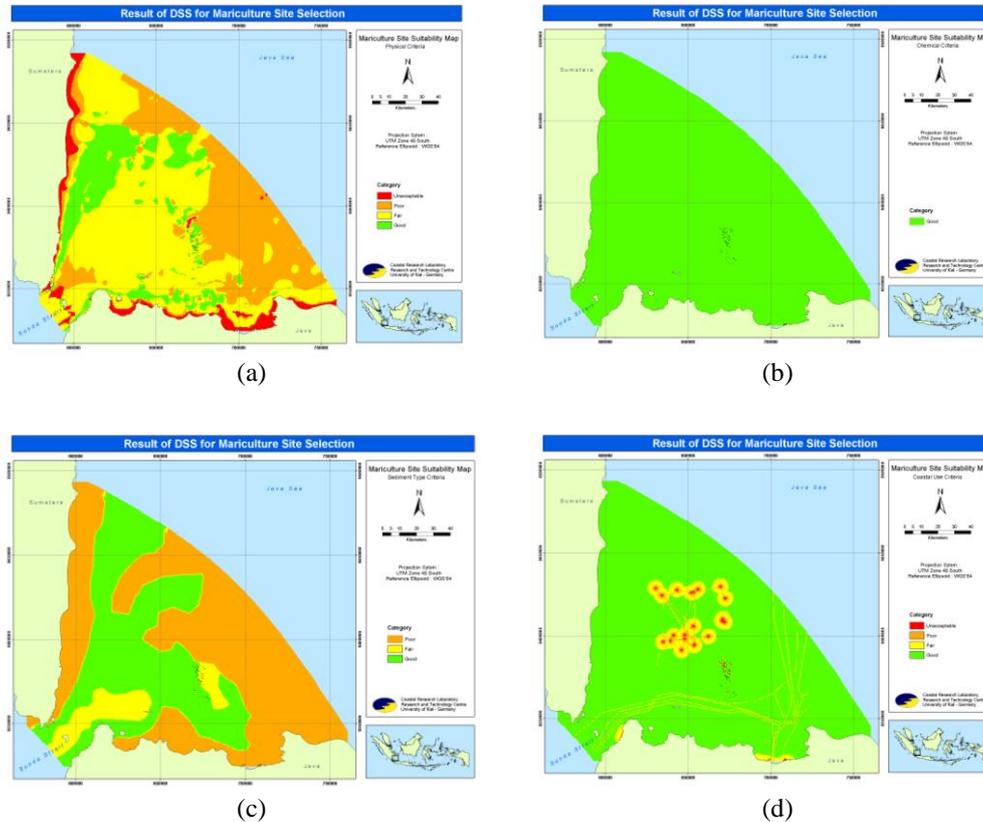
*Good* mariculture site locations, which are marked in green, are located about 7 – 10 km seaward from the north coast of Java, 1 km seaward from the west coast of Java, 10 – 15 km seaward from the east coast of Sumatera and Seribu Islands.

Mariculture site must not be implemented in areas with *unacceptable* conditions, which are marked by red color in the map. *Unacceptable* areas are located at the north coast of Java and Sumatera Island reaching from the coastline up to 5 km offshore; in the middle of the Sunda Strait channel where the current velocity is very strong and the navigation lines for ships are quite concentrated; and in the area within the buffer zone around harbors, industrial and tourism sites.

## 5 Discussions and Conclusions

The purpose of this work was to design a Decision Support System to assist the decision-makers for the selection of suitable mariculture sites. The DSS was implemented with ArcGIS software, which supports the main interface of the system and the database capabilities. The work is focused on the selection of the most suitable sites for offshore cage culture in floating cages, which is vitally important as it can greatly influence the degradation of surrounding environments, the economic viability of a venture by determining its capital outlay, running costs, production rates and mortality factors. It can also resolve

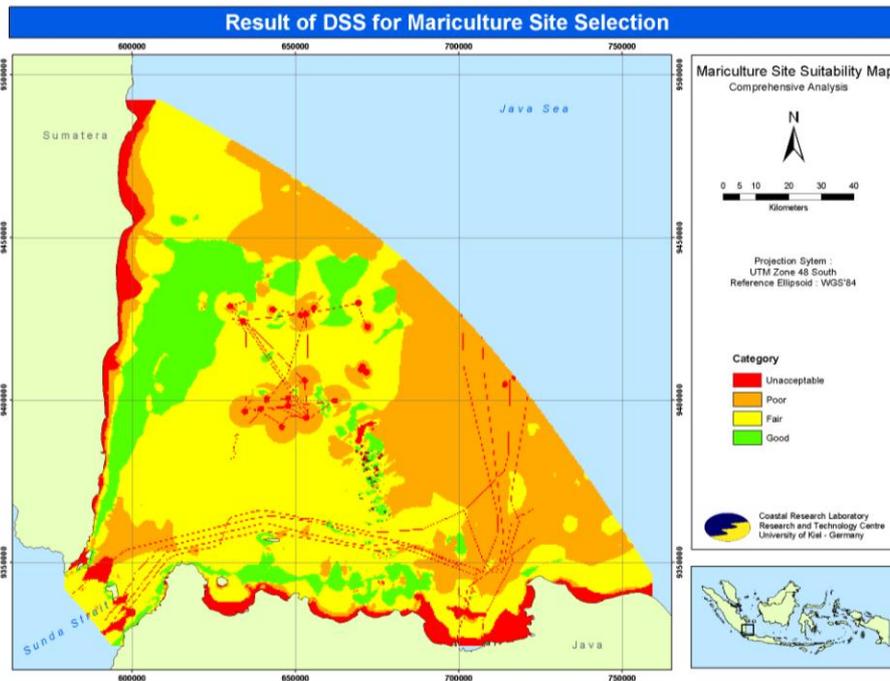
conflicts between different coastal activities and users, such as fishing or tourism, making rational and sustainable use of coastal space.



**Figure 5** Java Sea Mariculture Suitability Map based on (a) physical (b) chemical (c) sediment and (d) social-economics parameters.

The results of the DSS for mariculture site selection in the western part of Java Sea indicate that only 12.87% of the area is in *good* condition for mariculture, however, almost half of the area, about 43.78%, is in *fair* condition, 31.67% is in *poor* condition, and only 11.68% of the area is in *unacceptable* condition for mariculture industry. The most appropriately conditions areas for mariculture industry are located in the area lying about 7 – 10 km from the north coast of Java, 1 km from the west coast of Java, 10 – 15 km east of the coast of Sumatera and in Seribu Islands. The area within 5 km from the north coast of Java and the east coast of Sumatera should be avoided for mariculture site since it is categorized as *unacceptable* in the DSS results.

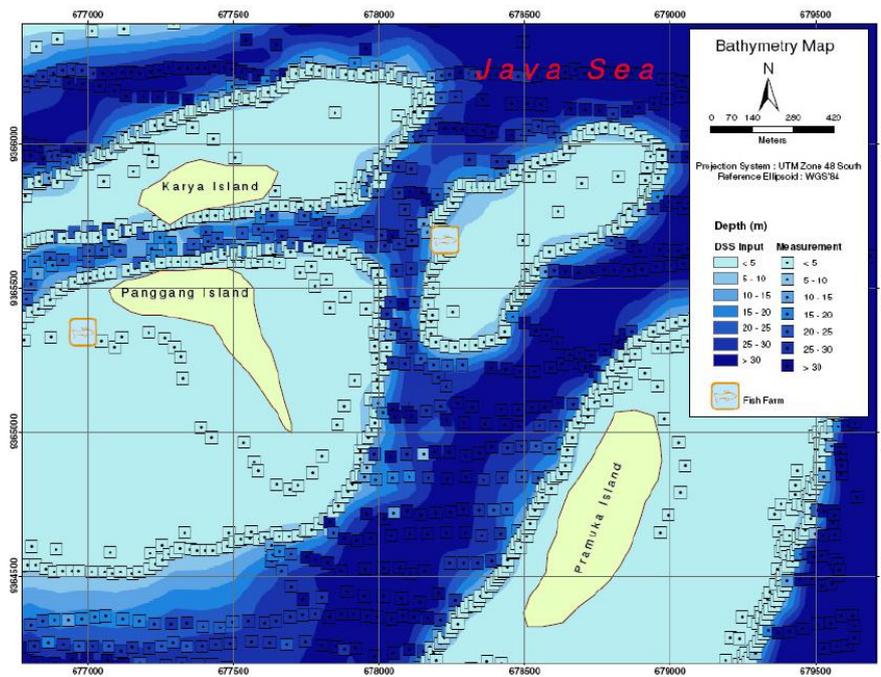
The best mariculture sites are located mainly in the areas with a depth of 5 – 15 m, with maximal current velocity of 0.5 m/s and lying far away from the industrial or navigational areas. The areas with one or more parameters in the outer limits of the threshold values for mariculture site are always classified as *unacceptable* and the mariculture site must be avoided.



**Figure 6** Comprehensive Mariculture Suitability Map for the Java Sea.

It is necessary to validate the input data for DSS and the output results by means of field measurements performed directly in the existing fish farm area. The fish farm site used for this study is located at Pramuka Island (Java Sea). The Pramuka fish farm site is located in a well-protected area inside a group of small islands (Pramuka, Karya and Panggang). Farming activities have started since the end of the 1990s. The facilities include a bureau, storing house, hatchery, residence and several fish cages with different shapes and dimensions. The field measurements were taken twice at the site, during the dry and rainy season, according to the Southeast Asian monsoon conditions. The measuring campaigns cover the physical and chemical as well as bottom sediment parameters.

A comparison of bathymetric data used for the DSS and the field measurements shows a very good agreement between the interpolated results used as input in the DSS and the measurement data from the pixels where measurements were available. In total more than 50% of the pixels exhibit minor differences of 0 – 1 m (Figure 7). It can therefore be concluded that the bathymetry values from interpolation are appropriate as DSS input data.

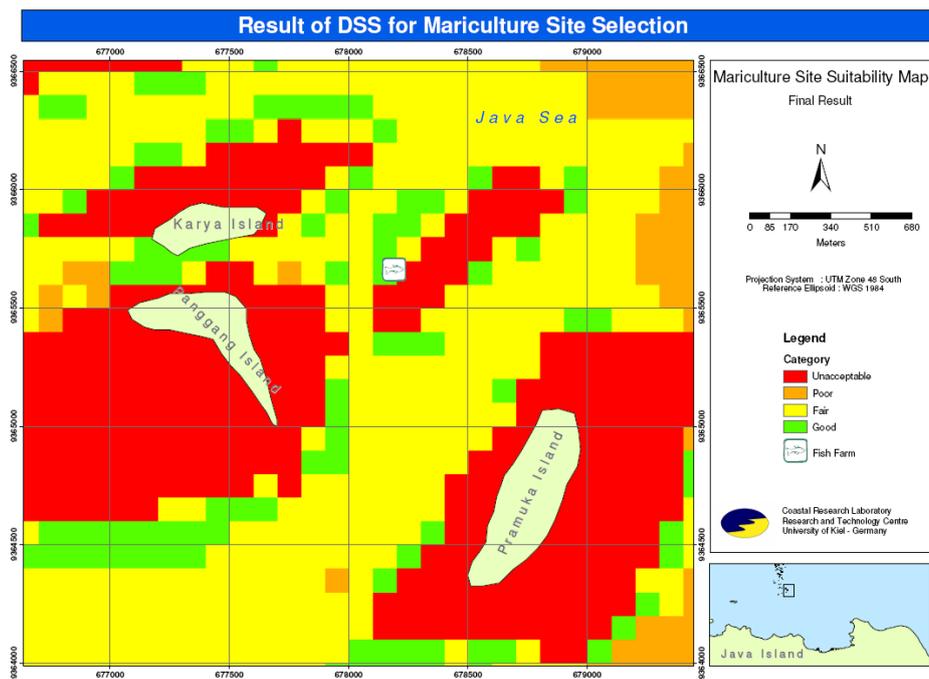


**Figure 7** Validation of Bathymetry Data between DSS Input and Measurement [3].

Using similar method of validation as in bathymetry data, validation of currents and waves as well as chemical parameters also present a good agreement between measurements and DSS input.

Figure 8 presents the enlarged results from the comprehensive mariculture suitability map for the Java Sea on the Pramuka site. It can be seen that the fish farm used as the case study is located in the most suitable (good category) area. This is in agreement with the field data from the measuring campaign as shown in Table 5. Almost all of the parameters are in the good category for mariculture implementation. Based on this validation, it can be concluded that the DSS is working adequately for the Pramuka Island area as well as Seribu Islands and Java Sea.

The involved criteria in the DSS are assumed to be sufficient to assess the suitability of the study areas. It should be noted that other important criteria, which cannot be addressed at the moment, may also improve the results. These criteria may be other nutrient concentrations, turbidity of seawater, heavy metals pollution, biological factors, the proximity to markets or short transports of farmed fish, recurrent blooms of toxic phytoplankton algae, organochloride contaminants, etc. However, this is hampered by the lack of data. It should, thus, be appropriate to do a coastal monitoring program.



**Figure 8** Final Result of DSS for the Pramuka Island area [3].

This study presents a methodology for siting offshore mariculture floating cages in suitable and sustainable fashion. Despite the fact that Seribu and Riau Islands were selected as the study areas, the developed methodology can be applied to other coastal areas in Indonesia or even worldwide. For other areas, certain criteria may be of low or no importance, whereas new ones may need to be added. However, despite these small differences, the framework and methodology should remain the same independent of the study location. Overall, this study revealed the usefulness and advantages of GIS-based DSS as a coastal mariculture planning and management tool.

Development of mariculture involves making decisions, amongst alternative possible site locations. It is important that this decision is made well, using the best information, methods and tools available. As the accuracy of the results of these studies is directly dependent on the quality of input data, updated and accurate thematic information is desired. There is a need to develop a coastal monitoring program in Indonesian waters to provide more accurate and updated data. One of good examples of coastal monitoring program is SEAWATCH Indonesia. Unfortunately, the time and spatial coverage is limited within the period of 1999 to 2001, with data from only 12 buoys, deployed in the Java Sea and Malacca Strait.

**Table 3** Validation of DSS result [3].

Parameter	DSS		Measurement	
	Value	Category	Value	Category
Minimum Depth at Spring Tide (m)	10 – 15	Good	10 – 15	Good
Maximum Current Velocity (m/s)	0.3 – 0.4	Good	0.4	Good
Maximum Wave Height (m)	0.3	Good	-	-
Dean Number	3.3	Fair	-	-
Water Temperature (°C)	28	Good	29	Good
Salinity (psu)	32	Good	34	Good
Dissolved Oxygen (mg/l)	4.23	Fair	4.37	Fair
Ammonia (mg/l)	0.3	Good	0.13	Good
Water pH	7.9	Good	7.93	Good
Nitrate (mg/l)	0.36	Good	0.11	Good
Phosphate (mg/l)	0.36	Good	0.02	Good
Bottom sediment type	Coral	Good	Sand	Good
Distance to harbour (km)	> 0.2	Good	> 0.2	Good
Distance to navigation line (km)	> 0.2	Good	> 0.2	Good
Distance to industrial area (km)	> 5	Good	> 5	Good
Distance to tourism area	> 1.5	Good	> 1.5	Good

For sustainable development, it is necessary to make decisions that do not have long term negative effects and assess the long term effects and impacts as well as the short term benefits. Because predictions can only be approximate, the decisions cannot be made only once and be expected to hold permanently. They

need to be revisited and revised as the real consequences of decisions are revealed in practice.

The developed numerical models for both study areas can be used further for sediment transport and water quality analysis of the fish farm areas. In the development of DSS, the question of carrying capacity of the mariculture site challenges this field of study. Database development and customization of the DSS is also recommended to improve the DSS performance and make the DSS as *user-friendly* as possible.

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