

Development of a Decision Support System for Suitability Assessment of Mariculture Site Selection

Dissertation
zur Erlangung des Doktorgrades
der Mathematisch-Naturwissenschaftlichen Fakultät
der Christian-Albrechts-Universität zu Kiel

vorgelegt von
Wiwin Windupranata

Kiel
November 2007

Referent: Prof. Dr. Roberto Mayerle
Koreferent: Prof. Dr. Franciscus Colijn
Tag der mündlichen Prüfung: 7 Februar 2007
Zum Druck genehmigt: 23 November 2007

Acknowledgements

The author wishes to express his deepest gratitude and profound appreciation to his supervisor, Prof. Dr. Roberto Mayerle. His exemplary guidance, continuous support and close supervision throughout his research are most deeply appreciated. He always challenged me to produce my best. He monitored my progress and advised me with valuable insights of coping with problems. I also appreciate Prof. Dr. Franciscus Colijn for accepting to be the *Korreferent* and reviewer of my dissertation.

My study and life in Kiel would have never been successful without any financial support from German Academic Exchange Service or Deutsche Akademische Austauschdienst (DAAD). Therefore, I feel very fortunate to receive this scholarship.

Special gratitude is also extended to Dr. Karl-Juergen Hesse and Dr. Karl-Heinz Runte for their invaluable advice and of support for my research and thesis. And also to all of my colleagues from Forschungs- und Technologiezentrum Westküste (FTZ) - Büsum and Coastal Research and Management (CRM) - Kiel, who were involved in SPICE project, for their help and support during the measuring campaign. My works for this research would never have been enjoy without the friendships and support from all of my colleagues in the Coastal Research Laboratory. In particular, I am grateful to Dr. Marcus Reckerman, Dr. Peter Weppen, Dr. Poerbandono, Dr. Jort Wilkens, Dr. Gatot Haryo Pramono, Dr. Piyamarn Leangruxa, Maryam Rahbani, Talal Etri, Nestor Jimenez, Ilgar Özgürel, Dirk Schultz, Carlos Escobar and José Manuel Fernandez Jaramillo. I give my special acknowledgment to Leslie Malick, who did the English review for my thesis.

Finally, the unconditional love and support of my family has undoubtedly played the major part in the success of my works. My wife, Intan Hayatiningsih, you lift my soul and give me courage to face the research each day. I may have started this journey on my own, but you gave me the strength to finish it. Delicious Indonesian foods, tidy rooms and a cute child are a few things which make me smile when returning home. Rafi Valerian Pratama, my beloved child, also help me to realize the significance of my research for his future.

Kiel, 23 November 2007
Wiwin Windupranata

Abstract

As the world's population increases, demand on fish products as a strong source of protein is increasing as well. To avoid the depletion of natural living resources in the ocean, the request cannot be supplied from capture fisheries alone, but must also be supported by aquaculture products. Due to regional limitation inland, aquaculture in the seas, or mariculture, had been introduced as an alternative to inland aquaculture by utilization of coastal and offshore areas. Over the last two-decades, mariculture has been intensified and has created essential employment opportunities. This development has also augmented environmental concerns and questions about possible environmental impacts. Intensive fish farming releases considerable amounts of nutrient waste in dissolved and particulate form into the environment through feed excess, soluble fish excretion and faeces production. It is important before the implementation of fish farming mariculture activities, appropriate site conditions for culturing the species should be selected in order to minimize environmental impacts arising from the farming activities (sustainability) as well as to guarantee adequate conditions from the operational point of view (suitability).

This study focuses on the development of a Decision Support System (DSS) as a tool for the decision maker in coastal zone management and mariculture for the appropriate selection of mariculture site location. Extensive use of GIS as part of the Decision Support System was deployed in this study. 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 Seribu Islands area in the Java Sea and the Riau Archipelago, Indonesia. The data were acquired from direct field measurement, numerical modelling and existing information from particular agencies. Numerical modelling was used to obtain spatial and temporal distributions of hydrodynamic parameters (i.e. current velocities and water levels). The Delft3D modelling system (Delft Hydraulics, The Netherlands) was employed for this purpose. The DSS was developed under GIS application of ESRI® ArcGIS™ v8.3 using weighted overlay method. Due to lack of data, some parameters were excluded from the analysis. 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.

Kurzfassung

Mit wachsender Weltbevölkerung steigt die Nachfrage nach Fischprodukten als Proteinquelle. Der Bedarf kann nicht allein durch den Fischfang befriedigt werden, sondern muss teilweise durch Aquakulturprodukte gedeckt werden, um eine Verarmung der natürlichen Ressourcen der Ozeane zu vermeiden. Aufgrund der räumlichen Beschränkung von Aquakultur auf dem Land hat sich alternativ die marine Aquakultur oder Marikultur entwickelt, welche Küstengebiete und vermehrt auch Offshoregebiete nutzt. In den letzten zwei Jahrzehnten hat sich der Zweig der Marikultur relativ stark entwickelt und dabei neue Beschäftigungsmöglichkeiten geschaffen. Diese Entwicklung hat darüber hinaus zu neuen Bedenken hinsichtlich der Umweltverträglichkeit und möglicher negativer Einflüsse von Marikultur auf die Umwelt geführt. Intensive Fischzucht kann durch überschüssige Fütterung und Fischausscheidungen erhebliche Mengen an nährstoffreichen Abfällen in gelöster und partikulärer Form verursachen. Vor der Durchführung von Marikulturprojekten sollte zur Bestimmung geeigneter Standortbedingungen für die zu kultivierende Spezies und ein bestimmtes Kultivierungssystem, sowie zur Vermeidung von negativen Umweltbeeinträchtigungen eine wissenschaftliche Untersuchung zur Wahl des Standorts und der Spezies erfolgen.

Diese Studie konzentriert sich auf die Entwicklung eines *Decision Support System*. Es dient als Werkzeug für Entscheidungsträger im Küstenzonenmanagement bei der Suche nach geeigneten Antworten zu Fragen der Standortwahl für Marikultur. Basierend auf der GIS-Methode, wurden physikalische-, chemische- und Sedimenteigenschaften, sowie Informationen zur Küstennutzung analysiert. Das Resultat ist eine Karte, welche die geeigneten Gebiete für eine verbesserte Offshore-Marikultur abbildet. In dieser Studie wurde der Schwerpunkt auf Finfisch spezies gesetzt aber Methode und Ergebnisse können, nach entsprechender Veränderung, auch für andere Spezies angewendet werden.

Das DSS für Marikultur wurde für die Seribu Inseln in der Javasee und den Riau Archipel in Indonesien entwickelt. Die Daten stammen von direkten Messungen in Messkampagnen, numerischen Modellierungen und speziellen Agenturen. Die numerischen Modellierungen wurde verwendet, um räumlich-zeitliche Verteilungen von physikalischen hydrodynamischen Parametern (z.B. Strömungsgeschwindigkeiten und Wasserstände) zu erlangen. Das DSS wurde mit der GIS-Anwendung von ESRI® ArcGIS™ v.8.3 unter Verwendung der „weighted overlay Methode“ entwickelt. Das Gewicht (weight) eines jeden Entscheidungsparameters repräsentiert seine Bedeutung für die Standortwahl. Aufgrund fehlender Daten, wurden einige Parameter von der Analyse ausgeschlossen.

Contents

| | |
|--|-------------|
| Acknowledgements | iii |
| Abstract | v |
| Kurzfassung | vii |
| Contents | ix |
| List of Figures | xiii |
| List of Tables | xvii |
| | |
| Chapter 1. Introduction | 1 |
| 1.1 Significance and statement of problem | 1 |
| 1.2 Scientific Background | 2 |
| 1.2.1 Previous Study of Numerical Models for Fish Farm Application..... | 2 |
| 1.2.2 Previous Study of Development of DSS for Mariculture | 6 |
| 1.3 Objectives | 8 |
| 1.4 Outline | 8 |
| | |
| Chapter 2. Environmental Sustainability and Site Selection of Mariculture | 9 |
| 2.1 Aquaculture and Mariculture | 9 |
| 2.2 Sustainable Development of Mariculture | 11 |
| 2.3 Parameters for Mariculture Site Selection | 12 |
| 2.3.1 Physical Properties..... | 13 |
| 2.3.2 Chemical Properties..... | 16 |
| 2.3.3 Sediment Properties..... | 19 |
| 2.3.4 Biological Properties..... | 19 |
| 2.3.5 Socio Economics..... | 20 |

| | |
|--|---------------|
| Chapter 3. Mariculture in Indonesia..... | 23 |
| 3.1 Potential Area and Production | 23 |
| 3.2 Problems | 29 |
| 3.2.1 Environmental Degradation | 29 |
| 3.2.2 Pollution..... | 29 |
| 3.2.3 Conflict with Other Coastal Uses | 30 |
| 3.2.4 Operation..... | 30 |
| 3.2.5 Regulation..... | 31 |
| Chapter 4. Strategy for Mariculture Site Selection | 35 |
| 4.1 Site Selection Strategy | 35 |
| 4.2 Introduction to the Decision Support System..... | 36 |
| 4.3 Geographic Information Systems for DSS..... | 37 |
| 4.4 Principles of the Development of Decision Support System | 39 |
| 4.4.1 Identification of Requirements | 40 |
| 4.4.2 Formulation of Specification | 40 |
| 4.4.3 Analytical Framework | 40 |
| 4.4.4 Data Sources | 45 |
| 4.4.5 Organization and Manipulation of Data | 46 |
| 4.4.6 Analysis and Verification | 46 |
| Chapter 5. Description of Study Areas, Data Availability and Development of | |
| Numerical Models | 47 |
| 5.1 General Characteristics of Indonesian Seas | 47 |
| 5.1.1 Seribu Islands and Java Sea..... | 50 |
| 5.1.2 Riau Archipelago | 52 |
| 5.2 Data Availability..... | 53 |
| 5.3 Development of Numerical Models..... | 56 |
| 5.3.1 Java Sea Model..... | 59 |
| 5.3.2 Riau Islands Model..... | 76 |

| | |
|---|------------|
| Chapter 6. Decision Support System for Mariculture Site Selection..... | 81 |
| 6.1 Components of the Decision Support System..... | 81 |
| 6.1.1 Interface..... | 81 |
| 6.1.2 Database | 82 |
| 6.1.3 Model of the DSS..... | 82 |
| 6.2 Mariculture Site Selection | 84 |
| 6.2.1 Java Sea..... | 84 |
| 6.2.1.1 Input Data | 84 |
| 6.2.1.2 Output and Discussion..... | 87 |
| 6.2.2 Riau Islands | 91 |
| 6.2.2.1 Input Data | 91 |
| 6.2.2.2 Output and Discussions | 94 |
| | |
| Chapter 7. Validation and Application of DSS for Small Scale Area..... | 99 |
| 7.1 Introduction | 99 |
| 7.2 Pramuka Island | 100 |
| 7.3 Serai Island..... | 105 |
| | |
| Chapter 8. Conclusions and Recommendation..... | 111 |
| 8.1 Conclusions..... | 111 |
| 8.2 Recommendations..... | 112 |
| | |
| References | 115 |

List of Figures

| | |
|---|----|
| Figure 2.1: Fish farming wastes..... | 10 |
| Figure 2.2: pH limits of physiological activities in marine environment [Boyd, 1979] | 17 |
| Figure 2.3: Various possible pollution sources in coastal area [Chua et al., 1989] | 18 |
| Figure 3.1: Indonesian mariculture potential sites map [BAKOSURTANAL, 1998]..... | 24 |
| Figure 3.2: Fish Production in Indonesia and percentage to the world production from 1997 – 2002 [DKP, 2005a and FAO, 2003]..... | 26 |
| Figure 3.3: National aquaculture production per type of culture in year 2004 [DKP, 2005b] . | 26 |
| Figure 3.4: Aquaculture production by type of culture in different Indonesian regions in 2004 [DKP, 2005b]..... | 27 |
| Figure 3.5: Production by area and species (in Ton) of year 2004 [DKP, 2005b]..... | 28 |
| Figure 3.6: Location of Indonesian Mariculture Research Institutions [Sugama (2002)] | 31 |
| Figure 4.1: Development of a GIS process [Nath et al., 2000] | 40 |
| Figure 4.2: Reclassification of minimum water depth | 41 |
| Figure 4.3: Parameter overlaying method | 45 |
| Figure 5.1: Topographic map of Indonesia..... | 48 |
| Figure 5.2: Indonesian bottom sediment type map [BAKOSURTANAL, 1998]..... | 49 |
| Figure 5.3: Indonesian Throughflow and circulation in Indian Ocean [Meyers, 1996]..... | 49 |
| Figure 5.4: Global Sea Surface Circulation in Southeast Asia [Wyrтки, 1961]..... | 50 |
| Figure 5.5: Seribu Islands Map (Islands under conservation zone are inside the dashed-line) | 51 |
| Figure 5.6: Riau Islands Map..... | 53 |
| Figure 5.7: Location of sample points of WOA'01 in Indonesian waters..... | 56 |
| Figure 5.8: General procedure of development of the hydrodynamic numerical model | 58 |
| Figure 5.9: Numerical grid of Java Sea Model domain..... | 60 |

| | |
|--|----|
| Figure 5.10: Sensitivity analysis due to change of time step..... | 63 |
| Figure 5.11: Sensitivity analysis due to change of wind conditions | 64 |
| Figure 5.12: Sensitivity analysis due to change of bottom roughness..... | 65 |
| Figure 5.13: Wind condition at Seribu Islands during verification period | 66 |
| Figure 5.14: Verification of water level from model results to measurement data before and after calibration | 69 |
| Figure 5.15: Verification of current velocity from calibrated model results to measurement data..... | 70 |
| Figure 5.16: Validation of water level model results versus field data | 72 |
| Figure 5.17: Validation of current velocity model results versus field data..... | 73 |
| Figure 5.18: Wind rose and class frequency distribution at Java Sea from NCEP wind data 1980 - 2005 | 74 |
| Figure 5.19: Significant Wave Height from the Java Sea Wave Model Result | 74 |
| Figure 5.20: Dean number distributions for the Java Sea..... | 75 |
| Figure 5.21: Numerical grid of Riau Islands model domain | 77 |
| Figure 5.22: Riau Islands flow model results | 79 |
| Figure 5.23: Wind conditions and wave model results for Riau Islands | 79 |
| Figure 5.24: Dean number distributions for the Riau Islands..... | 80 |
| Figure 6.1: General Components of the DSS..... | 82 |
| Figure 6.2: Conceptual model of mariculture site selection..... | 83 |
| Figure 6.3: Minimum Depth Map of Java Sea area | 85 |
| Figure 6.4: Maximum Current Velocity Map of Java Sea area | 85 |
| Figure 6.5: Dissolved Oxygen Map of Java Sea area..... | 86 |
| Figure 6.6: Sediment Map of Java Sea area | 86 |
| Figure 6.7: Coastal Use Map of Java Sea area | 87 |
| Figure 6.8: Java Sea Mariculture Suitability Map based on physical parameters..... | 88 |
| Figure 6.9: Java Sea Mariculture Suitability Map based on chemical parameters..... | 88 |
| Figure 6.10: Java Sea Mariculture Suitability Map based on sediment type | 89 |
| Figure 6.11: Java Sea Mariculture Suitability Map based on coastal use parameters | 90 |
| Figure 6.12: Comprehensive Mariculture Suitability Map for the Java Sea | 91 |
| Figure 6.13: Bathymetry of Riau Islands | 92 |
| Figure 6.14: Maximum Current Velocity Map of Riau Islands | 92 |
| Figure 6.15: Nitrate Concentrations Map of Riau Islands..... | 93 |

| | |
|---|-----|
| Figure 6.16: Sediment Map of Riau Islands | 93 |
| Figure 6.17: Coastal Use Map of Riau Islands | 94 |
| Figure 6.18: Riau Islands Mariculture Suitability Map based on physical parameters | 95 |
| Figure 6.19: Riau Islands Mariculture Suitability Map based on chemical parameters | 95 |
| Figure 6.20: Riau Islands Mariculture Suitability Map based on sediment parameter | 96 |
| Figure 6.21: Riau Islands Mariculture Suitability Map based on coastal use parameters | 97 |
| Figure 6.22: Riau Islands Mariculture Suitability Map | 98 |
| Figure 7.1: Location of the study area and the fish farms | 100 |
| Figure 7.2: Comparison of bathymetry value from DSS input and field measurement | 101 |
| Figure 7.3: Comparison of model and field data for current velocity value from DSS input and field measurement near Pramuka Island | 101 |
| Figure 7.4: Sediment Map of Pramuka Island based on DSS input | 103 |
| Figure 7.5: Final Result of DSS for the Pramuka Island area | 105 |
| Figure 7.6: Current Velocity Validation at Serai Island | 106 |
| Figure 7.7: Sediment Map of Serai Island based on DSS input | 107 |
| Figure 7.8: Serai Island sediment sampling positions and results of grain size analysis results [Niederndorfer, 2006] | 107 |
| Figure 7.9: Final Result of DSS for the Serai Island area | 109 |

List of Tables

| | |
|---|-----|
| Table 2.1: Mariculture site selection parameters | 13 |
| Table 2.2: Recommended limits of heavy metals for fish farming operations | 18 |
| Table 3.1: List of existing mariculture regulations in Indonesia..... | 32 |
| Table 4.1: List of GIS application in mariculture in chronological order | 38 |
| Table 4.2: Selected parameters with their weight and classification..... | 41 |
| Table 4.3: Scales of relative level of importance [modified after Trick, 1996]..... | 42 |
| Table 4.4: Relative importance of parameters for site selection (Comparison matrix)..... | 43 |
| Table 4.5: Normalized comparison matrix and weight for each parameter | 44 |
| Table 5.1: Existing data..... | 54 |
| Table 5.2: Astronomical constituent input for Java Sea Model..... | 61 |
| Table 5.3: Physical and numerical parameters of Java Sea Model | 62 |
| Table 5.4: Comparison of tidal astronomical constituents | 68 |
| Table 5.5: Astronomical constituent input for Riau Islands Model | 77 |
| Table 5.6: Physical and numerical parameters of Riau Islands Model | 78 |
| Table 7.1: Comparison of chemical parameters in Pramuka Island Fish Farm Area | 102 |
| Table 7.2: Recorded sediment parameters [FTZ, 2005]..... | 103 |
| Table 7.3: Comparison of DSS and measurement results for the Pramuka Island fish farm site | 104 |
| Table 7.4: Comparison of chemical parameters in Serai Island Fish Farm Area..... | 106 |
| Table 7.5: Comparison of DSS and measurement results for the Serai Island fish farm site. | 108 |

Chapter 1. Introduction

1.1 Significance and statement of problem

The world's population is increasing faster than the total food fish supply. The statistic of fisheries from FAO (Food and Agriculture Organization) [FAO, 2003] reveals a decrease in capture-fisheries which was to some extent compensated by an increase in aquaculture products. As inland aquaculture is limited by the availability of adequate space, offshore aquaculture, or mariculture, had been introduced as an alternative to aquaculture by utilization of coastal and offshore areas. This business has been intensively developed during the last two decades, since it does not only provide healthy and appetising food, but also creates essential employment opportunities, thus favouring economic and social prosperity.

However, this development has also raised environmental concerns and questions about possible environmental impacts. Intensive fish farming produces considerable amounts of nutrient waste in dissolved and particulate form into the environment through feed wastage, fish excretion and faeces production. The spatial and temporal dimensions of environmental impacts depend on many factors and can be significantly reduced by knowledge-based management practices (e.g. site selection, stock density, feed formulation, etc.). To guarantee appropriate environmental conditions for cultivation of the species in an operational sense (suitability) and also to avoid environmental damage by fish farm emissions (sustainability), the site and species selection should be scientifically assessed before the implementation of fish farming mariculture activities. In this context, holding capacity of fish farm activities in a certain area with respect to environmental sustainability should be determined as well.

The appropriate site selection will thus affect the economic success and sustainability of the fish farm operation. Mariculture site selection involves hydrodynamic as well as water and sediment quality parameters required by sustainable management relative to environmental impacts and optimal production. Furthermore, the conflicts with different forms of coastal utilization (e.g. tourism, industry, fishery, transportation, etc.) have also to be considered.

This dissertation designs and develops a Decision Support System (DSS) as a tool for the decision maker in mariculture and coastal zone management. The DSS is implemented using the Geographical Information System (GIS) because it has the capability to develop, manage, display, and analyse all input parameters both in spatial and textual information. Some parameters from different data sources are used to build the database for DSS.

The DSS is designed for Indonesian coastal waters. Two mariculture sites were selected as case studies. One is located at Seribu Islands, Java Sea and another one at Riau Archipelago. Two different scales of suitability maps were produced for each study area. The first one is covering a regional scale of around 1:1,000,000 and another one a local scale of only three or four islands surrounding the existing fish farm with a scale of 1:25,000. Two intensive measurement campaigns were conducted at both sites in the study areas in order to get information on hydrodynamics, water quality and sediment conditions around the fish farm cages and the adjacent waters.

The hydrodynamic numerical model is developed to simulate hydrodynamic and wave conditions in the study areas. The model results are important to evaluate flow conditions required by the fish farm operation in order to ensure adequate fish growth and to avoid detrimental effects of the fish farm to the water column and sediment. Later on the hydrodynamic model can be coupled to a water quality or sediment transport module to assess the spatial impact of fish farm emissions to the water or sediment quality in the surrounding area.

This study addresses mainly four issues:

1. The appropriate choice of parameters to be included in the mariculture site selection process.
2. The development and application of a numerical model to provide hydrodynamic information required for the DSS.
3. Relationship between the parameters in the determination of the mariculture site.
4. Development of a Decision Support System based on threshold values of the measured and modelled parameters to provide proper answers on the site selection for mariculture.

1.2 Scientific Background

Studies focusing on numerical models and the development of Decision Support Systems for mariculture siting, environmental effects and management of fish farms that have been conducted in the last three decades are reviewed in this section. These former studies are divided into development of numerical models and decision support developments as described in the following sections.

1.2.1 Previous Study of Numerical Models for Fish Farm Application

Starting in the early seventies, Wallis (1974) developed a simple mathematical model to simulate the relation between fish population and fish waste discharge. The model was developed to express the effect of waste discharge on a stable fish population in a randomly varying environment. The conditions for the model were derived analytically. The study can give order of magnitude estimates of population changes resulting from waste discharge.

Krant et al. (1981) presented a mathematical model for temperatures and salinities of mixed seawater fishponds. The model developed based on fundamental energy and mass balance equations using hydrological characteristics and simple weather data. The results indicate that pond temperatures can be accurately estimated if the transfer coefficients are known.

A mathematical model to simulate the material transformation in the ecosystem was also developed by Svirezhev et al. (1983). The model was constructed for a fish breeding carp, silver carp and bighead using ordinary differential equations.

Another study on simulation of physical parameters in the fish farm site was done by Falconer and Cox (1989). A two-dimensional breadth averaged mathematical model to predict the tide-induced vertical current and salinity structure in deep estuarine and coastal waters was introduced. Particular emphasis had been placed on applying the model to Loch Eil in Scotland. Simulations of tide- and wind-induced vertical circulation in Loch Eil were undertaken.

Kishi et al. (1994) built a numerical model to simulate the distribution of deposits from fish aquaculture. The numerical model consists of a current simulation model to calculate tidal and wind-induced currents, a chemical oxygen demand diffusion model to calculate spatial distribution of COD (Chemical Oxygen Demand) using simulated current, a dissolved oxygen diffusion model to calculate the spatial distribution of DO (Dissolved Oxygen), and an accumulation model to calculate the distribution of deposits from fish aquaculture. The model is able to assess the influence of the selection of location or the area of aquaculture rafts on the ecological and/or environmental system. The model is applied to Mikame Bay in Ehime Pref., West Japan as a case study.

The Modelling-Ongrowing Fish Farms–Monitoring (MOM) was introduced by Stigebradt & Aure (1995) as a tool to relate the environmental impact of fish farms to the holding capacity of a site, the concept of the modelling lately described in Ervik et al. (1997). The holding capacity is defined as the sediment ability to receive organic effluents without causing the benthic impact to exceed a predefined level. MOM system consist of three integrated parts, which are environmental quality standards, a standard monitoring program for checking the environmental conditions on a site according to environmental quality standards, and a mathematical model for predicting the expected environmental impact in relation to farm specifications and information on the hydrography and topography of the site. The mathematical model computes maximum fish production under the prerequisite that acceptable living conditions for benthic animals at the site have to be maintained.

Environmental impact assessments by numerical modelling were also done by Wu (1995). He found in general, some 85% of phosphorus, 80–88% of carbon and 52–95% of nitrogen input into a marine fish culture system through feed wastage, fish excretion, faeces production and respiration may be lost into the environment. They can be accumulated in the bottom sediments and the significant impact is normally confined to within 1 km of the farm. The major impact is on the sea bottom, where high sediment oxygen demand, anoxic sediments, production of toxic gases and a decrease in benthic diversity may result. Marine fish culture can be a sustainable development, provided pollution loadings generated by fish farms are kept well below the carrying capacity of the water body. An example of the application of computer modelling in mariculture management is demonstrated.

Wu et al. (1999) developed two deterministic models to simulate hydrographic and water quality conditions within a sub-tropical marine fish culture site, where trash fish is used as food. A two-dimensional, two-layer hydrodynamic model of tidal flows and salt transport calculated the water level, velocity and salinity in each grid cell of 50 m² in each layer within the culture area. Results from this flow model were used as input for a three-dimensional

water quality model, which was run to simulate water quality due to specified pollutant loadings from the marine fish culture operations. Simulated output from the models agreed reasonably well with observed field data, except for dissolved oxygen and nitrate levels in surface waters. This could be due to a conservative estimation of re-aeration rates in the model system. The models were applied to sub-tropical waters of Hong Kong using varying fish stock and pollutant loadings. It was shown that impacts of fish culture activities on water quality at the test culture site were localized due to strong advection by tidal residual flows.

Extensive numerical drogue tracking experiments using 3D hydrodynamic models in 4 and 10 layers had been performed by Lee and Qu (2001). The models were used to study the role of hydrodynamics in the massive red tide and fish kill in Hong Kong waters in March-April 1998. It was found that the massive red tide and fish kill in east Lamma Island is mainly caused by the change of wind direction, strong wind, and strongly diurnal tidal conditions. While useful insights have been gained, many important factors such as turbulent diffusion, algal growth and sinking, and vertical migration should be studied in future work.

Cromey et al. (2002) developed a computer-tracking model, so-called DEPOMOD to enable better predictive capability of the impact of large marine cage fish farms on the benthos and improved objectivity in the regulatory decision-making process. The model predicts the solids accumulation on the seabed arising from a fish farm and associated changes in the benthic faunal community. The model consists of grid generation, particle tracking and resuspension modules. The grid generation module allows the user to set up a grid containing information on depth, cage and sampling station positions for the area of interest. Given the information on wastage rates of fish food and faeces and hydrodynamics of the area, the initial deposition of particles on the seabed can then be predicted with the particle tracking model. The resuspension model then redistributes particles according to near-bed current flow fields to predict the net solids accumulated on the seabed within the grid area. From quantitative relationships between benthic community indicators and solids accumulation, predictions of the level of benthic community impact can then be made. DEPOMOD may be used for assessing the potential impact of a farm throughout a growing cycle, or if the biomass concentration is increased. It may also be used in the site selection process of a new farm to investigate the proposed farm position and biomass levels. Prediction of the dispersion of particulates during use of in-feed medicines may also be undertaken.

A simple method to determine the carrying capacity of a fish farm has been developed by Lee et al. (2003) using three-dimensional (3D) hydrodynamic modelling and its effective coupling with a diagenetic water quality model. A systematic methodology using numerical tracer experiments has been developed to compute the tidal flushing in a fish farm. The flushing time is determined from the results of a numerical tracer experiment using robust 3D hydrodynamic and mass transport models. Unit tracer concentrations are initially prescribed inside the region of interest and zero elsewhere; the subsequent mass transport and the mass removal processes are then tracked. The fish farms are usually situated in well-sheltered shallow embayment and may not be connected directly to the open water. It is found that it is necessary to define both "local" and "system-wide" flushing times to represent the effectiveness of the mass exchange with the surrounding water body and the open sea respectively. A diagenetic water quality model simulating the sediment-water-pollutant interaction is employed to address the response of the water column and the

benthic layer to pollution discharges. With the flushing rate reliably computed, the carrying capacity of the fish farm can be determined in terms of key water quality parameters: chlorophyll-*a*, dissolved oxygen, organic nitrogen and potential lowest dissolved oxygen level on a day of negligible photosynthetic production. The predictions are well supported by field data.

In order to simulate the dispersion of pollutants released from a marine fish farm in the Ligurian Sea (Western Mediterranean), Doglioli et al. (2004) used the Lagrangian particle model LAMP3D and the numerical hydrodynamic model POM. Dispersion patterns of nitrogen, phosphorus and organic carbon were estimated using a three-dimensional mesoscale grid and compared to in situ experimental data. In the numerical simulations, the dispersion of different aquaculture wastes (dissolved nutrients, fecal matter and feed wastes) was evaluated by changing the rates of particles settling and their condition of release (continuous or periodical). Results of the simulations clearly showed that dissolved particles tend to spread rapidly and undergo rapid dilution depending on dominant wind and surface current direction. In contrast, settling particles remain mainly confined in the fish farm area and readily sink. Predicted concentration of wastes was low in both the water column and sediment compartments and never exceeded the threshold of environmental crises.

Alver et al. (2004) derived a model to describe the short-term spatial distribution of feed pellets in a cage of Atlantic salmon (*Salmo salar* L.), under the influence of current, gravity and the presence of fish. The fish are represented with appetite depending on stomach content, and with feeding rates affected by their size distribution. Feed distribution, feed intake by various size classes of the fish population, and feed waste can be simulated during single meals or longer feeding periods under various physical conditions, with different pellet sizes, feeding frequencies and pellet release rates, and different fish size distributions. Fish motion is not explicitly modelled. The model is formulated with Atlantic salmon as the model species, but can be adapted to other species that feed on sinking feed particles in the water column. The model has been compared to measured data with respect to feed intake and wastage rates, showing good agreement. Average feeding depth during meals is part of the model output, and simulations of the model have indicated that this could be a key factor in detecting the reduction of the fish's appetite and deciding when feeding should be reduced or stopped in order to minimize feed waste.

Numerical simulation and design of an inflatable open-ocean-aquaculture cage is presented in Suhey et al. (2005) using nonlinear finite element analysis of membrane structures. Numerical instability caused by the tension-only membrane has been removed by adding an artificial shell with small stiffness. The material properties of a fabric material are obtained from tensile tests in both hoop and longitudinal directions, assuming the material is anisotropic. Wrinkling, defined as an onset of compressive stress, is monitored as design criteria. The finite element model is validated using a modified beam theory for the inflatable structure by comparing the maximum deflection and stress. Good agreement is observed between the numerical and theoretical results. A full-scale cage model is created using membrane, shell, and string elements to test the stiffness and integrity of the system. The feasibility study indicates that the inflated structure has sufficient stiffness to be used as the structural support within a fish cage. Based on the parameter study, several designs are suggested.

No literature on the development of numerical models for mariculture or aquaculture applications in Indonesian waters was found.

1.2.2 Previous Study of Development of DSS for Mariculture

Development of a Decision Support System using GIS for mariculture was initially done by Kapetsky (1989) in Johor, Malaysia as the results from FAO Technical Cooperation Programme Project TCP/MAL/6754. The main objective of the project was to locate and quantify opportunities for the further development of shrimp farming ponds and fish culture in cages. Criteria of location and rating systems were established by considering species physiology and culture technologies in relation to the local physical and chemical environments and infrastructures.

Silvert (1994a) and Silvert (1994b) proposed a DSS for finfish aquaculture site licensing. The DSS was developed to incorporate several simplified version models used to assess the environmental impacts of aquaculture as they are becoming increasingly numerous and complicated. Therefore the DSS is very useful as a tool for communicating scientific advice to managers, by specifically addressing the use of models in evaluation of environmental impacts in order to assess whether the licensing of finfish aquaculture is likely to lead to degradation of natural marine habitat.

A DSS called POND was developed by Nath et al. (1996) which enables definition of an entire pond mariculture facility (in terms of location, fish populations, and species). The system includes several parameters such as source water, fish lots, species, sites, soils, fertilizers, lime materials, feed, economics, weather and simulation parameters in its databases. The DSS was applied for species/facility customization, economic optimization, estimation of feed requirements, as well as water and sediment quality management.

The criteria of parameters included in the site selection are varied in fish species, climate, location and farming method as can be read in Ross et al. (1993). The parameters of bathymetry, exposure, current intensity and salinity were included in the determination of mariculture site location. The objectives of the work were to examine GIS as a tool for assessing the potential of salmonid cage mariculture in a small bay in West Coast of Scotland and develop a general methodology for spatial analysis of coastal cage mariculture potential. The results presents only 6% of the areal expanse of the bay would be suitable for cage culture as the analysis was based on the 'worst case modelling' in the wave height.

Aguilar-Manjarrez & Ross (1995) developed a detailed GIS that can serve as an analytical and predictive tool to guide shrimp aquaculture development at a state-level in Mexico. Water resources, land use, environmental characteristics, protected area, pollution sources, as well as urban development were included in the analysis.

British Columbia Aquaculture System in LUCO (1998) used some biophysical criteria to evaluate the capability of waterways to support salmonid cage culture. The criteria were temperature, dissolved oxygen, salinity, plankton, pollution, currents, water depth, bottom slope, substrate, hydrology, predators, marine plants and winds.

Shepherd (2001) assessed the potential to develop land-based mariculture in Western Australia. The assessment has used a comprehensive GIS. The GIS analysis was carried-out in three steps, namely, collation and preparation of digital data for analysis, GIS analysis of

relationships between land parcels and site selection features, and finally comparison with contour data/terrain models and coastline features of parcels identified through the previous step to identify suitable sites for production. Site suitability was analyzed based on several parameters such as distance from low water mark, distance from major population centre, distance from river mouth, proximity to road and power, elevation, land tenure, soil type, as well as freshwater availability.

Hargrave (2002) developed a DSS to assess far- and near-field variables potentially affected by marine finfish aquaculture. The DSS consists of twenty questions that produce positive to negative scores for ecosystem-level (far-field) and site-specific (near-field) variables based on pre-determined or proposed qualitative criteria and known or proposed threshold values for variables. DSS was tested using data from salmon farm license applications in eastern Canada.

The advantage of GIS for mariculture was also demonstrated by Pérez et al. (2002). The paper presents an improved version of an existing predictive particulate waste distribution model for farmed Atlantic salmon using GIS combined with a spreadsheet. Output from the model is in the form of a contour plot of organic carbon, showing distribution of the particulate organic carbon material as deposited on the seabed. The model was validated using measured data and presented a significant correlation between predicted and actual sediment loading.

Pérez et al. (2003a, 2003b and 2003c) have applied the GIS for mariculture management in Tenerife (Canary Islands). In Pérez et al. (2003a), a GIS-based model was developed for integrating and developing marine fish cages within a touristic area. Decision criteria were grouped into three sub models (distance to beaches, nautical sports and view shed), which were combined to generate a final output showing the most suitable areas for cage culture development in coexistence with tourism. Pérez et al. (2003b) presents a novel methodology for wave climate characterisation in offshore fish cage site selection, based on a case study for siting offshore sea bass and sea bream cages. The mid-term statistic was used to identify prevailing wave heights and the long-term statistic was used to identify the highest likely waves over a 15-year period. GIS was used to create a suitability map for the selected three cage systems. Pérez et al. (2003c) used GIS to develop a predictive modelling and analysis to identify water quality requirements for marine fish cage site selection. The water quality variables were temperature, turbidity (runoff soil erosion and sewage), disease stress (sewage) and possibility of waste feedback from fish-cages. Variables were grouped in a logical model and combined to generate outputs showing the most suitable areas for siting cage culture.

Several DSS and GIS research initiatives have taken place in mariculture management applied in Indonesian waters. Populus et al. (1995) applied remote sensing satellite imagery to evaluate the water quality in Indonesian seas (esp. in Java Sea) and its relation to shrimp culture.

Darmawan et al. (1998), Santoso & Nursetiarso (1999) and Riyadi & Adibroto (1999) created general concepts of using SEAWATCH buoy data (wave, current velocity, meteorology, salinity and temperature) to determine and evaluate suitable areas in Indonesian waters for mariculture. SEAWATCH Indonesia is a joint project between Indonesia and Norway. The short-term objective of the project was to collect relevant environmental information through

buoys and sensors, operated in certain areas of the Indonesian waters, while the long-term was to improve the knowledge of sustainable marine environment. Unfortunately, due to several reasons, only 10 buoys operated and the project was terminated, thus leading to very little marine environmental data.

Riqqi (2001) applied GIS technology to determine site location for pond aquaculture in the coastal area of Kabupaten Serang, West Java. The ecosystem model of GIS consists of land use information along watershed and coastal areas. The information was analyzed based on suitability and sustainability criteria. The results indicate that nearly the entire coastal area in Kabupaten Serang is suitable for aquaculture. However, based on sustainability analysis, only 19% of the area is considered environmentally sustainable for aquaculture industry.

This dissertation will focus on the development of a Decision Support System for anchored floating cage mariculture site selection in Indonesian coastal waters based on the results of field measurement and numerical modelling of hydrodynamics for two locations serving as case studies, Seribu Islands and Riau Archipelago.

1.3 Objectives

The objectives, which will be accomplished by this study, are as follows:

1. To propose parameters for site selection of finfish anchored floating cage mariculture in Indonesian waters
2. To develop a hydrodynamic numerical model for both study areas
3. To develop a Decision Support System using GIS software as a tool, based on the results of field measurement and numerical modelling of hydrodynamics

1.4 Outline

This dissertation consists of eight chapters. In chapter 2, the proposed criteria for mariculture site selection based on the literature review are discussed. Chapter 3 describes mariculture conditions and their specific problems in Indonesia. The DSS development as one of the strategies for mariculture site selection problems is described in Chapter 4. Description of the study area, data sources and development of numerical models for the study areas are explained in Chapter 5. Chapter 6 describes the DSS results for both study areas. Validation and application of the DSS on a smaller scale in the study areas are described in detail in Chapter 7. Finally, in Chapter 8 the results of this research are summarized and complemented by conclusions and recommendations for future developments in this field of study.

Chapter 2. Environmental Sustainability and Site Selection of Mariculture

The rapid expansion and development of marine cage culture around the world has increased the number of environmental concerns and questions about possible ecological impacts. In addition, the increasing number of marine farms threatens to cause competition between farmers and other actual and potential users of coastal space. Therefore, to ensure sustainable development of this industry, there is a great need to allocate suitable locations (site selection) to resolve competing demands for coastal space and to avoid undesirable impact on the marine environment, as well as ensuring the profitability of the operation. This chapter describes the development of mariculture, sustainability concept of mariculture development and parameters used for determination of suitable site location for mariculture.

2.1 Aquaculture and Mariculture

Aquaculture is a form of bioproduction that involves the propagation, cultivation and marketing of aquatic animals and plants in a human controlled environment. The internet-based encyclopaedia (Wikipedia) considers mariculture as 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.

World fish farming was first practiced as long ago as 2000 B.C. in China as ornamental fishponds appear in paintings from ancient Egypt. European aquaculture began sometime in the Middle Ages and transformed the *art* of Asian aquaculture into a science that studied spawning, pathology and food webs. One of the most significant developments was the invention of culture methods for trout, which were being introduced into natural waters by the mid-1800s [Swann, 1992].

The mariculture business has tremendously developed in the last two-decades, since it does not only provide high quality proteins, but also creates essential employment opportunities, thus favouring economic and social prosperity. Global aquaculture production is growing at more than 10% a year, compared to 3% for terrestrial livestock and 1.5% for capture fisheries [GESAMP, 2001]. This mariculture development has also augmented environmental

concerns and questions about environmental impacts. Intensive fish farming by its nature grows many fish in a confined area that produces considerable amounts of nutrient waste in dissolved form (i.e. ammonia and urea) and particulate form (i.e. uneaten food and faeces) [Bergheim & Asgard, 1996]. In general, some 85% of phosphorus, 80-88% of carbon and 52-95% of nitrogen input as feed into a marine fish culture system may be lost into the environment through feed wastage, fish excretion, faeces production and respiration [Wu, 1995]. Figure 2.1 schematically shows paths of waste released from a fish cage. It is obvious that mariculture operations may have the potential for detrimental effects threatening the marine environment. Thus, before a new farm is established or an increase in production of an existing farm is permitted, the potential impact of the farm on the environment should be assessed.

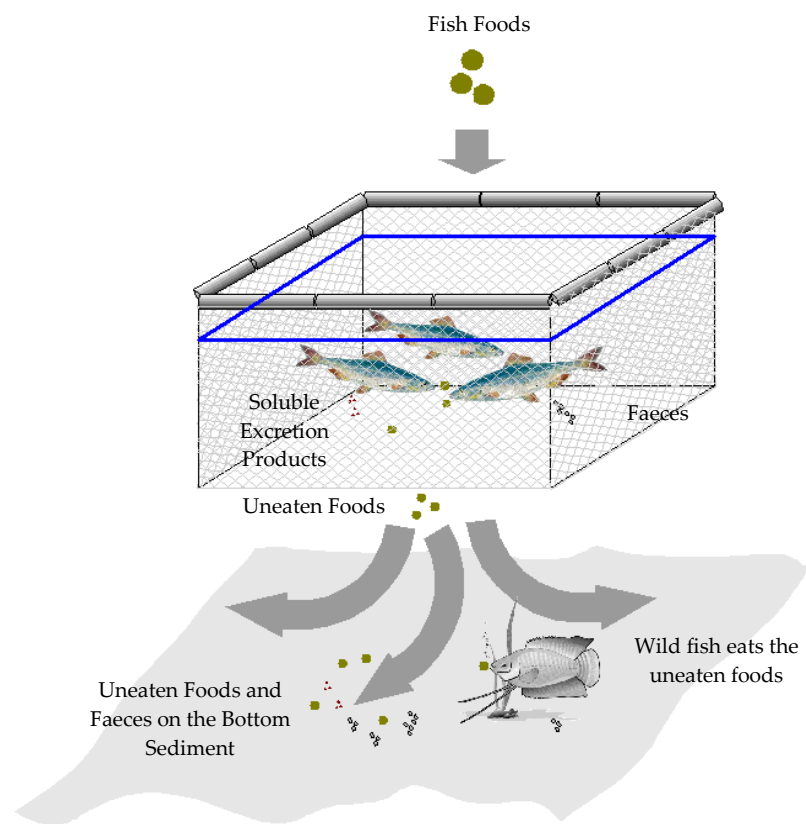


Figure 2.1: Fish farming wastes

2.2 Sustainable Development of Mariculture

One of the most widely quoted and supported definitions for sustainable development is:

Development that meets the needs of the present without compromising the ability of future generations to meet their own need [WCED, 1987]

Specific to agriculture and fisheries, FAO has defined sustainability as:

The management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable [FAO Fisheries Department, 1997]

Planning for sustainable development and for improved natural resource management implies a thorough examination of different development options in terms of their financial, economic, social and environmental costs and benefits through time and space. Short-term economic perspectives without sustainability consideration may tend to dominate development decisions to the detriment of environmental and social objectives. For coastal aquaculture and many activities in the coastal zone, there is a strong need for finding strategic answers rather than for those that are reactive and uncoordinated.

The problems associated with coastal aquaculture development may be grouped into three broad categories [GESAMP, 2001]:

1. unsuccessful development, where the potential for development is not realised, especially among the poorer sectors of society.
2. the vulnerability of aquaculture to poor water quality and aquatic pollution, caused by industrial domestic, agricultural and aquacultural wastes.
3. over-rapid development, where the undoubted successes of the sector have been tarnished by environmental and social problems, disease and in some cases, marketing problems.

The environmental impact of mariculture depends very much on species, culture method, stocking density, feed type, hydrography of the site, husbandry practices and the sensitivity of the specific coastal environment that may be impacted. The effects can be significantly reduced by careful site selection, control stock density, improved feed formulation and integrated culture (with macro-algae, filter-feeders and deposit-feeders) [Wu, 1995]. Therefore to assure appropriate environmental conditions for the species to be cultured in, in an operational sense (suitability) and also to avoid the environmental damage (sustainability), the site and species selection should be assessed before the mariculture activities begin.

In order to ensure that culture activities are environmentally sustainable, before the mariculture activity is begun, environmental monitoring and forecasting must be carried out by sampling and analysing data of physical parameters (e.g. current, wave, tide and wind), chemical parameters (e.g. salinity, oxygen saturation, temperature, and nutrients) and biological parameters (e.g. plankton and benthos). If the data sets do not suffice, additional

field measurements must be done. Since field measurements covering large areas will be time and cost consuming, the most effective tools to assess the environmental effects and sustainability of mariculture are numerical models, due to their capabilities of spatial and temporal coverage. Numerical models can be used to simulate the dispersion of different pollutants (dissolved nutrients, faecal pellets, uneaten food, etc), different conditions of release (continuous or periodical) and/or different locations of sources (fish cage location) and their impacts on the environment at the mariculture site.

2.3 Parameters for Mariculture Site Selection

Proper site selection for mariculture significantly determines construction and operating costs, growth and survival rate of the cultured fish, and the period of operation of the cages. There are some guidelines for defining suitable site location of the fish farm based on several parameters. Obviously the site selection criteria are different for different type of culture structure and cultured species. TCMP (2001) distinguish between three types of mariculture:

1. *Hatchery*

The culture is aimed to supply juveniles or seed of any species. The culture is started from holding or rearing an adequate broodstock; spawning or stripping and fertilization of ova; incubation of fertilized ova; and rearing of larvae to required stage (i.e. fingerling) for transfer to nurseries or other culture facilities.

In general, an ideal location for a hatchery requires optimum water quality, water quantity, accessibility, appropriate topography, technology and adherence to environmental standards. Details of site selection for hatchery culture can be found in Sim et al. (2005).

2. *Earthen pond culture*

This type of culture can be established in agricultural and unarable land, saltflats, and mangrove zones. This can be done without difficulty in areas where the land is more or less flat or has a slight slope and the tidal range is adequate.

Soil quality, water quality and quantity, socio-economics and environmental factors are the parameters that should be taken into account for the site selection of the pond culture. More comprehensive details of site selection for pond culture in tropical countries can be found in STREAM (2005).

3. *Open water culture system*

Open water culture includes mollusc culture in shallow salt-water areas, seaweed farming in coastal seas, pen and cage culture in seawater bodies.

The fish-farmers should consider water quality, substrate type, primary productivity, hydrography, availability of seeds, degree of exposure and socio-economic factors to select an appropriate location of the culture. One advantage of floating net cage is its capability to be moved and re-sited when the conditions become unfavourable, but still it is important to carefully select a suitable site for farming at the planning stage.

This study will focus on open water culture systems in suspended net cages.

The selection of caged fish farming sites has to be based on several parameters, which are related to the suitability and sustainability analysis. Parameters for suitability analysis are related to the conditions required for the successful cultivation of the farmed fish. Sustainability analysis parameters are associated to the operation of the fish farm in a way that the buffering capacity of the ecosystem with respect to emission is not exceeded. Environmental degradation will take place if the ecosystem cannot cope with pollutant load (The idea of sustainability implies that a source should be used in that way, that it is not depleted so that future generation may still have advantage or profit of this resource). Table 2.1 presents some important parameters for the mariculture site selection.

Table 2.1: Mariculture site selection parameters

| Criteria | Parameter |
|------------------|---|
| 1. Physical | <ul style="list-style-type: none"> - Exposure due to wind and wave - Water Depth - Current velocity - Water temperature - Salinity |
| 2. Chemical | <ul style="list-style-type: none"> - Dissolved oxygen - Ammonium - Hydrogen ion index (pH) - Nitrate and nitrite - Phosphate - Organic load - Heavy metals |
| 3. Sediment | <ul style="list-style-type: none"> - Bottom condition - Turbidity |
| 4. Biological | <ul style="list-style-type: none"> - Fouling organism - Phytoplankton - Disease and predators |
| 5. Socioeconomic | <ul style="list-style-type: none"> - Accessibility - Social problem and conflict with other coastal uses - Legal aspects |

In this study, the parameters were analysed mainly for finfish species; for other species the similar parameters can be used with some modifications. For example, classification of the limitation category of water quality parameters needs to be changed for other species based on their physiology.

2.3.1 Physical Properties

Exposure

In order to realize a safe operation and to ensure the stability of the cage architecture, the cage clusters should be sited in sheltered areas protected from strong winds and waves. Strong winds will easily destroy any structure above the water while waves will bear on any object on and under the water. According to FAO (1989) criteria, the wind velocities should

in general not exceed 10 knots for floating cages and the wave heights should preferably be less than 1 m.

Another classification was made by Ross et al. (1993), which identifies an area with wave heights less than 0.6 meters as a good site location and an area with wave heights of 0.6 meters or more is fair for site location. Pérez et al. (2003b) classified 8 classes of wave heights for 3 types of cage structures. For the rectangular cage (Ocean Spar®) the most suitable location is the area with the wave height 0 – 0.89 meters and the least suitable site with the wave height more than 1.76 meters. In Caine (1987), the area with wave heights less than 0.6 m is classified as a good location, wave height 0.6 – 1.0 m is classified as medium and wave heights more than 1.2 meters is classified as a poor location.

Waves are also responsible for entraining seabed sediment which play a significant role in the fish farm by lifting up the accumulation of uneaten food and faeces under the cage. Dean (1973) expressed one parameter called *Dean number* to estimate the erosion potential in a beach with certain grain distribution and its relationship to the wave characteristics. The parameter can be calculated by equation 2.1.

$$n_0 = \frac{H_s}{T_s \cdot w_s} \quad \dots(2.1)$$

where : H_s = Significant wave height
 T_s = Significant wave period
 w_s = Falling velocity for the mean particle size

Based on this parameter, from 99 experiments in different beaches, Kraus et al. (1991) concluded the relationship between Dean number and erosion as:

$n_0 > 4.0$ → highly probable erosion
 $3.2 \leq n_0 \leq 4.0$ → probable erosion
 $2.4 \leq n_0 < 3.2$ → probable accretion
 $n_0 < 2.4$ → highly probable accretion

Depth

In order to facilitate water flow below the floating net cages, maximize water exchange, avoid accumulation of uneaten food, faeces and debris in the net bottom, avoid oxygen depletion, disease infection, and build up of some noxious gases such as H₂S generated by the anaerobic decomposition of the deposited wastes at the sea bottom, it is necessary to allow sufficient depth under the cages. The clearance for a floating cage should be at least 2 – 3 m at the lowest low water of spring tide [FAO, 1989]. Typical net cage dimensions are around 2m x 2m, 3m x 3m or 5m x 5m, with a depth of 2 – 3 m [BPPT, 2001]. Therefore it is recommended that the depth of the lowest low water from surface must be more than 5 meters. According to Ross et al. (1993), a lowest depth from the surface of less than 6 meters is not acceptable.

By contrast, there is also a limit for maximum depth since the deeper the water, the higher the investment and maintenance costs due to the need of longer anchoring ropes and heavier anchor blocks. FAO (1989) recommends that the maximum depth for floating cage culture be preferably less than 20 m.

Current Velocity

There are two main types of currents in the sea, tidal currents and wave-induced currents. The tidal currents depend on the tidal range, whereas wave-induced currents increase with the wavelengths which in turn depend on the wind and fetch conditions.

A stronger current generally indicates better conditions for water exchange and enables higher stocking density of fish in the cages. The current will bring fresh oxygenated water to and remove waste from the cage. On the other hand, if the current is too strong, it will lead to excessive strain on the cage anchoring system or fixed poles, distortion of the nets and cage structures, slow growth of fish caused by too much expense of energy in swimming against the current and food losses. The fish stress will occur when the fish are unable to swim against the current in order to avoid accumulation on one side of the net. As a consequence, it is necessary to reduce the stocking density of fish.

The direction of the flow is important for positioning of the cages. To minimize the strain on the anchoring system resulting from strong currents, the cage should be in a direction parallel to the current. If the current is weak, the cage should be positioned against the current for a better flow.

BPPT (2001) suggests velocity values of 0.2 – 0.5 m/s as the best condition for fish farming. The maximum current velocity should never be less than 0.05 m/s and never be higher than 1 m/s [FAO, 1989]. Ross et al. (1993) combined current velocities with the wave height for classification of site suitability. According to the authors the most suitable location is the area with a wave height less than 0.6 m and velocities less than 0.5 m/s. According to Caine (1987), the best location for mariculture is the area with velocities between 0.1 – 0.5 m/s, velocities between 0.5 – 1 m/s reflect only fair conditions, whereas areas with velocities between 1 – 2 m/s are poorly suited. Areas with velocities beyond these ranges are unacceptable for mariculture.

Water Temperature

The water temperature will affect fish metabolism and activity and as a consequence, oxygen consumption, ammonia and carbon dioxide production, feeding rate, food conversion, as well as fish growth [FAO, 1989]. Moreover it determines the maximum concentration of oxygen dissolved in the water. The water temperature normally changes with the seasons, solar radiation, river run-off, and wind.

For most tropical species, FAO (1989) recommends an optimum water temperature of 27 – 31°C. Although some fish can survive out of the temperature range, growth is usually inhibited. For Indonesian waters, DITJEN PERIKANAN (1982) proposed an optimum temperature range of 25 – 32°C.

Salinity

Water salinity plays an important role in osmotic pressure, which, in turn, greatly affects the ion balance of fish. For most marine tropical species, the optimal salinity is that of the seawater; they cannot tolerate lower salinities of 10-15 psu [FAO, 1989]. Although fish usually have a certain range of salinity tolerance, it would be better for fish growth if the salinity of water at the selected site is optimal to the fish species selected. For example, the optimal salinity is 27 - 32 psu for grouper and sea bass, and 32 - 33 psu for red-snapper [BPPT, 2001]. A value between 18 - 32 psu with ± 10 psu variation is a water quality standard for mariculture in Indonesia [KLH, 1984]

2.3.2 Chemical Properties

Dissolved Oxygen

The dissolved oxygen problem in net cage culture is not as serious as in pond culture due to current movements. However, the oxygen level in the cage will decrease if the site is located in shallow areas with high concentrations of zoo benthic organisms and deposited waste.

Oxygen consumption in fish is species-specific. In general, fish can be divided into demersal (living on the sea floor or just above it) and pelagic (swimming in the free water column) species. FAO (1989) suggests a minimum oxygen concentration of 4 mg/l for pelagic fish and 3 mg/l for demersal species. DITJEN PERIKANAN (1982) proposed a minimum 4 mg/l oxygen concentration for any mariculture species, while the Indonesian Ministry of the Environment suggests a minimum value of 5 mg/l [KLH, 1984].

Ammonium

The concentration of ammonium in the fish cage water is very important since high ammonium levels may lead to mortality of the fish. The concentration of the ammonium must be less than 0.5 mg/l [FAO, 1989] since higher concentrations may lead to death of the fish. The ammonium level in the fish cage water is usually caused by the decomposition of uneaten food at the seafloor and fish excretion. In the coastal area, additional ammonium sources may come from sewage discharge and industrial pollution. According to Karthik et al. (2005), suitable ammonium levels for mariculture are always less than 1 mg/l. Water quality standards for mariculture in Indonesia claim less than 0.3 mg/l [KLH, 1984].

Hydrogen Ion Index (pH)

The pH is important because it affects the toxicity of several common pollutants such as ammonia cyanide, and heavy metals like aluminium. Extreme values of pH can directly damage gill surfaces, leading to death [FAO, 1989]. Figure 2.2 shows the pH limits of physiological activities in fish. According to the figure, the optimum value of pH for cage culture is around 7 - 8.5. It also agrees with the mariculture water quality standards in Indonesia, which recommend values ranging between 6.5 and 8.5 [KLH, 1984].

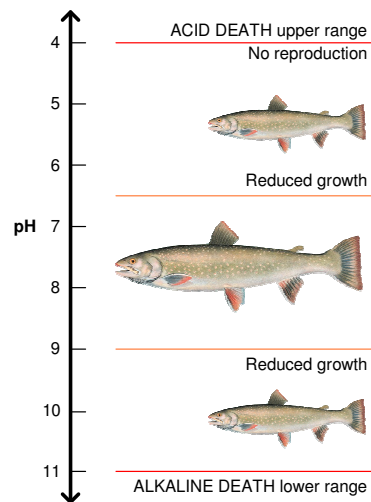


Figure 2.2: pH limits of physiological activities in marine environment [Boyd, 1979]

Nitrate and Nitrite

High amounts of nitrite ($\text{NO}_2\text{-N}$) in sea water may be toxic to fish due to oxidation of iron in haemoglobin from the ferrous to the ferric state [Tiensongrusmee, 1986]. This causes hypoxia in fish because the haemoglobin molecule cannot bind with oxygen. A same, but more moderate, effect is due to an over concentration of nitrate ($\text{NO}_3\text{-N}$). FAO (1989) suggests nitrite levels up to 4 mg/l while nitrate levels should be below 200 mg/l.

Phosphate

As it is the case for ammonium, nitrate and nitrite, an excessive level of phosphate in sea water may lead to phytoplankton mass development, which upon degradation, may cause a depletion of oxygen. According to FAO (1989) maximum phosphate levels should be less than 70 mg/l.

Organic Load

Organic loads in the fish cage water can originate from several sources such as phytoplankton blooms, uneaten food and fish waste in the cage, sewage and animal waste discharges, as well as industrial effluents. High organic loads may cause bacterial infections in fish and lead to oxygen deficiency of the water. The organic load in water is usually measured by the Chemical Oxygen Demand (COD). Chou (1988) recommends COD values in fish farm waters to be less than 3 mg/l. KLH (1984) tolerates a value of less than 11 mg/l for mariculture water quality standards in Indonesia.

Heavy Metals

Heavy metals that are accumulated in cultured fish can be toxic to humans when ingested. Sources of heavy metals are usually industrial discharges. Therefore it is necessary to put the fish cages far away from any industrial area. Table 2.2 shows threshold concentrations of several heavy metals in fish farming.

Table 2.2: Recommended limits of heavy metals for fish farming operations

| Type | FAO, 1989 Limitation (mg/l) | KLH, 1984 Limitation (mg/l) |
|----------------|--------------------------------|--------------------------------|
| Manganese (Mn) | 1.0 | - |
| Iron (Fe) | 1.0 | - |
| Chromium (Cr) | 1.0 | 0.01 |
| Tin (Sn) | 1.0 | - |
| Lead (Pb) | 0.1 | 0.01 |
| Nickel (Ni) | 0.1 | 0.002 |
| Zinc (Zn) | 0.1 | - |
| Aluminium (Al) | 0.1 | - |
| Copper (Cu) | 0.01 | - |
| Cadmium (Cd) | 0.03 | 0.01 |
| Mercury (Hg) | 0.004 | 0.003 |

Other Pollutants

Other pollutants such as detergents, cyanide, sulphide, chlorine, formaldehydes, phenols, oil, etc may also have a negative impact on fish farm operations. Agricultural wastes, other than animal waste, such as insecticides and herbicides may spill into the culture site and may accumulate in fish or cause their mortality. Another problem may result from oil spills from tankers or rigs. Figure 2.3 shows the various pollution sources that may occur in coastal waters as a result of different activities in the coastal area. The main solution to avoid these problems is to put the fish farm area as far as possible from industrial, sewage and intensively used agricultural areas. According to Tiensoongrasmee (1986) a measure of the degree of degradable organics of pollution is the Biological Oxygen Demand (BOD) in the water, which should not exceed 5 mg/l in a 5 days period.

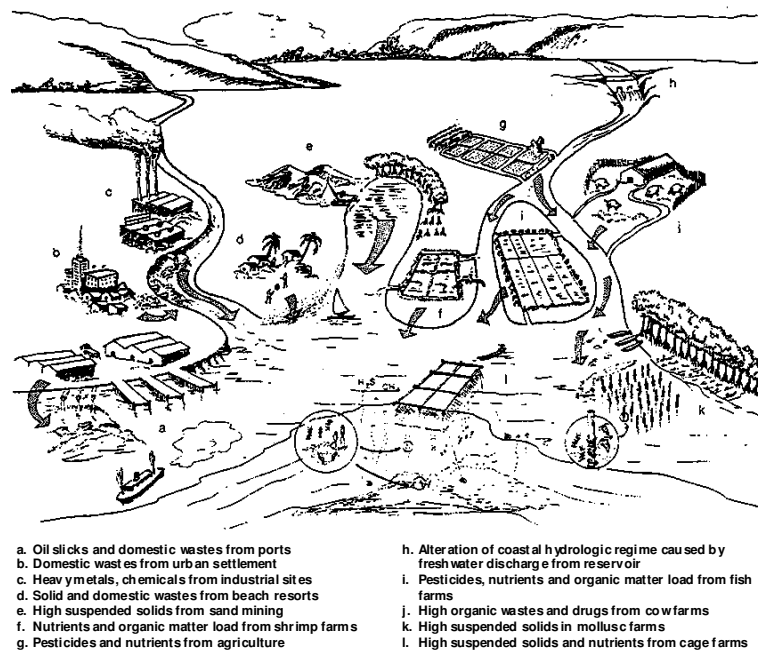


Figure 2.3: Various possible pollution sources in coastal area [Chua et al., 1989]

2.3.3 Sediment Properties

Bottom Conditions

The ideal site for cage culture should have a firm substrate, with a combination of fine gravel, sand and clay [FAO, 1989]. The type of substrate directly influences the design of the cage. Floating cages over rocky substrate require more expensive anchoring blocks, but often have better water exchange rates, whereas on muddy substrates the installation of floating cages is easier and cheaper but they are not suitable for a high stocking density since usually low water exchange rates prevail.

There is also a correlation between the degree of bottom slope under the cages and the sediment deterioration rate. Positioning of floating cages in the steeper areas is preferred due to a higher removal rate of build-up waste through flushing at the bottom.

Turbidity

Coastal areas with high turbidity levels, normally caused by freshwater run-off during rainy season, are not suitable for cage culture. The run-off brings particulate organic and inorganic materials as well as heavy metals into suspension. High concentrations of suspended sediment in the water will also lead to high deposition on the nets. The sediments on the net act as a substrate for the growth of fouling organisms which prevent proper water circulation. In addition, suspended sediments tend to clog fish gills, which may lead to mortality form asphyxiation or cause gill epithelial tissues to proliferate and thicken [FAO, 1989]. Fish growth will also be reduced due to bad visibility of fish with respect to food items.

According to FAO (1989), the suspended solid concentrations should not exceed 10 mg/l in the weak current area, but can be up to 100 mg/l in the strong current area. Based on water quality standards proposed for Indonesian coastal waters [KLH,1984], the turbidity in the water column should be less than 30 mg/l.

2.3.4 Biological Properties

Fouling Organism

Lovegrove (1979) identified about 200 species of marine fouling organisms in the world. Cheah & Chua (1979) found more than 34 species of algae (cyanophytes, rhodophytes, chlorophytes) coelenterates, polyzoans, annelids, arthropods, mollusc and simple chordates clinging to netcages after immersion for only two months. Colonization of fouling organism is primarily caused by silt particles deposited on the net which serve as substrate for fouling organisms. Silt particles can constitute more than 50% of total fouling weight (Chou, 1988). Clogging of the net by fouling organisms can effect the water flow and thus decrease the rate of oxygen supply and the removal of fish waste in the net cage. Fouling organisms can also effect the cage structure and anchoring systems since they will increase the surface net area and causes deformation of the cage in strong currents and an increase in stress.

The intensity of fouling differs according to environmental conditions and materials. In general high rates of fouling will prevail in areas with low velocities, high temperatures, high turbidity and high salinity [FAO, 1989]. In areas with high rates, netcages should be

cleaned and washed more often to facilitate water exchange. In order to minimize the maintenance costs, the fish cages should be sited in areas that are unfavourable to the growth of fouling organisms.

Phytoplankton

High light intensity and nutrient levels, warm water temperatures, and stagnant hydrological conditions may lead to excessive blooms of phytoplankton [FAO, 1989]. The algal blooms can affect the fish by clogging the gills and reducing the dissolved oxygen at night. Toxic blooms can be dangerous to humans, if the toxins accumulate in the consumed fish beyond critical levels. Thus, it is recommended to site the fish cages away from regions with favourable conditions for algal blooms and toxic species.

2.3.5 Socio Economics

Accessibility

For maintenance and marketing purposes, culture sites should have a good connection to the mainland and markets. In the large-scale production, the fish farm is usually equipped with housing facilities on the floating rafts or on the shore close to the cages. The housing facilities always include an office, feed store, laboratory, hatchery and dormitory. It should be noted that fresh water is needed in the fish farm operations for human consumption and washing the farm equipments. Housing facilities on the raft can minimize production cost but on the other hand it will increase the possibility of pollution by sewage and toilet waste directly emitted from the building.

Social Problems and Conflict with Other Coastal Uses

One major social problem is security. The fish cages are usually placed in public waters that are easily accessible by people. The security system will increase the production costs in terms of guarding, transportation and management costs. Therefore, another advantage of using housing facilities on the raft is lower security costs.

From the socioeconomic view point, mariculture should also consider competing resource uses, market conditions (e.g. demand for mariculture products and accessibility to market), infrastructure support and availability of technical expertise [Nath et al., 2000].

A problem may be the conflict with other coastal uses such as industry, tourism, transportation, fishery and nature conservation. Consequently, appropriate coastal zone management is a very important point to be taken into account. It is recommended that mariculture sites are located in some distance from the other coastal uses or from other mariculture sites to avoid conflicts and mutual pollution. Guidelines on distance restrictions between farms vary tremendously between countries, environments, farmed species and systems used. For example, the distance between finfish farms in Scotland is suggested to be more than 8 km unless the fish farms are small or located in open waters [Scottish Executive, 1999]. In New Brunswick (Canada) the allowable distance can be as short as 300 m [Pérez et al., 2005]. Pérez et al. (2003a) recommend that sites for mariculture should be in the distance of more than 2.5 km from touristic areas and should in no case be less than 0.3 km.

For reasons of safety, wave disturbance generated by ships, and pollutions the fish farm should be far away from navigation lines. According to Scottish Executive (1999) a fish farm should be located at least 0.5 km from navigation lines and harbours.

Legal Aspects

Most of the coastal countries have a standard law on lease of public water for any construction and for fisheries, including mariculture. In some countries, fish farmers have to obtain a licence to culture fish in cages which comprises restrictions concerning site, species, structure size and type of developments. The licence usually contains a regulation of size of the cage as well as the size of the entire farm, lay-out plan and strength of cages, fish species and culture methods.

Suitable sites for farming should be selected applying the criteria as described above, however existing regulations should also be carefully studied to avoid any inconsistencies.

Chapter 3. Mariculture in Indonesia

As one of the largest archipelagic countries in the world, Indonesia has a great potential for mariculture development. Indonesian coastal and marine areas have been used for farming activities since 1977. The development gives some positive hope in terms of reducing pressure on natural marine fish stocks, creating new job opportunities and as a source of livelihood. Meanwhile, like many other countries, Indonesia is facing some environmental problems related to mariculture development. This chapter will describe the development of mariculture in Indonesia as well as the specific problems related to this development.

3.1 Potential Area and Production

Indonesia is an archipelagic country consisting of about 17,508 islands with a total area of around 7.7 million km². Two thirds of the total area consists of seawater with a total coastline of about 81,000 km. This constitutes a great natural potential for mariculture development. During the past years, the Indonesian government has introduced mariculture as an alternative source of income from the marine and coastal environment.

Ramelan (2000) describes the potential area in Indonesia as follows: In West Indonesia, many large estuarine areas with a clay bed substrate of about 2.95 million ha are potentially convenient for sea bass and bivalve cultures. The Eastern part of Indonesia (Nusa Tenggara and Maluku) is suited for seaweed, pearl and abalone culture, while the area is characterized by large coral reefs. The potential area for those species is about 1.11 million ha. In Sulawesi, Maluku and Papua, the bottom sandy substrate (2.28 million ha) and clay (333,000 ha) have a potential for grouper and sea cucumber culture. The estimations were based on a 5 km distance from the coastline and a sufficient water depth for each species. The potential space was estimated assuming a depth of 5 – 30 meters for finfish, 5 meters for oysters, and 1 – 5 meters for pen-culture. BAKOSURTANAL (1998) created a marine resource atlas including a map of mariculture potential sites for sea bass, grouper, oyster, anadara, sea cucumber, abalone, pearl shell and seaweeds (Figure 3.1). Unfortunately there is no information about the method used for of the determination of potential mariculture sites.

Based on Glude (1982), initial studies of mariculture in Indonesia were done in 1977 by the FAO/UNDP South China Sea Fisheries Development and Coordinating Programme (SCSP-RAS/74/013) in order to identify small-scale fisheries pilot projects in the Pulau Tujuh area of the Riau Archipelago District. The study recommended a resource survey to identify areas for development of sea farming of shellfish, seaweed and marine finfish and a marine turtle species. Another study was organized by the FAO and Indonesian Directorate General of Fisheries in 1980 to investigate the potential seaweed farming in Bali, West Nusa Tenggara and East Nusa Tenggara.

The first mariculture industry project in Indonesia was started in 1989 in Lampung province for the commercial purpose with sea bass as cultured species [BPPT, 2001]. In the mid nineties, mariculture was already well developed in many provinces such as North Sumatera, Riau, Lampung, Jakarta, East Java, and Maluku. The fish species that has been raised are finfish like grouper (*Epinephelus sp.*), snaper (*Lates calcatifer*), clown fish (*Siganus sp.*); bivalves like pearl (*Pinclada sp.*), cockles (*Anadaragranosa*), green mussel (*Mytilus viridis*); seaweed like *Euchema sp.* and *Gracilaria sp.*; sea cucumber (*Holothuria sp.*) and others [Adisukresno & Perbowo, 1996].

Total fish production can be divided into captured and cultured fish. Mariculture belongs to one of the culture types in aquaculture. National fisheries statistics for the period 1997 to 2002 [DKP, 2005a] reveals that about 80% of total Indonesian national fish production comes from the marine capture fisheries and only 20% was gathered from freshwater and marine aquaculture. However, there was significant progress in the aquaculture production during this period. In 1997, total aquaculture production accounted for about 0.66 million tons, whereas in 2002 it reached 1.14 million tons. The increase of about 16.68 % per year in aquaculture production clearly exceeded that of wild fisheries which increased only by 2.22% per year (Figure 3.2). The figure also shows the percentage of national on world production during this period. During this period, Indonesian aquaculture production has slightly increased from 1.85% to 2.13% of world production. Production of national capture fisheries also shows a slight increase from 4.10% to 4.63% of world production.

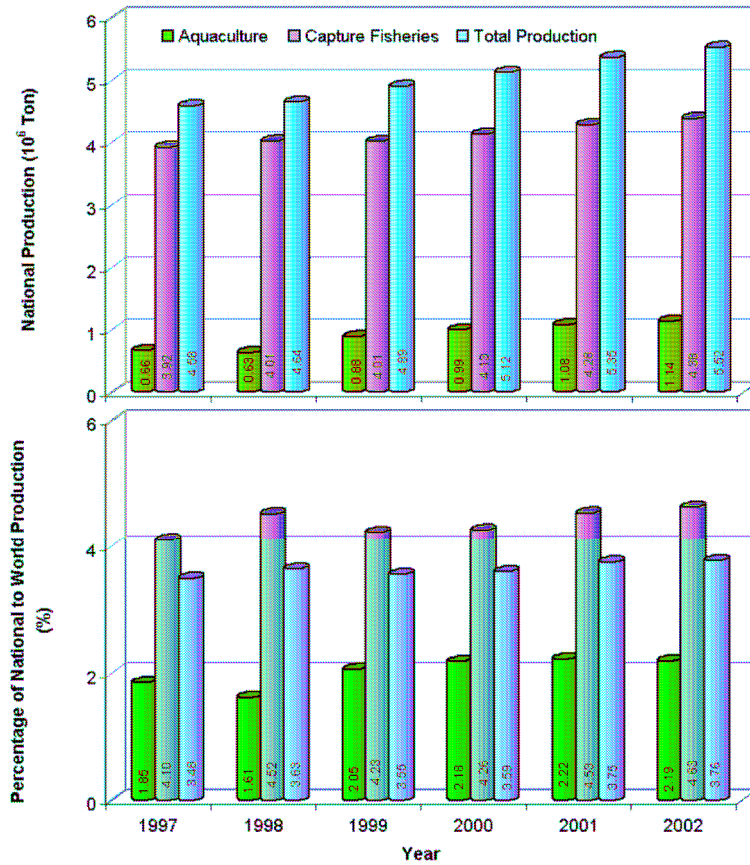


Figure 3.2: Fish Production in Indonesia and percentage to the world production from 1997 – 2002 [DKP, 2005a and FAO, 2003]

Aquaculture products can be classified into six types of culture [DKP, 2005b]: mariculture, brackish water, freshwater pond, floating cages on a river, floating cages on a lake/reservoir, and paddy or rice fields. In the year 2004, the mariculture production in Indonesia reached a total of 420,919 Tons from total culture production of 1,468,609 Tons or about 28.66 % of total aquaculture products (Figure 3.3). The mariculture product percentage is only less than brackish water product and significantly higher than other freshwater culture type products [DKP, 2005b].

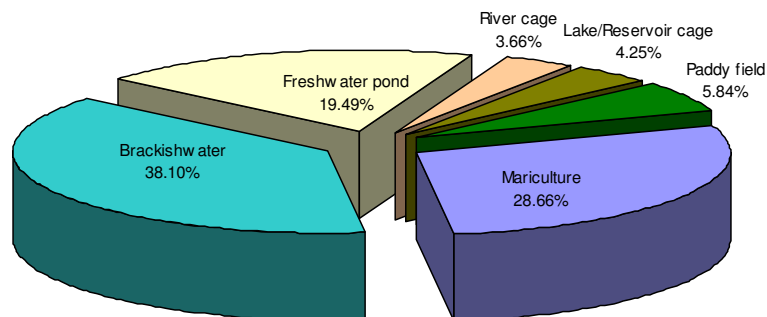


Figure 3.3: National aquaculture production per type of culture in year 2004 [DKP, 2005b]

A statistical plot of aquaculture products by culture type in different regions of Indonesia is presented in Figure 3.4. The figure reveals that the highest aquaculture productions lie in the Java Island area with a total production of 532,580 Tons (about 36.3 % of total national production). Most of the Java Island product comes from brackish water cultures (milkfish and shrimp in pond culture).

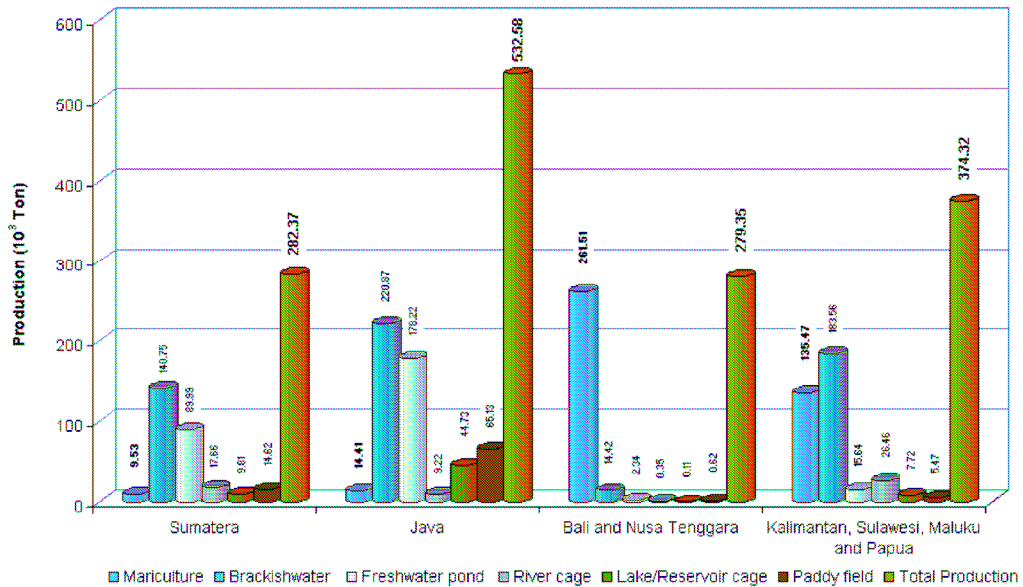
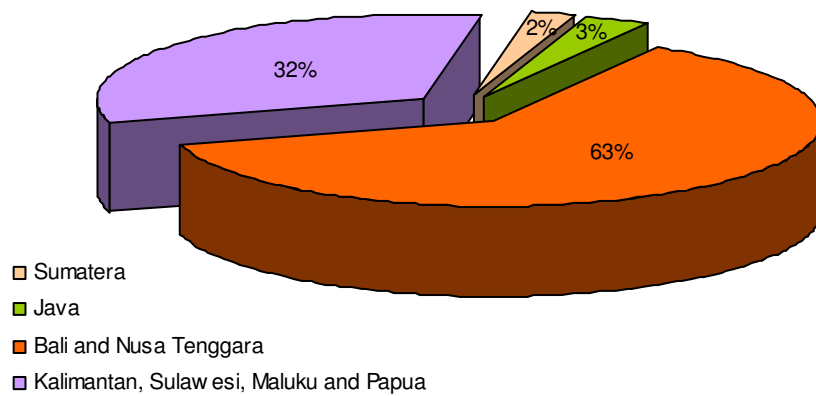
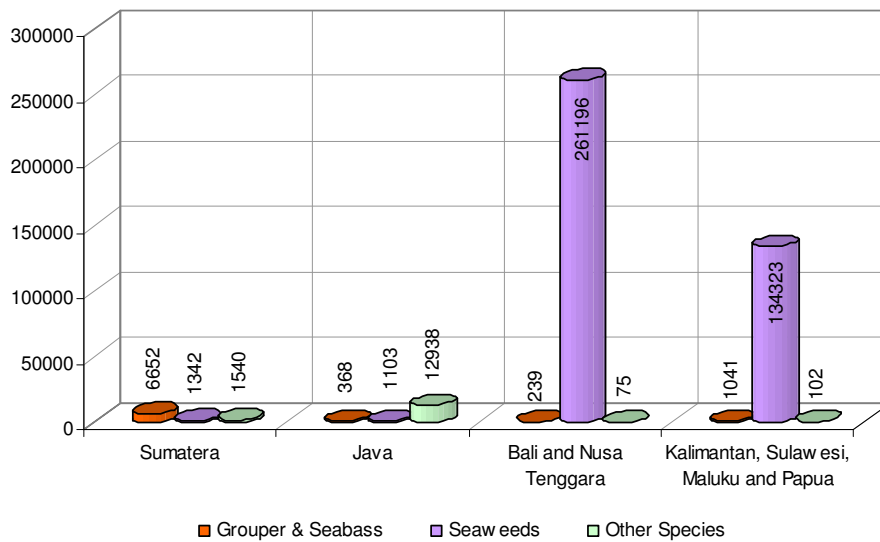


Figure 3.4: Aquaculture production by type of culture in different Indonesian regions in 2004 [DKP, 2005b]

Focused on mariculture products, Figure 3.5 presents the products by region and cultured species for 2004. Around 63% of mariculture national products were produced from the Bali and Nusa Tenggara area (Figure 3.5a). Mariculture in Java and Sumatera contributed only a little to the national productions (about 3% and 2% respectively). The most dominant mariculture product in this year were seaweeds (Figure 3.5b), with Bali and Nusa Tenggara as the most productive area (261,196 Tons of a total of 397,964 Tons seaweed national product). Production of seaweeds in Kalimantan, Sulawesi, Maluku and Papua accounted for 134,232 Tons. Grouper and sea bass species are cultured almost in all provinces in Indonesia, in total the production for these species was 8,300 Tons. Riau was the most productive province in this context. Other species in Figure 3.5 comprise shellfishes, shrimps, pearl shells and miscellaneous forms. Most shellfish products were from mariculture in West Java, where they produced about 10,000 Ton shells in the year 2004.



(a) Mariculture production per region in 2004 (in percentage)



(b) Mariculture production by species per region in 2004 (in Ton)

Figure 3.5: Production by area and species (in Ton) of year 2004 [DKP, 2005b]

As illustrated in Figure 3.5, seaweeds form the bulk of cultured products in almost every area, followed by groupers. Seaweeds are easily cultured using ropes or rafts without any complex requirements. They also require a short farming time (45 – 60 days) compared to groupers or other finfish, which require a farming time of 6 – 8 months [BPPT, 2001]. Thus seaweed culture demands a low production cost. For fish farming, the most common used structure types in mariculture in Indonesia are floating net cages and earth ponds. Seaweed, finfish (groupers, sea bass and red snappers), pearl shell and shrimps are the common culture organisms in Indonesia [Ramelan (2000), Sugama (2002)].

3.2 Problems

Main issues and problems in the development of mariculture in Indonesia are related to environmental degradation, seawater pollution, conflicts with other coastal uses, operational problems of mariculture and implementation of mariculture regulations. In the following an overview of the problems is given based on studies of fish farm literatures from Indonesia and Southeast Asia.

3.2.1 Environmental Degradation

Rapid development of mariculture in coastal areas is going along with an expansion of these activities in the coastal sea. As a consequence, there are several natural coastal habitats that will be occupied by the industry. Two main natural coastal habitats in Indonesia that are commonly destroyed by fish farming activities are mangroves and coral reefs.

Most shrimp and milkfish farming in Southeast Asia takes place in ponds in reclaimed mangrove forests [Landesman, 1994]. However, mangrove forests are very important since they not only serve as a nursery ground for marine coastal fisheries, but also protect coastal shores from erosion and storm damage. In December 2004, only 7% of villages covered by natural mangrove forest were severely devastated by the tsunami wave along the east coast of Sumatera. In areas where the mangrove forests have been degraded by aquaculture or tourist industries, the percentage of destroyed areas reached over 80% [Dahdouh-Guebas, 2005].

Offshore cage mariculture is normally less destructive to the environment than shrimp or pond farming. Recently however mariculture of seaweed and other species in Indonesia and other Southeast Asian countries on and near coral reefs is increasing [Best, 2002], and destroying coral reef areas as a consequence. Coral reefs are important breeding and nursery grounds for fish as well as protect of the shoreline against the big ocean waves by dissipating the energy.

The coastal environmental problems are more severe on the west coast, particularly in northern and southern Sumatera, Bali, and the Java Sea. Intensive mariculture projects, coral mining practices and destructive fishing in these areas are causing serious damage to reefs, mangroves and fish populations [Purwaka and Sunoto, 1999].

3.2.2 Pollution

Human impacts affecting mariculture differ considerably from place to place in Indonesia. In general, problems are more severe around the extensively populated island of Java and parts of Sumatera. In less populated areas, however, some local problems of contamination arising from agricultural and industrial development may occur. In general, main pollution sources in Indonesian waters are industrial waste, domestic waste from major population centres, hydrocarbons from oil spills and land based discharges, siltation and sedimentation, as well as pesticides emissions from agricultural activities.

3.2.3 Conflict with Other Coastal Uses

As already mentioned, one of the general problems in the implementation of mariculture is the overlapping of conflicting coastal uses. Coastal zones in Indonesia are subjected to a variety of human activities such as tourism and recreation, mariculture, transportation, waste disposal, mining, energy production and fishing. The occupants change as a consequence of economic and social pressures. More than 60% of Indonesia's population lives in coastal areas. The contribution of marine-based activities to the national economy has increased from 12% in 1987 to 24% in 1992 and is expected to accelerate economic growth over the next years [Purwaka and Sunoto, 1999].

Besides tourism and recreation, mariculture, waste space, transportation and the lingering military, there are some minor players: energy development, coastal mining and the declining fishing industry. All have their patronage in legislative and executive parts of the government. Economic and social pressures will prevail. Expert knowledge will help maintain and improve coastal zone quality.

3.2.4 Operation

The following problems are persistent with respect to mariculture operations in Indonesia:

1. *Human resources*: Most Indonesian fishers are experts in capture fishery rather than in fish farming. They prefer to have fish instantly instead of growing them and waiting for longer time.
2. *Seed sources*: Most of the fish in mariculture are already grown up from the broodstock. However in some cases, hatcheries are not well distributed while some areas have sufficient fingerling supply from the hatcheries and others do not. Problems were encountered in the maintenance of broodstock and in egg transportation. The supply of fry and fingerling is insufficient and their quality is poor. The mortality at hatcheries is very high, which reduces the profitability. APEC/NACA/BOBP/GOI (2002) recommends small-scale nurseries for small-scale coastal fishers and farmers instead of hatcheries. However, it is necessary for nurseries to have access to eggs and fry from hatcheries.
3. *Infrastructure and technology*; There is a lack of support from the industry for mariculture as a business system. Technologies for food and seed supply are not well implemented as of yet [Ahmad, 2001]. Most of the mariculture in Indonesia is only developed on a small scale with conventional methods. Use of trash fish is a limiting factor. Formulated feeds are available to some extent but need to be improved. Use of fishmeal as the main ingredient is a problem in terms of both supply and price. Hygienic standards in fish production have to be improved. Another problem is disease of fish due to infection. To improve the technology, bilateral or multilateral cooperation as well as private sector involvement has to be established. There are already some institutions for mariculture research and development in Indonesia (Figure 3.6).

4. *Marketing*; Shorter marketing chains leads to higher profits per fish without a loss of income of the farmer. Some of the mariculture in the Java Sea and Riau Islands already has direct clients from Hong Kong and Singapore, where the price for cultured fish is slightly higher than on local markets.

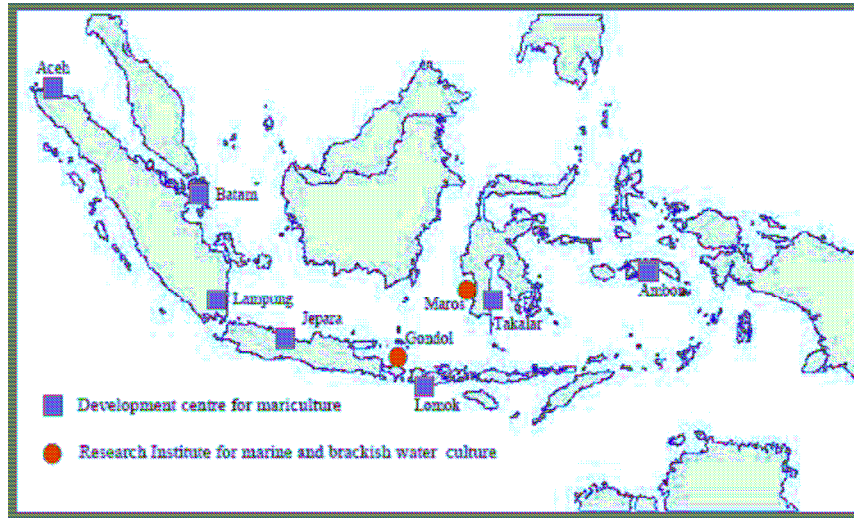


Figure 3.6: Location of Indonesian Mariculture Research Institutions [Sugama (2002)]

3.2.5 Regulation

Development and management of mariculture require strong and efficient legislation. Ramelan (2000) suggested five factors to be considered in the regulations for management of mariculture development in Indonesia. These include (1) licensing, (2) coastal planning, (3) environment, (4) fish product quality, and (5) coordination and co-management.

The Ministry of Marine Affairs and Fisheries (Departemen Kelautan dan Perikanan, DKP) is the main fisheries authority in Indonesia. The Ministry operates on matters related to aquaculture and mariculture through the Directorate General of Aquaculture Development. Indonesian fisheries at the national level are regulated most recently by National Law No. 31/2004 on Fisheries. This regulation underlines the importance of sustainable use of aquatic resources in the development of fisheries. Based on National Law No. 22/1999 on Regional Administration, each Provincial Government has its own responsibility for the management, use and conservation of marine resources in their territory, within national waters.

Procedures for the granting of mariculture licences are regulated by Government Regulation No. 54/2002 on Fisheries Business. However, small-scale mariculture industries and small fish breeders are exempt from such requirements. A license for the implementation of mariculture by an Indonesian company must be issued by the Provincial Governor or by the Regent or Head of the Municipality, depending on the location of the farm. Companies applying for a license must provide their business plan, the mariculture location as well as an Environmental Impact Assessment. The Ministry of Marine Affairs and Fisheries has a right to cancel or deny the license on any reason.

Based on Presidential Decree No. 23/1982 on Mariculture Development in Indonesian Waters, Provincial Governors are in charge of identifying marine or coastal areas for the development of mariculture in the territories under their jurisdiction.

With respect to water quality standards, the discharge of effluents and waste into marine waters are dealt with Government Regulation No. 19/1999 on control over marine contamination and/or damage and by Decree of State Minister for Environmental Affairs No. 110/2003 on the guidelines of the accommodating capacity load of water pollution in water sources. Especially for shellfish farming, water quality standards are established by Decree of the Minister of Marine Affairs and Fisheries No. 17/2004 on Indonesian Shellfish Sanitation Systems.

A number of other laws concerning fisheries and other marine resources along with regulations have been established and provide some legal basis for government institutions to manage coastal and marine fisheries resources. Table 3.1 presents some government regulations concerning mariculture development in Indonesia, which were still valid up to 2004. The existing laws and regulations allow the private sector, communities and other legal entities to use coastal and marine resources. However, implementation is hampered by legal constraints, misinterpretation, conflicts of interest, and overlapping jurisdictions. The results is a climate of uncertainty and inconsistency on law enforcement. Lack of coordination and cooperation among government institutions further hampers the process of promoting integrated fisheries and coastal and marine resources management. There are often conflicts among stakeholders regarding licenses and permits as well.

Table 3.1: List of existing mariculture regulations in Indonesia

| Nr. | Title of Regulation | Notes |
|-------------------------|---|---|
| LICENSING | | |
| 1. | Government Regulation No. 54/2002 on Fisheries Business. | Procedures for the granting of mariculture license |
| COASTAL PLANNING | | |
| 1. | Presidential Decree Nr. 23/1982 on Development of Mariculture in Indonesia | Identification of marine and coastal area for mariculture industry |
| 2. | Presidential Decree Nr. 32/1990 on Management of Protected Zone | Coastal planning and environmental protection zone |
| 3. | National Laws Nr. 24/1992 on Spatial Use Management | Coastal planning |
| ENVIRONMENT | | |
| 1. | Government Regulation Nr. 19/1999 on Marine Contamination Control | Control over marine contamination and/or damage |
| 2. | Government Regulation Nr. 104/2000 on Equilibrium Funds | Environmental quality control |
| 3. | Presidential Decree Nr. 10/2000 on The Agency for Controlling Environmental Impacts | Formation of agency for environmental impact management |
| 4. | Ministerial Decree, State Minister for Environmental Affairs Nr. 110/2003 on capacity of load of water pollution in water sources | Guidelines on stipulation of accommodating capacity of load of water pollution in water sources |

| | | |
|--|---|--|
| 5. | Ministerial Decree, Ministry of Marine Affairs and Fisheries Nr. 17/2004 on Shellfish Sanitation System | Water quality standards for shellfish farming |
| FISH PRODUCT QUALITY | | |
| 1. | Presidential Instruction Nr. 2/1990 on Fresh and Frozen Fish Quality Control | Fish products quality control |
| 2. | Act. No. 7/1996 on Food | Basic provisions of food processing, storage, packaging, labelling and transport. |
| 3. | Ministerial Decree, Ministry of Marine Affairs and Fisheries Nr. 33/2001 on Technical Directives for the Utilization of Food Security Credit in the Marine and Fishery Sector | Fish products quality control |
| COORDINATION & COMANAGEMENT | | |
| 1. | National Law Nr. 22/1999 on Regional Administration | Responsibility of provincial government for the management, use and conservation of marine resources |
| 2. | Government Regulation Nr. 25/2000 on National and Provincial Rights | Responsibility of provincial government for the management, use and conservation of marine resources |
| 3. | Ministerial Decree, Ministry of Marine Affairs and Fisheries Nr. 41/2000 on General Guidelines on the Sustainable and Community-based Management of Small Islands | Coordination and co-management of coastal spatial use and activity licensing in small islands |
| 4. | National Law Nr. 31/2004 on Fisheries | General fisheries and aquaculture (including mariculture) regulation |

Chapter 4. Strategy for Mariculture Site Selection

The rapid growth of mariculture in Indonesia and worldwide has led to increased concerns about its environmental sustainability. As already pointed out, 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 chapter 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.

4.1 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. The parameters for site selection have already been discussed in section 2.3.1. Mariculture cage installations have to fulfil 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.

4.2 Introduction to the Decision Support System

Power (2004) defines a Decision Support System as 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. 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.

There are four main elements in a Decision Support System:

1. The *interface* component, which is the part of the DSS that interacts with the user; it should be user-friendly and usually includes graphical components; in this case called a Graphical User Interface (GUI).
2. The *database*, which is the collection of data that is organised so that its contents can easily be accessed, managed and updated.
3. The *model*, which is the component of the DSS account for the evaluation, analysis and correlation of the information from different sources available in the database.
4. The last components, *architecture and networking design*, refer to how hardware is organised, how software and data are distributed in the system, and how components of the system are integrated and connected.

There are several types of DSS, which can be categorized based on the dominant technology component or driver of decision support; the targeted users; the specific purpose of the system, or the primary deployment of technology [Power, 2000].

Based on the dominant technology component, Power (2000) proposed five generic categories:

1. *Data-driven DSS*

This type of DSS emphasizes access to and manipulation of large databases of structured data and especially a time series of internal company data and some times external data. Simple file systems accessed by query and retrieval tools provide the most elementary level of functionality. The DSS includes file drawers and management reporting systems, data warehousing and analysis systems, Executive Information Systems (EIS) and Spatial Decision Support Systems.

2. *Model-driven DSS*

Model-driven DSS emphasize access to and manipulation of a model. Simple statistical and analytical tools provide the most elementary level of functionality. The DSS uses data and parameters provided by decision-makers to aid them in analyzing a situation,

but they are not usually data intensive. Very large databases are usually not needed for Model-driven DSS.

3. *Knowledge-driven DSS*

The other type of DSS is knowledge-driven DSS, since it is a person-computer system with specialized problem solving expertise. The DSS focuses on the dominant knowledge base component. Knowledge-driven DSS may suggest or recommend actions to managers. The “expertise” consists of knowledge about a particular domain, understanding of problems within that domain, and “skill” at solving some of these problems.

4. *Document-driven DSS*

Document-driven DSS is evolving to help managers to retrieve and manage unstructured documents and Web pages. This type of DSS integrates a variety of storage and processing technologies to provide complete document retrieval and analysis.

5. *Communications-driven DSS*

Communications-driven DSS is an interactive computer-based system intended to facilitate the solutions of problems by decision-makers working together as a group. This type of DSS emphasizes both the use of communications and decision models. The other name for this type of DSS is Group DSS.

Based on user target, a DSS can be classified into an internal and an external type. DSS targeted externally are called Inter-Organizational DSS. These DSS serve a company's stakeholders including customers and/or suppliers. An Inter-Organizational DSS provides stakeholders with access to a company's intranet and authority or privileges to use specific DSS capabilities. Another type of DSS based on user target is Intra-Organizational DSS that are designed for use by individuals in a company as “stand-alone” DSS or for use by a group of managers in a company as a Group or Enterprise-Wide DSS.

DSS may have broad or narrow purposes. Many DSS are designed to support specific business functions or types of businesses and industries. A DSS with a narrow purpose is called a function or industry specific DSS and those with the most general purpose are DSS generators.

Another classification of DSS can be made based on the deployment of technology. The DSS can be classified into three categories, which are mainframe computer; client/server LAN; and Web-Based DSS.

4.3 Geographic Information Systems for DSS

A Geographic Information System (GIS) is an integrated assembly of computer hardware, software, geographic data and personnel designed to efficiently acquire, store, manipulate, retrieve, analyze, display and report all forms of geographically referenced information geared towards a particular set of purposes [Burrough, 1986]. GIS has the ability to pre-process data into a form suitable for analysis, direct support for analysis and modelling and post processing of results. The ability to handle appropriately both spatial and non-spatial data is needed to better support management in a range of applications. GIS can be applied

for DSS as a *DSS generator*, which is defined as a computer software package that provides tools and capabilities that help a developer easily build a specific Decision Support System [Sprague and Carlson, 1982].

GIS is capable of integrating geographical data with other data from various sources to provide the information necessary for effective decision-making in planning sustainable development. Typically a GIS serves both as a toolbox and as a database. As a toolbox, GIS allows planners to perform spatial analysis using its geoprocessing or cartographic modelling functions such as data retrieval, map overlay and connectivity. Of all the geoprocessing functions, map overlay is probably the most useful tool for planning and decision-making. In land suitability analysis, there is a long tradition of using map overlays. Decision makers can also extract data from one database and input it to other modelling and analysis programs together with data from other databases or specially conducted surveys. It has been used in information retrieval, development control, mapping, site selection, land use planning, land suitability analysis, and programming and monitoring.

In the case of mariculture site selection, all of the information needs for decision-makers who evaluate such technical and socio-economic characteristics, as part of mariculture planning efforts can also be well served by geographical information systems (GIS) [Kapetsky and Travaglia, 1995]. However, the application of GIS for mariculture is hampered by several constraints including [Nath et al., 2000]:

1. a lack of appreciation of the benefits of such systems on the part of key decision-makers
2. limited understanding about GIS principles and associated methodology
3. inadequate administrative support to ensure GIS continuity among organizations
4. poor levels of interaction among GIS analysts, subject matter specialists and end-users of the technology.

The use of GIS in mariculture decision support systems has been widely applied in the last two decades. Table 4.1 shows a comprehensive listing of GIS applications in mariculture management.

Table 4.1: List of GIS application in mariculture in chronological order

| Author | Region | Brief Description |
|------------------------|-------------------|--|
| Meaden, 1987 | England and Wales | Site selection for trout farming in Britain |
| Kapetsky et al., 1988 | USA | GIS for catfish farming development |
| Kapetsky, 1989 | Malaysia | GIS for aquaculture development in Johor State, Malaysia |
| Kapetsky et al., 1990a | USA | Assessing potential for aquaculture development with a GIS |
| Kapetsky et al., 1990b | Ghana | GIS as a decision-making tool for Tilapia and Clarias culture development in ponds |
| Ali et al, 1991 | Pakistan | Application of GIS in carp culture (ponds farming) |
| Legault, 1992 | Canada | Using a GIS to evaluate the effects of shellfish closure zones on shellfish leases, aquaculture and habitat availability |
| Ross et al., 1993 | Scotland | Salmonid cage culture |

| | | |
|--------------------------|----------------|--|
| Wibowo, 1994 | Indonesia | Application of remote sensing and GIS in brackish water aquaculture monitoring |
| Bolte & Nath, 1995 | USA | Decision support for Pond aquaculture: Parameter estimation for simulation models |
| Nath, 1996 | USA | Development of a decision support system for pond aquaculture |
| Populus et al., 1995 | Indonesia | Use of remote sensing data water quality assessment for shrimp culture in Java Sea |
| LUCO, 1998 | Canada | Shellfish and salmon aquaculture |
| Scott et al., 1998 | Brazil | Shellfish culture |
| Arnold et al., 2000 | USA | Shellfish culture |
| Bolte & Hillyer, 2001 | USA | Decision support systems for fish population management and scheduling in commercial pond aquaculture operations |
| Coppola & Crosetti, 2001 | Italy | Decision Support Systems for Fisheries, The ITAFISH case study |
| Riqqi, 2001 | Indonesia | Prototype of Geographic Information Systems for Pond Aquaculture (Case Study: Kabupaten Serang) |
| Pérez et al., 2002 | UK | GIS as a simple tool to aid modelling of particulate waste distribution at marine fish cage site |
| Hargrave B.T, 2002 | Canada | A traffic light decision support system for marine finfish aquaculture siting |
| Pérez et al., 2003a | Canary Islands | Use of GIS-based model for integrating and developing marine fish cages within the tourism industry |
| Pérez et al., 2003b | Canary Islands | Cage culture site selection based on wave calculation |
| Pérez et al., 2003c | Canary Islands | Cage culture site selection based on water quality requirements |
| Pérez et al., 2005 | Canary Islands | GIS-based model for marine fish cage culture site selection |
| LAPAN, 2005 | Indonesia | Preliminary results of application of remote sensing and GIS for development of mariculture (case study: Seribu Islands) |

4.4 Principles of the 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 [Nath et al., 2000]. Iteration within the overall process, particularly among the first four phases may be necessary. Figure 4.1 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.

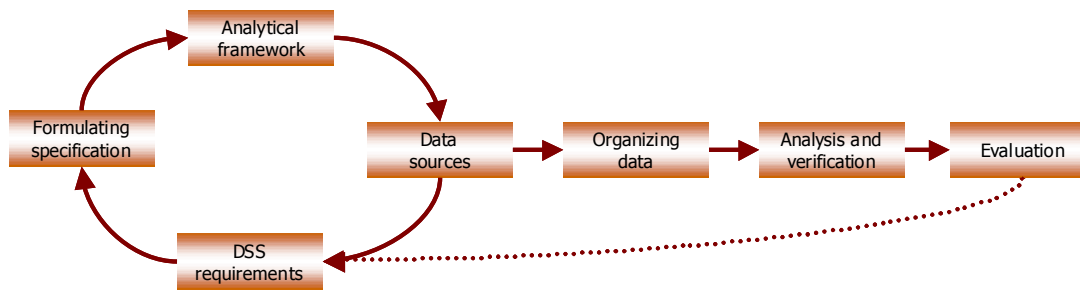


Figure 4.1: Development of a GIS process [Nath et al., 2000]

4.4.1 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.

4.4.2 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 4.2. The DSS for offshore cage finfish mariculture site selection is developed on the base of the Desktop GIS using ArcGIS v8.3 software.

4.4.3 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, neighbourhood analysis, connectivity analysis, hierarchical models, and multi objective land allocation [Nath et al, 2000].

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 [Berry J.K, 2004].

Selected parameters, their classification and weight are presented in Table 4.2. 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. An example of a reclassification process is presented in Figure 4.2. In this figure a bathymetry map was reclassified based on scoring of suitability as shown in Table 4.2. 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.

Table 4.2: Selected parameters with their weight and classification

| 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 |

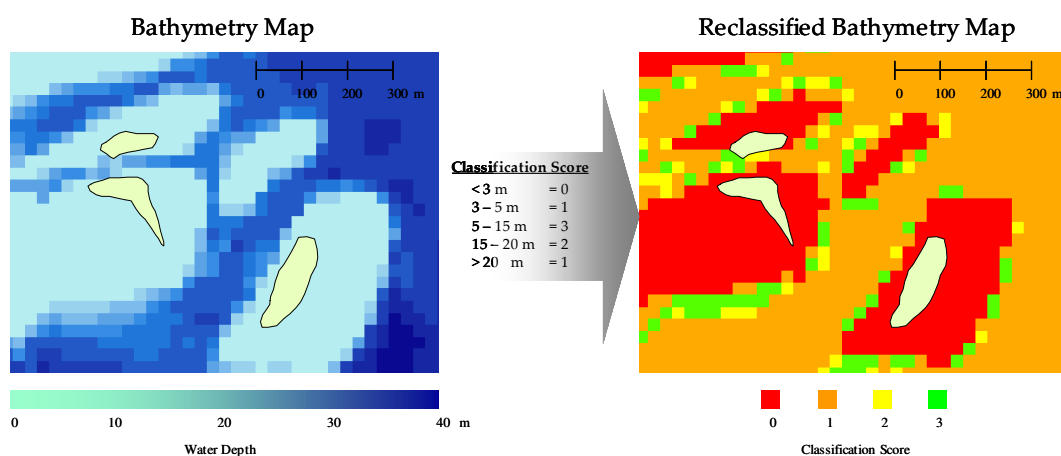


Figure 4.2: Reclassification of minimum water depth

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 [Saaty, 1980]. The procedure involves mathematically summarizing paired comparisons of the relative importance of the map layers. The results is 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 4.3) is used to record the relative level of importance for the pairwise combinations of the decision parameters. Parameters are compared to each other and recorded in a comparison matrix as shown in Table 4.4. The number of matrix elements as number of pairwise combinations is equal to $(N*(N-1)/2)$, where N is the number of decision parameters. The responses from the pairwise 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.

Table 4.3: Scales of relative level of importance [modified after Trick, 1996]

| 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 |

In the case of mariculture site selection in this study, fifteen parameters are compared with one another. As an example, *Water Depth* is defined as **equally important** to *Current Velocity*, therefore the value 1 is placed on the comparison of those parameters. Another example, *Wave Height* is defined as **very strongly important** to *Bottom Sediment Type*, thus the value 7 is given in the comparison of *Wave Height* to *Bottom Sediment Type*. The reciprocal value of 1/7 or 0.143 is placed in the reverse statement position (intersection of *Bottom Sediment Type* to *Wave Height*). The complete list of the pairwise comparisons is presented in Table 4.4. The last row of the table indicates the summarized values of each column.

Table 4.4: Relative importance of parameters for site selection (Comparison matrix)

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

Table 4.5 presents the normalized value derived from Table 4.4, 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 4.5. The weight is the average value of the normalized weights.

Table 4.5: Normalized comparison matrix and weight for each parameter

| | DP | VL | WV | SE | TM | SL | DO | AM | PH | NI | PO | SD | HR | NL | IA | TA | Weight |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-------------|
| DP | 0.16 | 0.16 | 0.18 | 0.14 | 0.12 | 0.12 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.10 | 0.11 | 0.11 | 0.17 | 0.11 | 0.15 |
| VL | 0.16 | 0.16 | 0.18 | 0.14 | 0.12 | 0.12 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.10 | 0.11 | 0.11 | 0.17 | 0.11 | 0.15 |
| WV | 0.05 | 0.05 | 0.06 | 0.08 | 0.09 | 0.09 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.08 | 0.08 | 0.06 | 0.08 | 0.07 |
| SE | 0.03 | 0.03 | 0.02 | 0.03 | 0.05 | 0.05 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.06 | 0.06 | 0.06 | 0.03 | 0.06 | 0.04 |
| TM | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.04 | 0.04 | 0.02 | 0.04 | 0.02 |
| SL | 0.05 | 0.05 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.04 | 0.04 | 0.02 | 0.04 | 0.02 |
| DO | 0.05 | 0.05 | 0.06 | 0.08 | 0.09 | 0.09 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.08 | 0.08 | 0.06 | 0.08 | 0.07 |
| AM | 0.05 | 0.05 | 0.06 | 0.08 | 0.09 | 0.09 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.08 | 0.08 | 0.06 | 0.08 | 0.07 |
| PH | 0.05 | 0.05 | 0.06 | 0.08 | 0.09 | 0.09 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.08 | 0.08 | 0.06 | 0.08 | 0.07 |
| NI | 0.05 | 0.05 | 0.06 | 0.08 | 0.09 | 0.09 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.08 | 0.08 | 0.06 | 0.08 | 0.07 |
| PO | 0.05 | 0.05 | 0.06 | 0.08 | 0.09 | 0.09 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.08 | 0.08 | 0.06 | 0.08 | 0.07 |
| SD | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.02 | 0.00 | 0.01 |
| HR | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| NL | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| IA | 0.16 | 0.16 | 0.18 | 0.14 | 0.12 | 0.12 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.10 | 0.11 | 0.11 | 0.17 | 0.11 | 0.15 |
| TA | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| TOT | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

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 4.5) 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 4.1. An example of conceptual computation is presented in the Figure 4.3.

$$TS = \sum_{i=1}^n w_i \cdot x_i \quad \dots (4.1)$$

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

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

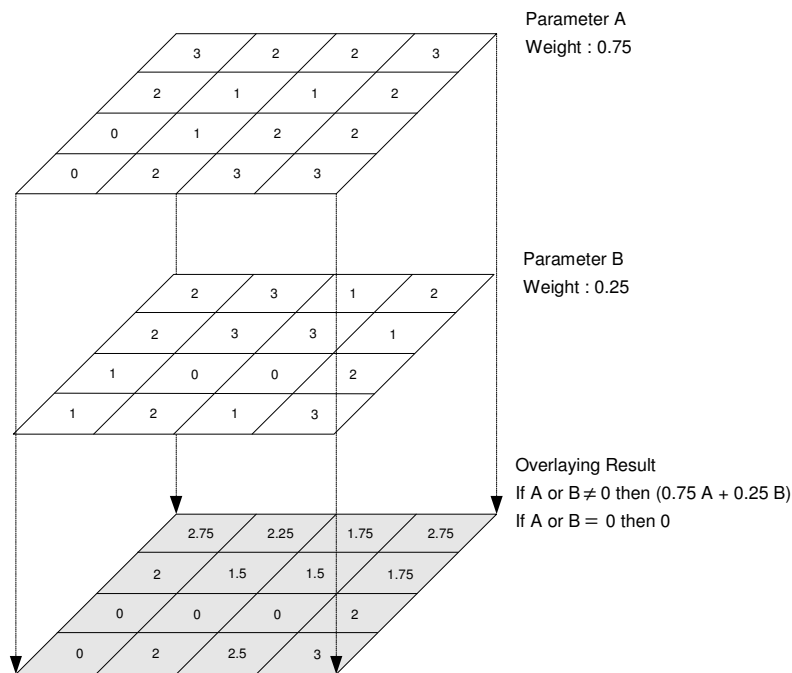


Figure 4.3: Parameter overlaying method

4.4.4 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 4.2.). In this study, data for the selected parameters are taken from previous field measurements data and numerical modelling results as described later in Chapter 5.

4.4.5 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.

4.4.6 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.

Chapter 5. Description of Study Areas, Data Availability and Development of Numerical Models

It is necessary to know the general conditions of Indonesian waters as well as the specific condition in the study areas since the DSS is attended to be applied for the entire Indonesian coastal area. In this context it is important to identify available data for the study areas. In order to fulfil the data requirements for physical parameters (e.g. water level, current velocity and wave), numerical models were developed for the study areas to supplement field data. The study areas, data availability and the development of numerical models are described comprehensively in this chapter.

5.1 General Characteristics of Indonesian Seas

The Indonesian Archipelago is located at the tropical equator at about 6°N – 11°S and 94°E – 141°E. It lies between two continents (Australia and Asia) and two oceans (Indian and Pacific). The archipelago consists of 17,508 islands [SETNEG, 2005], which includes five main islands (Sumatera, Java, Kalimantan, Sulawesi and Papua). According to the population census in 2000 [BPS, 2002], the Indonesian population is approximately 206 million, most of which is concentrated on these five islands.

The physical structure of Indonesia encompasses the junction of three major sections of the Earth's crust and involves a complex series of shelves, volcanic mountain chains and deep-sea trenches. The arc of islands including Sumatera, Java, Bali and Nusa Tenggara, together with Kalimantan and Sulawesi lie on the Sunda Shelf, a southward extension of the continental mass of Asia. Java Trench, with a depth of around 7,500 meters, bounds the shelf on the south and west and forms the continental boundary in the southern part of Java, Bali and Nusa Tenggara; and in the western part of Sumatera (Figure 5.1).

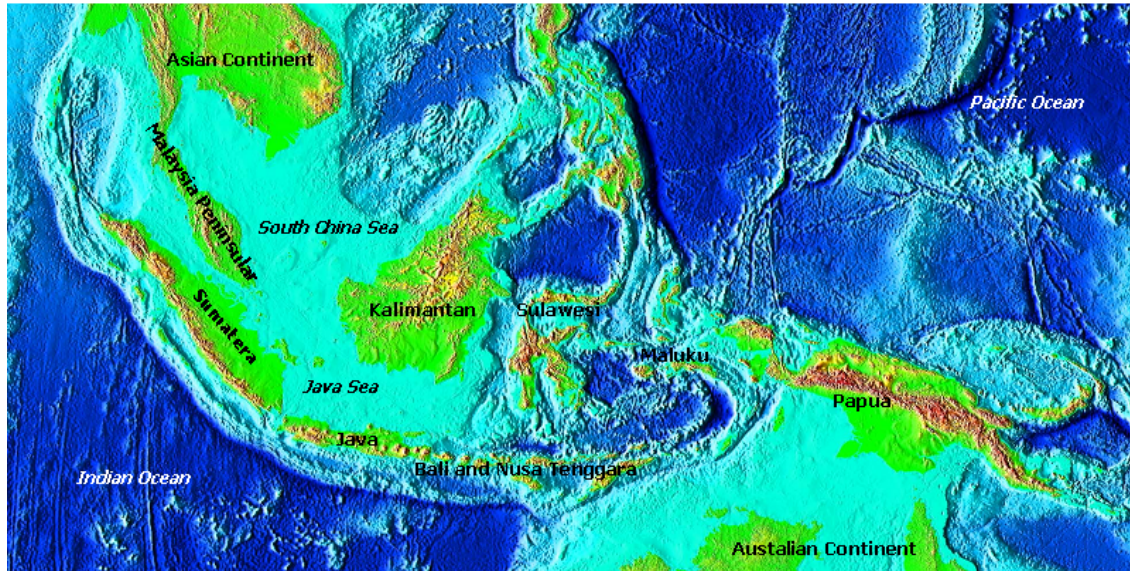


Figure 5.1: Topographic map of Indonesia

The Sahul Shelf, which is a northwestern extension of the Australian continental mass, is bounded to the northeast by a series of deep-sea troughs and to the northwest by troughs, a chain of coral reefs and a series of submarine ridges. On this shelf lie the Papua Island and adjacent islands (some part of Maluku Islands and Halmahera). The last Earth's crust is an extension of the belt of mountains of Japan and Philippines that runs south between Kalimantan and Papua. Sulawesi and Maluku are located on this shelf. As a compensation to the Earth's crust structure, Indonesian seas are characterized by shallow waters with a depth less than 200 meters in the western parts and deep seas of more than 3000 meters depth in the eastern parts.

Based on the bottom sediment map from BAKOSURTANAL (1998) (Figure 5.2), the sediment types in the deep waters are mainly characterized by clay, whereas in the shallow water mud and sand prevail.

The difference of sea surface topography between the Pacific and Indian Oceans causes the currents to flow from the Pacific to the Indian Ocean through Indonesian waters, which is usually called the Indonesian Throughflow or Pacific – Indian Throughflow. The throughflows are passing the deep sea between Sulawesi Sea – Makassar Strait – Java Sea – Lombok Strait (Figure 5.3). According to Meyers (1996), the Indonesian Throughflow is one of the primary links in the global exchange of water and heat between the Pacific and Indian Oceans. It influences the climate conditions in eastern Indonesia and western Australia. If the throughflow is not present, the ocean and climate conditions of Western Australia would be as dry and cold as the western coast of South America.

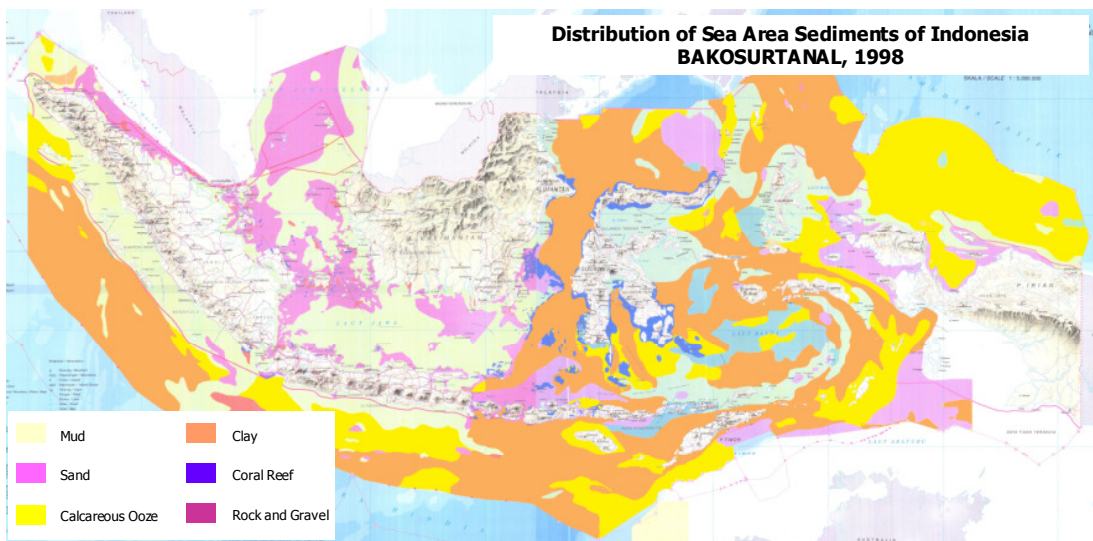


Figure 5.2: Indonesian bottom sediment type map [BAKOSURTANAL, 1998]

The geographical position of Indonesia influences the characteristics of climate and ocean dynamics. The inter-tropical convergence zone (ITCZ) shifts from the northern (21 June) to the southern (21 December) hemisphere crossing the equator. This condition leads to difference in air pressure between the Asian and Australian continents every 6 months and causes the monsoonal winds over Indonesia and drives the sea surface current patterns. The northwestern winds, which occur between October – March, bring a lot of water vapour from the Indian Oceans. During this time, the rainy season occurs in Indonesia. The dry season occurs between April – September when the dry winds blow from the southeast direction (Australian continent). The monsoon winds also influence the global sea surface circulation. Wyrcki (1961) has analysed the properties of water mass and ocean dynamics of South East Asian waters based on survey data during 1959 – 1961. Figure 5.4 shows the global sea surface circulation as an influence of monsoonal wind based on Wyrcki (1961).

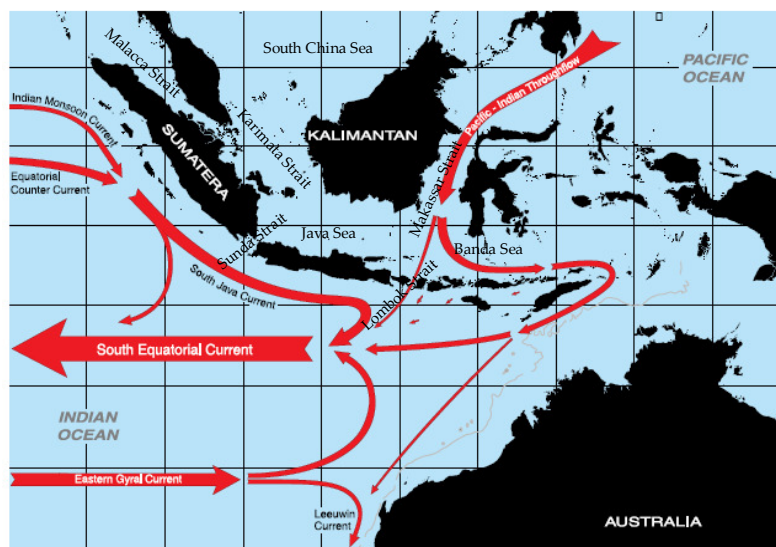


Figure 5.3: Indonesian Throughflow and circulation in Indian Ocean [Meyers, 1996]

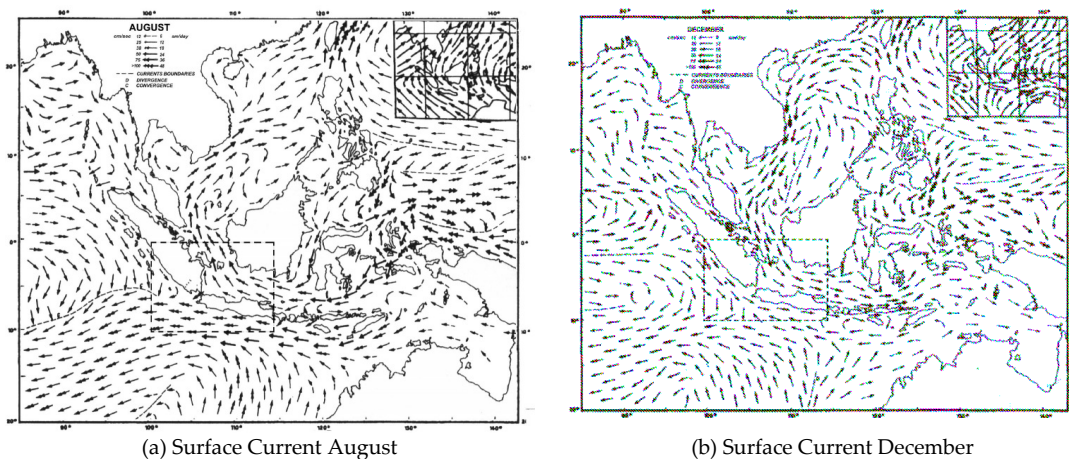


Figure 5.4: Global Sea Surface Circulation in Southeast Asia [Wyrтки, 1961]

In this research two study areas were selected for the development of a Decision Support System for mariculture site selection. The areas are Seribu Islands and Riau Archipelago. In the following sections, detailed characteristics of both study areas are described.

5.1.1 Seribu Islands and Java Sea

Seribu Islands are located in the Southwestern part of the Java Sea. They are under administration of Kabupaten Kepulauan Seribu (Seribu Islands District), DKI Jakarta Province. Based on the DKI Jakarta government website (www.jakarta.go.id), the archipelago consists of 105 islands, with only 11 islands populated by a total number of inhabitants of about 15,600. Forty-four islands of the group are located in the national conservation zone (Figure 5.5). The main occupation of the peoples in the region is fishery.

The Java Sea 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 5.3).

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 [Wyrтки, 1961]. Based on SEAWATCH buoy data from BPPT, which was located at coordinate 5.65 °S; 106.625 °E (close to Kelapa Island, northeast of Pramuka Island), the time average surface current velocity was about 0.22 m/s from November 6th 1998 – August 8th 1999 with a maximum of 0.8 m/s and minimum of 0.05 m/s. The monsoons are capable of creating and maintaining surface currents in the Java Sea because of the following factors: (1) the wind is steady, and (2) the axis of the wind more or less coincides with the axis of the sea areas formed by the South China Sea, Karimata Strait, Java Sea, Flores Sea and Banda Sea [Ilahude, 1980].

According to meteorological measurements in the period 1999 and 2000, the wind speed in Seribu Islands generally varied between 5 - 15 m/s [KK Hidrografi, 2000]. SEAWATCH buoy data revealed a wind speed average of 4 m/s with a maximum value of 13 m/s, while the wind direction followed the monsoonal periods.

The tidal type in the sea around Seribu Islands region is mixed diurnal with a tidal range of about 0.8 meters. The waves in the region are relatively weak with a wave height of about 0.6 meters in the outer area of the islands and 0.2 meters in the inner area [KK Hidrografi, 2000]. SEAWATCH buoy data indicates an average wave height value of 0.35 meters and maximum of 1.1 meters. The buoy was located on the outer area of the islands.

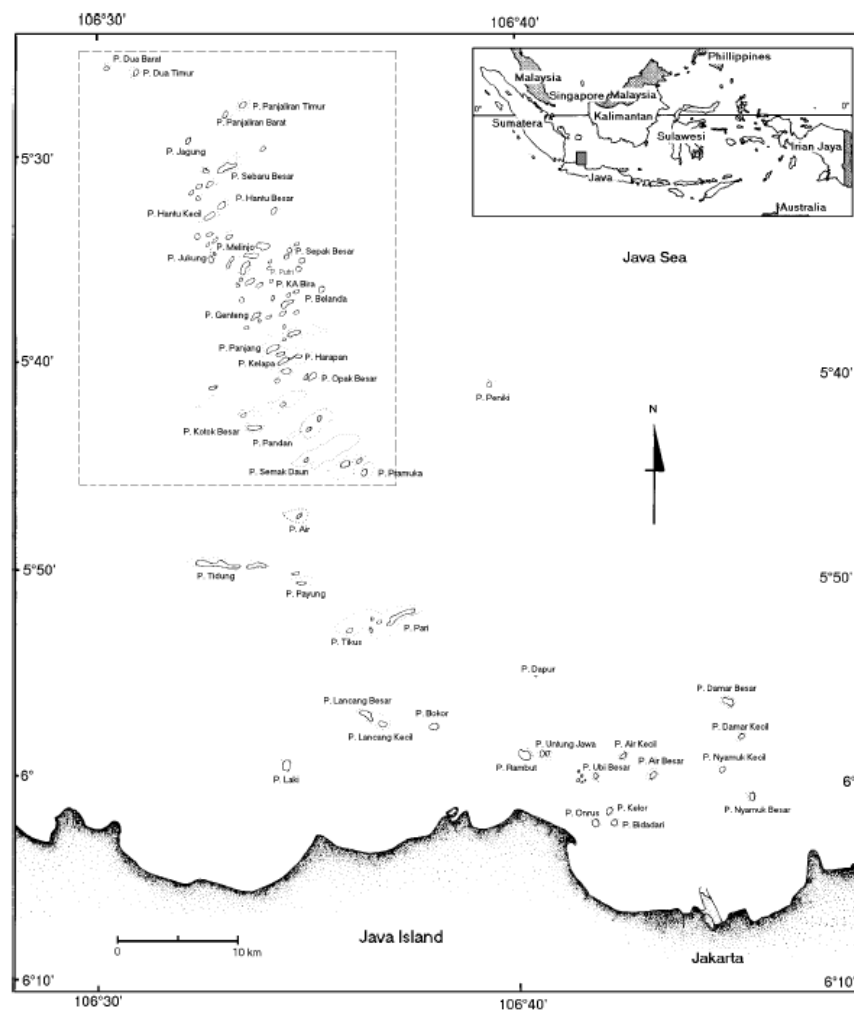


Figure 5.5: Seribu Islands Map (Islands under conservation zone are inside the dashed-line)

The salinity in Seribu Islands varies between 31 – 33 psu. A primary maximum, with salinity value of 32.5 – 33.0, is usually found in November. This is due to the end of the dry seasons and inflow of high salinity water of about 34.2 psu from Flores Sea driven by the southeast monsoon current. The secondary maximum usually occurs in May when water from the South China Sea with a salinity of about 32.5 psu is brought up by the northeast monsoon. The average water temperature in the region is about 29 – 31 °C. Higher temperatures occur

during the transition period from the northwest to the southeast monsoon (April – May), whereas lower temperatures occur during the transition of the southeast to the northwest monsoon (October – November) [Ilahude, 1980]. The SEAWATCH buoy data gives an average value of 28 °C for temperature and 32.5 psu for salinity.

Concentration of suspended particulate matter in the offshore areas of Jakarta Bay amount to 5.0 – 19.4 mg/l. Higher concentrations are generally found in the coastal area close to the river mouth (Ciliwung) where they can reach to 186.49 mg/l [Ilahude, 1980]. Santoso et al. (1977) measured a pH in Jakarta Bay of about 7.5 – 8.2 close to river mouths and 7.9 – 8.2 in the offshore area. An average dissolved oxygen value of 4.51 mg/l was observed in the Java Sea [Ilahude, 1980].

Concerning plankton primary productivity, Praseno (1980) found a value of 1.86 to 8.96 mg C/m³ / hour in the Seribu Islands area. In Jakarta Bay the chlorophyll concentration ranged from 0.9 – 5.41 mg/m³ with a maximum value of 17.96 mg/m³.

5.1.2 Riau Archipelago

Riau Archipelago spreads over the southern part of the Malacca Strait, the Karimata Strait and the southern part of South China Sea (Figure 5.6). The Archipelago consists of 1062 islands, with about 345 islands inhabited by a population of about 5 million [DITP3K, 2002]. The islands are separated by narrow and usually deep channels. Although the coasts tend to be steep, flat areas partly exposed during low tide exist in some bays.

Glude (1982) found vast stretches of the shorelines covered with mangrove forests. Intertidal beaches also occur varying from solid rock to gravel, sandy silt and silt. A few coral sand beaches can be found in areas exposed to waves. The islands themselves are mostly covered by forest and are moderately high with hills between 200m to 400m. In many places the mineral soil consists of red bauxite ore, which is mined and exported overseas. Higher silt loads have been observed in some of the channels due to the mining activities.

The main current type in the area is tidal current. SEAWATCH data, from a buoy installed at 1.184 °N; 104.252 °E (North-western side of the Bintan Island), reveal an average value of 0.4 m/s and maximum values of about 1.5 m/s. The buoy registered measurements from March 4th – September 17th 1999.

The tidal range in the islands is about 0.8 m during neap tides and up to 1.8 m during spring tides. According to DITP3K (2002), tidal conditions affect capture fisheries in the area. Based on the fishermen's experiences, the fish yield during neap tide is much higher than during spring tide. Average wave height (SEAWATCH buoy) is 0.3 m with a maximum height of 1.2 m. The average wave period is 3.5 seconds.



Figure 5.6: Riau Islands Map

The climate of the Riau Islands is uniformly warm with average air temperatures of 27.5 °C. Like any other place in Indonesia, the area is affected by the monsoon. The winds are moderately strong during the northwest monsoon seasons. Tropical typhoons do not occur in this area. The average wind speed as assessed by the SEAWATCH buoy is about 3.3 m/s with a maximum wind speed of 12 m/s.

Due to investigation of Glude (1982), the temperature and chemical properties of the Riau Islands waters are suitable for the mariculture of tropical species. Seawater temperatures in the area lie in the range of 26 – 30 °C. Salinity ranges from 26 to 32 psu. Typical pH values of 7.1 – 7.6 were observed. Dissolved oxygen concentrations are around 4.5 – 5.0 mg/l. Nitrate concentrations in the area are generally around 0.43 mg/l in open waters and up to 2.45 mg/l in the bays close to the lands. Concentrations of phosphate are in the range of 0.25 – 0.45 mg/l. Both nitrate and phosphate levels indicate a low level of pollution.

5.2 Data Availability

In general, data for this study can be divided into three categories; (1) existing data, (2) direct field measurement data and (3) data derived from numerical model simulations.

Existing data are available through the internet, previous measurements done by several Indonesian and foreign agencies, data from the global ocean model for physical or chemical properties of seawater, and nautical charts. A complete list of existing data is presented in the Table 5.1.

Table 5.1: Existing data

| Nr. | Project/Agency | Parameters/Data Type |
|-----|---|--|
| 1. | BAKOSURTANAL (<i>Badan Koordinasi Survey dan Pemetaan Nasional</i>) National Coordinating Agency for Surveys and Mapping | <ul style="list-style-type: none"> - Hourly water level (26 stations, 1995 – 2000) - Bottom sediment type map - Coastline of Indonesia (ArcGIS format) |
| 2. | DISHIDROS (<i>Dinas Hidro-Oseanografi</i>) Hydro-Oceanographic Service | Bathymetry data from the following charts: <ul style="list-style-type: none"> - Sea Chart Nr. 414-KK : Jukung to Peniki Island 1 : 50,000 - Sea Chart Nr. 941A : Singapore Strait to Java Sea 1 : 1,552,500 - Sea Chart Nr. 2056 : Selat Sunda and Approaches 1 : 250,000 - Sea Chart Nr. 3482 : Singapore Strait to Song Sai Gon 1 : 500,000 - Sea Chart Nr. 3946 : Port Klang to Malacca 1 : 200,000 - Sea Chart Nr. 3947 : Malacca to Singapore 1 : 200,000 - Sea Chart Nr. 3949 : Riau Strait 1 : 125,000 |
| 3. | BPPT (<i>Badan Pengkajian dan Penerapan Teknologi</i>) Agency for the Assessment and Application of Technology | SEAWATCH buoys time series data from the buoy in Seribu Islands (November 1998 – August 1999) and Bintan Islands (March – September 1999) for the following parameters: <ul style="list-style-type: none"> - Current velocity and direction - Water temperature - Salinity - Wave height and period - Wind speed and direction - Air pressure - Air temperature |
| 4. | LAPAN (<i>Lembaga Antariksa dan Penerbangan Nasional</i>) The National Institute of Aeronautics and Space | Field measurements data on July 2005 at Seribu Islands for the following parameters: <ul style="list-style-type: none"> - Current velocity and direction - Depth - Light penetration - Water temperature - Salinity - PH - DO - BOD - Chlorophyll-a |
| 5. | DKP (<i>Departemen Kelautan dan Perikanan</i>) Ministry of Marine Affairs and Fisheries | Indonesian fisheries statistics (including mariculture) |

| | | |
|-----|---|--|
| 6. | SEKNEG (<i>Sekretariat Negara</i>) National Secretary | Mariculture regulations |
| 7. | Hydrography Working Group, Faculty of Civil Engineering and Planning, Bandung Institute of Technology | Field measurement data on December 1999 and February 2000 at Pramuka Island for the following parameters: <ul style="list-style-type: none"> - Current velocity and direction - Bathymetry - Wave height and period - Salinity - Temperature - Wind speed and direction - Air temperature |
| 8. | National Center for Environmental Prediction (NCEP) – USA | Global six hourly reanalysis data with the resolution of 1.87 degrees (192 x 94 grid) for wind and sea level pressure |
| 9. | National Oceanographic Data Center (NODC) – USA | World Ocean Atlas (WOA) 2001, which provides monthly, seasonal and annual average values in 33 standard depths and one degree resolution for: <ul style="list-style-type: none"> - Water temperature - Salinity - Dissolved oxygen - Apparent oxygen utilization - Percent oxygen saturation - Phosphate - Nitrate - Silicate - Chlorophyll - Plankton Biomass World Ocean ¼ degree resolution world wide data of Salinity and Temperature |
| 10. | National Geophysical Data Center (NGDC) – USA | ETOPO-5, which provides 2 minutes resolution of Earth's topography data |

There are four categories of data used as DSS input as shown in Figure 6.2. The categories are (1) physical, (2) chemical, (3) sediment, and (4) coastal use parameters. Physical parameter data were derived from nautical charts (water depth) and numerical modelling of flows and waves. The development and results of the numerical models are described in detail in the section 5.3. Sediment data were taken from sediment maps provided by BAKOSURTANAL (1998) as shown in Figure 5.2. Coastal use data (location of navigation line, harbour, industrial and tourism area) were derived from nautical charts.

Chemical properties including water temperature, salinity, dissolved oxygen, ammonia, pH, nitrate and phosphate were derived from the World Ocean Atlas 2001 (WOA'01) [Conkright et al., 2002]. WOA'01 is a set of global statistic data (monthly, seasonally, and annually) at standard depth levels by with a one-degree square spatial resolution of several commonly measured ocean variables, as well as objectively analyzed fields of these variables. The ocean

variables included in this series are in-situ temperature, salinity, dissolved oxygen, apparent oxygen utilization, percent oxygen saturation, phosphate, nitrate, silicate, chlorophyll and plankton biomass. There are 33 standard depths from surface (0 m) up to 5500 m depth, and the number of standard depth for each sample location depends on the water depth on that point. Figure 5.7 shows the location of sample points of WOA in Indonesian waters for 1° and $\frac{1}{4}^\circ$ data resolutions. For the inner area of Indonesian waters (Java Sea, Karimata Strait, and Malacca Strait), each data contains up to 7 standard depths (up to 100 m depth). For the purpose of DSS input, only the surface layer of mean annual WOA'01 data was selected.

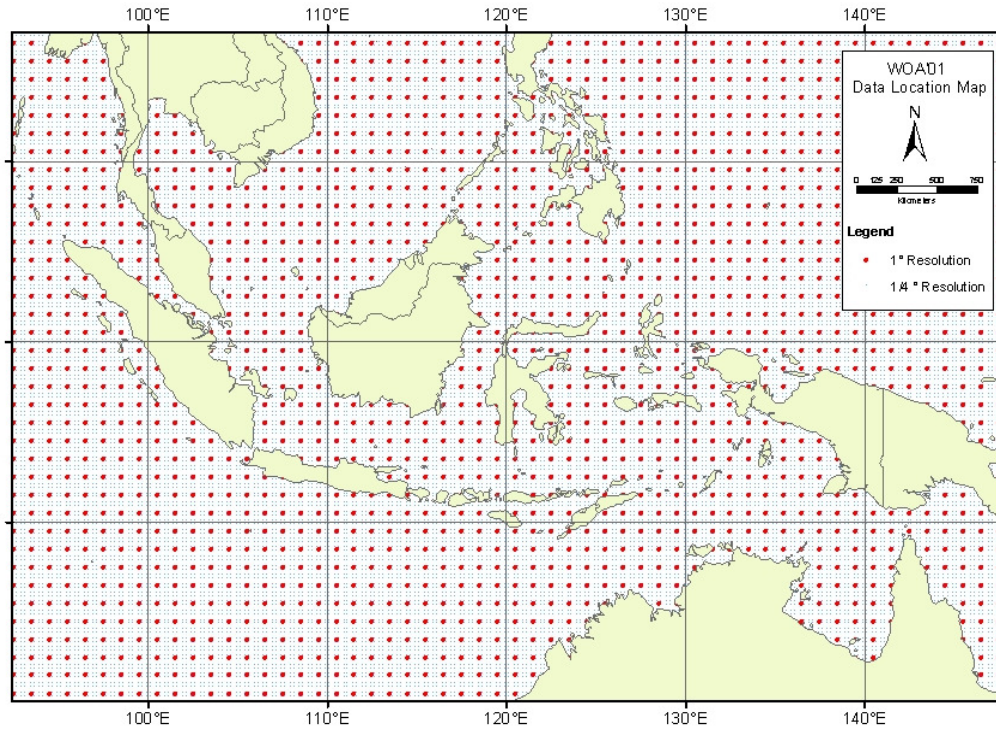


Figure 5.7: Location of sample points of WOA'01 in Indonesian waters

5.3 Development of Numerical Models

Numerical models for the study areas were developed in order to generate simulated hydrodynamic data (water level, current velocity and wave) covering the entire area of investigation. Simulations were carried out applying the Delft3D Modelling System developed at Delft Hydraulics, the Netherlands. In this study both Delft3D version 3.23.02.01 under LINUX and Delft3D version 3.25 under WINDOWS operating system were used.

The Delft3D modelling system is a flexible, integrated modelling environment, capable of simulating, among others:

- flows due to tide, wind, density gradients and waves
- propagation of directionally spread waves over uneven bathymetries
- Initial and/or dynamic waves (time varying)
- 2D-morphological changes (including the effects of waves on sediment stirring and bed-load transport)

The hydrodynamic module used in this study is a multi-dimensional hydrodynamic simulation program which calculates non-steady flow phenomena resulting from tidal and meteorological forcing on a curvilinear, boundary fitted grid. A 2DH-approach was employed throughout this study. The 2DH module solves the non-steady depth-integrated momentum and continuity equations for the depth-integrated velocities and water levels on curvilinear grids. An implicit scheme is adopted for the time integration that enables simulations with Courant numbers as high as 10. Hydrostatic pressure is assumed. Details of the flow module can be found in the User Manual of the package (WU|DELFT HYDRAULICS, 2005).

The general procedure of the development of a hydrodynamic numerical model consists of the following steps (see Figure 5.8.):

1. *Development of model domain*

The first step is the development of model domain, including that of the numerical grid and the interpolation of bathymetry data. It requires coastline shape and location, as well as bathymetry data for the whole domain.

2. *Definition of boundary and initial conditions*

Since the numerical model is based on the solution of the ordinary or partial differential equations, boundary and initial conditions have to be imposed to fit the solutions to the actual problem. The boundary condition is a condition specified for the solution to a set of differential equations. In terms of hydrodynamic numerical model boundary conditions, it is the value imposed along the boundary to generate the simulation. Initial conditions are conditions imposed at a time $t = 0$ all over the domain.

The locations of open boundaries (water boundaries) and closed boundaries (land boundaries) have to be defined. The value for the boundary can be defined as time series data, harmonic-constituents, discharge, or as numerical formulation. It requires measurement data (e.g. water level, current velocity or river discharge).

3. *Definition of input parameters and selected processes*

There are some options of selected processes and parameters to be included in the simulation. The selected processes and parameters require data input from measurements or from another numerical model. Examples of the parameter input are information about meteorological conditions (wind, precipitation, humidity, air temperature etc), bed sediment properties (bed roughness), and physical properties of water (salinity and temperature).

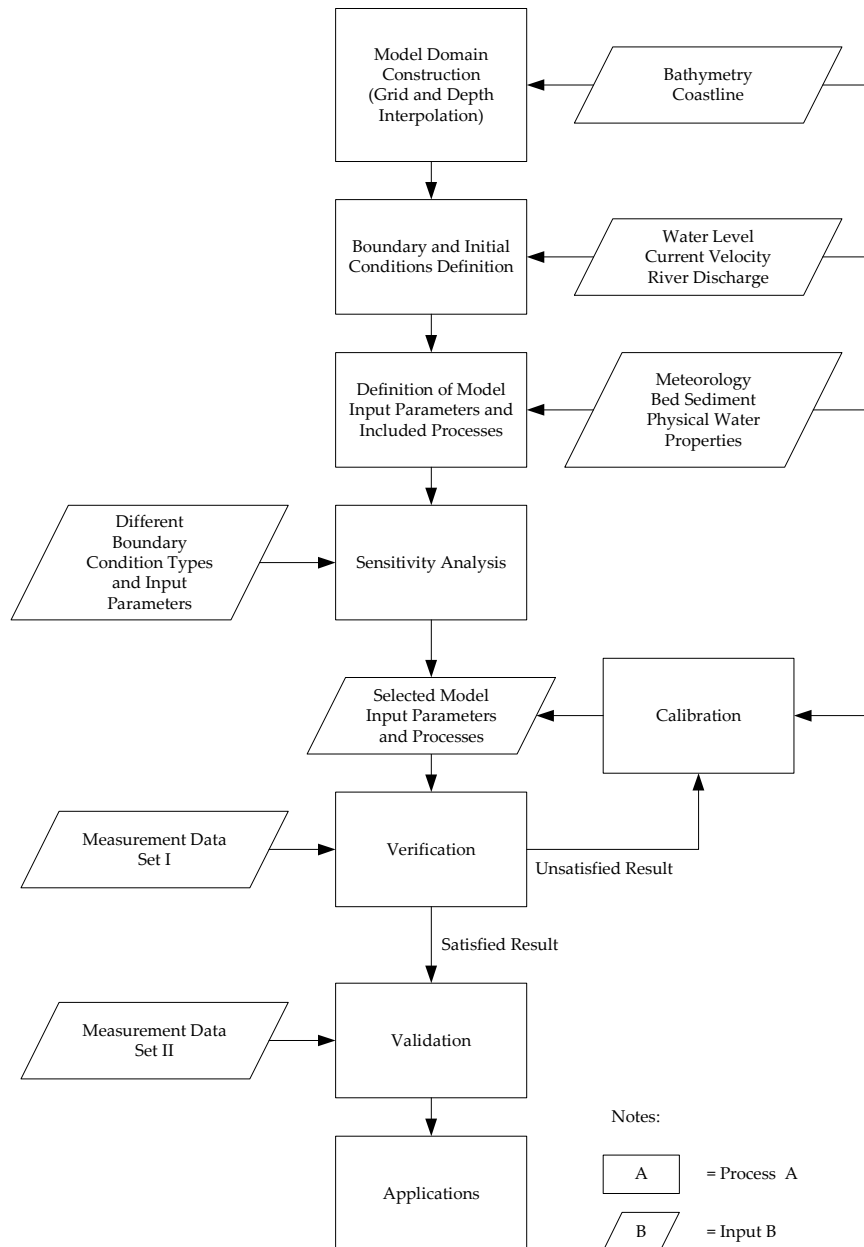


Figure 5.8: General procedure of development of the hydrodynamic numerical model

4. Sensitivity analysis

Different selections of boundary condition type, initial condition values, included processes and input parameters may affect the model results. Sensitivity analysis is aimed to assess this effect. The results of the sensitivity analysis is the conclusion of which processes and parameters will be selected for the future simulations.

5. Verification of model results

Model results may exhibit different behaviours with the natural phenomena; therefore model results have to be verified with the measurement data. If the results are not satisfied then the selected processes or parameters may have to be calibrated. The satisfaction level is usually based on the statistical parameter.

6. *Model Calibration*

Calibration of the model is done by selection of different processes or input parameters. Generally the calibrated parameters or processes are based on the measurement data. The process of calibration may be iterated until the results come to a satisfied level.

7. *Validation of model results*

After the verification and calibration, further assessment of the model performance on a period different than the verification period must be done. This assessment is called validation. In the validation, capability of the model is assessed, i.e. whether the model is also capable to produce good results in different period of simulation.

8. *Application of model*

The model can be applied if the validation gives satisfying results. The simulation results is then assumed to represent natural realistic conditions. Furthermore, in the case of a hydrodynamic model, it can be coupled to other numerical model modules, such as water quality, sediment transport, wave and morphology.

The flow model provides information about water level and current velocity conditions over the model domain. In order to provide wave information, in this research, the wave module SWAN was also employed after the simulation of flow condition.

5.3.1 Java Sea Model

A. **Bathymetry and Grid**

The Java Sea Model covers the Java Sea between 4°10' S - 6°10' S and 105°45' E - 117°0' E. The bathymetry of the model domain was digitised from the nautical chart nr.2056 (Selat Sunda and Approaches) 2003 edition and nr. 414.KK (Pulau Jukung hingga Pulau Peniki) 1995 edition in combination with the depth measurements from December 1999 in the area of Pramuka Island.

The model grid is curvilinear with a grid size of 170 - 400 m. There are 297 x 363 cells in total. The grid and its position relative to Sumatera and Java Island are presented in Figure 5.9. The grid was made with respect to the Universal Transverse Mercator Coordinate Systems zone 48 South with the central meridian of 105°E and central latitude at the equator.

The model domain is located in the Java Sea with a depth around 50 m. The domain is mainly influenced by the flow conditions of the Java Sea and the Indian Ocean through the Sunda Strait on the Southwest boundary. The tidal range in this area is around 80 – 100 cm with a semi diurnal type in the western part and diurnal type in the eastern part.

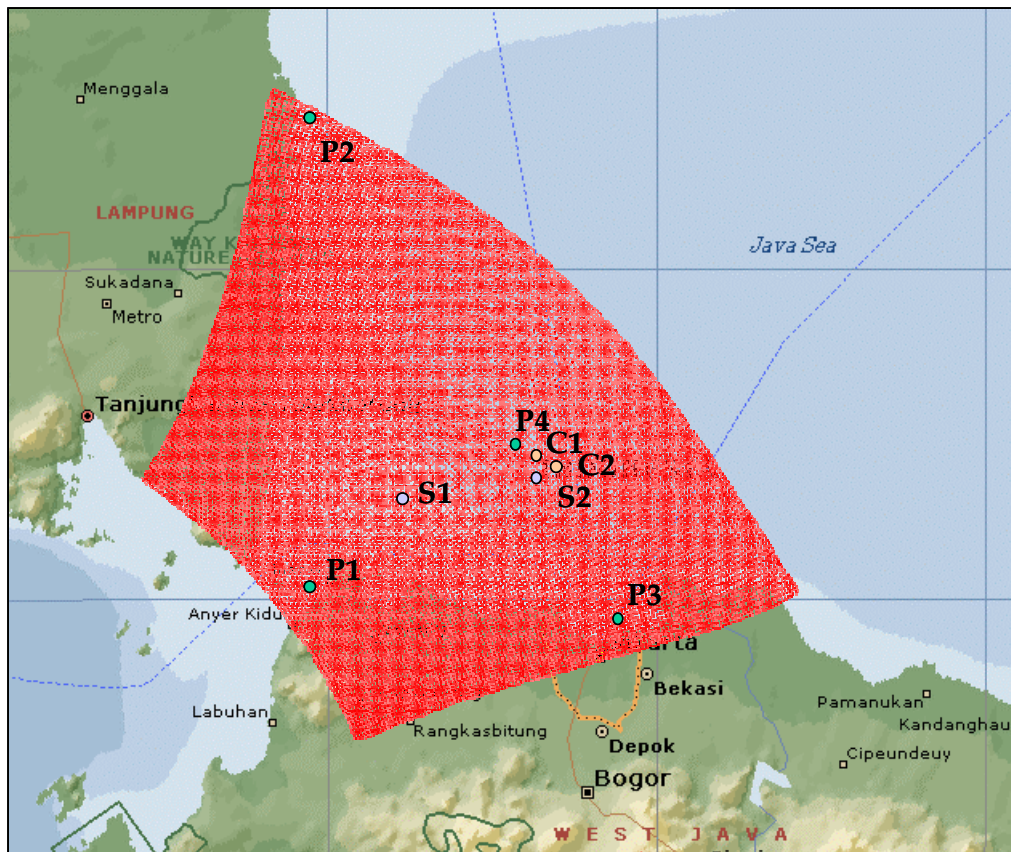


Figure 5.9: Numerical grid of Java Sea Model domain

B. Open Sea Boundaries

The open sea boundaries are imposed by astronomical tides derived from a global ocean tide model (i.e. TPXO 3.0). Eight harmonic components (M2, S2, K2, N2, O1, K1, P1, and Q1) are used to drive the model. The open boundaries are located on the southwest, the north and the east. There are 16 boundary segments at western part and 63 segments at the eastern boundary. The boundary value should be given at the end of each segment; the boundary value at the middle of the segment will be interpolated automatically by DELFT3D. Table 5.2 shows the examples of harmonic component values as they were given for first and last segments at the western and eastern boundary.

Table 5.2: Astronomical constituent input for Java Sea Model

| Constituent | Western Boundary | | | |
|-------------|----------------------------|---------|---------------------|---------|
| | Beginning of First Segment | | End of Last Segment | |
| | Amplitude | Phase | Amplitude | Phase |
| M2 | 0.372 | 20.023 | 0.234 | 203.355 |
| S2 | 0.155 | 83.263 | 0.116 | 270.750 |
| K1 | 0.148 | 83.234 | 0.065 | 222.120 |
| O1 | 0.093 | 70.033 | 0.036 | 227.463 |
| N2 | 0.079 | 349.905 | 0.047 | 170.767 |
| P1 | 0.045 | 80.747 | 0.018 | 217.008 |
| K2 | 0.052 | 88.772 | 0.034 | 275.219 |
| Q1 | 0.019 | 52.385 | 0.007 | 208.225 |
| Constituent | Eastern Boundary | | | |
| | Beginning of First Segment | | End of Last Segment | |
| | Amplitude | Phase | Amplitude | Phase |
| M2 | 0.066 | 359.325 | 0.020 | 110.161 |
| S2 | 0.005 | 17.604 | 0.057 | 311.577 |
| K1 | 0.158 | 131.031 | 0.280 | 137.121 |
| O1 | 0.079 | 113.475 | 0.139 | 99.207 |
| N2 | 0.020 | 292.480 | 0.024 | 61.070 |
| P1 | 0.043 | 116.563 | 0.085 | 134.259 |
| K2 | 0.007 | 234.813 | 0.018 | 13.340 |
| Q1 | 0.002 | 453.083 | 0.028 | 84.085 |

C. Initial Conditions

The initial velocity was taken to be zero and the water surface elevation was set to zero relative to the mean sea level. To avoid the effects of the artificial values on the computational results, a sufficient warming up period of about 48 hours was considered.

D. Physical and Numerical Parameters

Table 5.3 summarises the physical and numerical parameters selected as base input parameters for the Java Sea Flow Model.

Table 5.3: Physical and numerical parameters of Java Sea Model

| Parameter | Setting |
|---------------------------|---|
| Gravity acceleration | 9.81 m/s ² |
| Water density | 1023 kg/m ³ |
| Manning Roughness | 0.03 m ^{1/2} /s |
| Horizontal Eddy Viscosity | 1 m ² /s |
| Wind | NCEP wind data |
| Threshold depth | 0.1 m |
| Marginal depth | -999.99 m |
| Smoothing time | 60 |
| Simulation Periods | Oct 5 th – 17 th , 2004 |
| Time Step | 2.5 minutes |
| Interval Data Stored | 10 minutes |

A velocity point is set dry when the actual water depth is below that of the threshold depth; when the local water depth is above twice the threshold, the velocity point is set again. This is done to prevent drying and flooding in two consecutive time steps. The marginal depth is a default depth value for the model to recognize whether the grid point is active or not. The smoothing time is the time during which the assignation of the model's initial water level to the imposed boundary water levels is enhanced.

E. Sensitivity Analysis

The sensitivity analysis of the Java Sea Model with respect to different time steps, roughness and wind input were done. The original/base model used the parameters as described in paragraph D. A three-day simulation period (October 10th to October 13th 2004) was considered. Two observation points representing deep (± 40 m) and shallow (± 5 m) water for analysis of the model results were used. The first observation point is located at the western part of model domain and another one at the eastern part (point S1 and S2 in Figure 5.9 respectively).

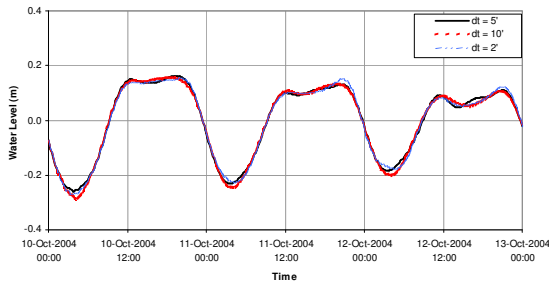
Effect of Time Step

Time steps equal to 2.5, 5 and 10 minutes were considered. The simulations are run with the base scenario and the variation in the time step. Comparison of the resulting water surface elevations, velocity magnitudes and directions covering the selected period at the observation points located in the deep and shallow water are shown in Figure 5.10.

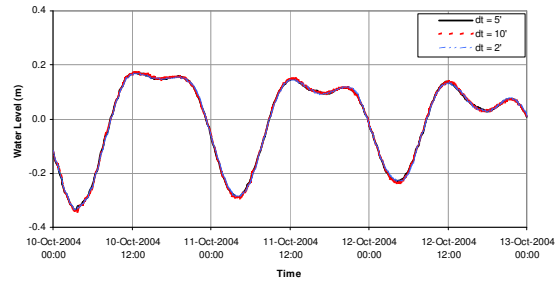
It can be seen that the current velocities and directions are very sensitive to the time step changes (although the water level is not really affected). This occurs particularly in the deep water (point S1), since the time step affects the Courant number, which is related to the numerical solution stability (see Equation 5.1). In DELFT3D computation scheme, generally it is necessary to keep the Courant number no more than 10 [WL|DELFT HYDRAULICS, 2005]. Based on equation 5.1, a Courant number of about 45 results in the depth of 40 m and 17 in the depth of 5 m, if the time-step is 10 minutes. A Courant number less than 10 will be produced if the time step is reduced to 2.5 minutes. Therefore, based on these results the time step of 2.5 minutes is satisfactory and is adopted for the future use in the model.

$$Cr = \frac{\Delta t \cdot \sqrt{gH}}{\{\Delta x, \Delta y\}} \quad \dots (5.1)$$

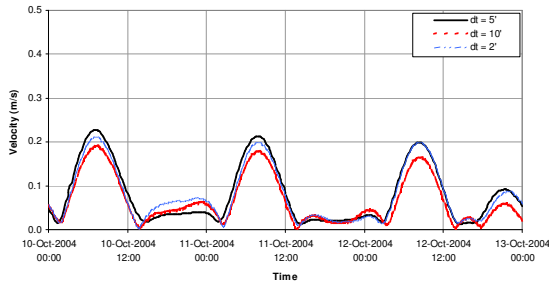
where Cr = Courant number
 Δt = Time step (second)
 g = gravity acceleration coefficient (m/s²)
 H = water depth (m)
 $\{\Delta x, \Delta y\}$ = minimum of Δx or Δy (m)



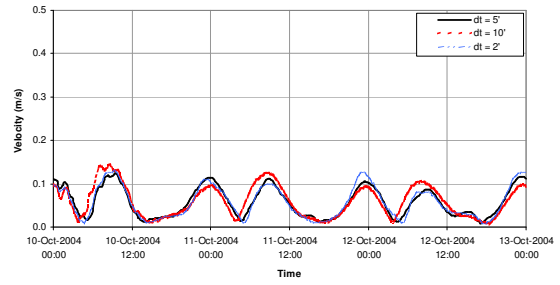
a1. water level at point S1



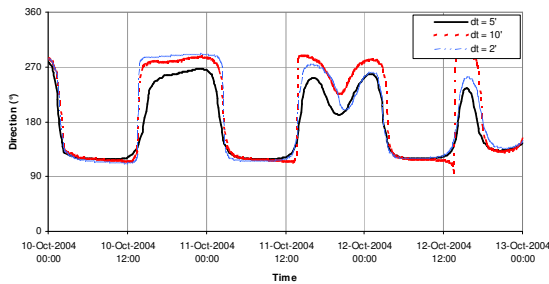
a2. water level at point S2



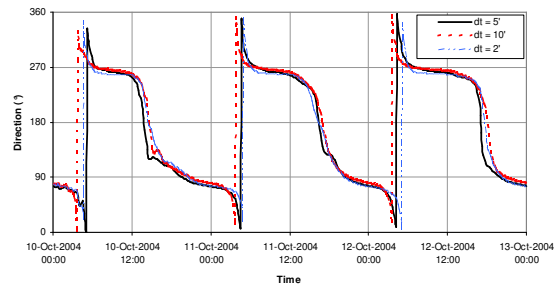
b1. current magnitude at point S1



b2. current magnitude at point S2



c1. current direction at point S1



c2. current direction at point S2

Figure 5.10: Sensitivity analysis due to change of time step

Effect of the wind

The effect of local wind fields on computed water levels and velocities was investigated. Simulations were carried out considering the following conditions in terms of wind fields (constant in time and space): 1) no wind; 2) constant wind field of 5 m/s from west; and 3) constant wind field of 10 m/s from west.

The results obtained in the observation points are shown in Figure 5.11. The variation in water levels do not show significant changes except for the condition of 10 m/s constant wind. Since the domain area is quite large, the wind effect can be shown clearly in the current velocities and direction variations even with 5 m/s constant wind over the entire time. Therefore, in the future simulations wind data should be included in the computation.

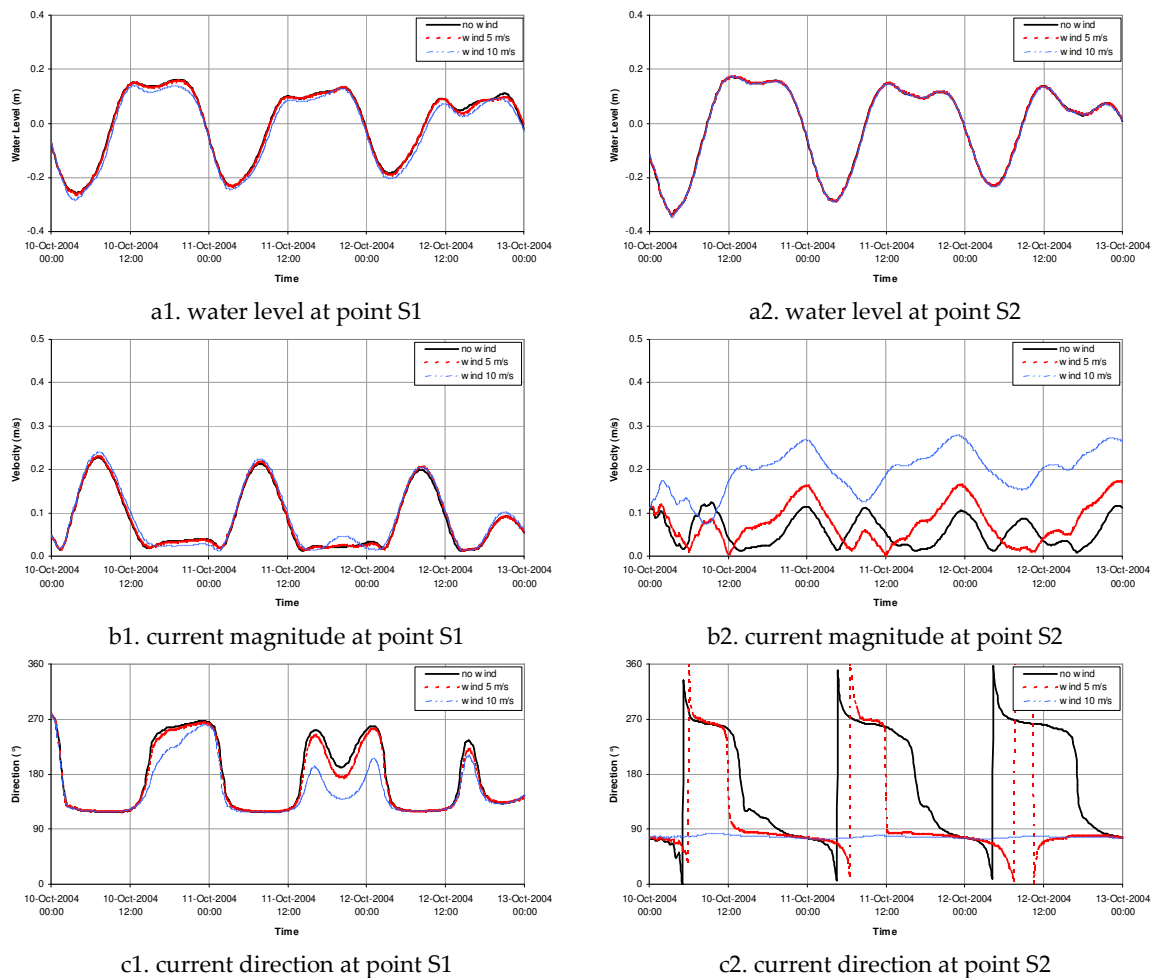


Figure 5.11: Sensitivity analysis due to change of wind conditions

Effect of bottom roughness

In the model the effect of roughness was accounted for through Manning coefficients. Constant bottom roughness coefficients of 0.02, 0.025, and 0.03 were considered.

The results obtained in the monitoring points in terms of the water surface elevations and velocities (magnitude and direction) covering the selected period for the analysis are shown in Figure 5.12. The results show a clear dependency of the computed velocities on the bottom roughness. Therefore, bottom roughness is also important to include in the simulation. Information of bottom roughness can be derived from bottom sediment type maps. Further simulations will use the bottom roughness coefficient of 0.03, based on the sediment type of the area (mostly characterized by sandy sediment).

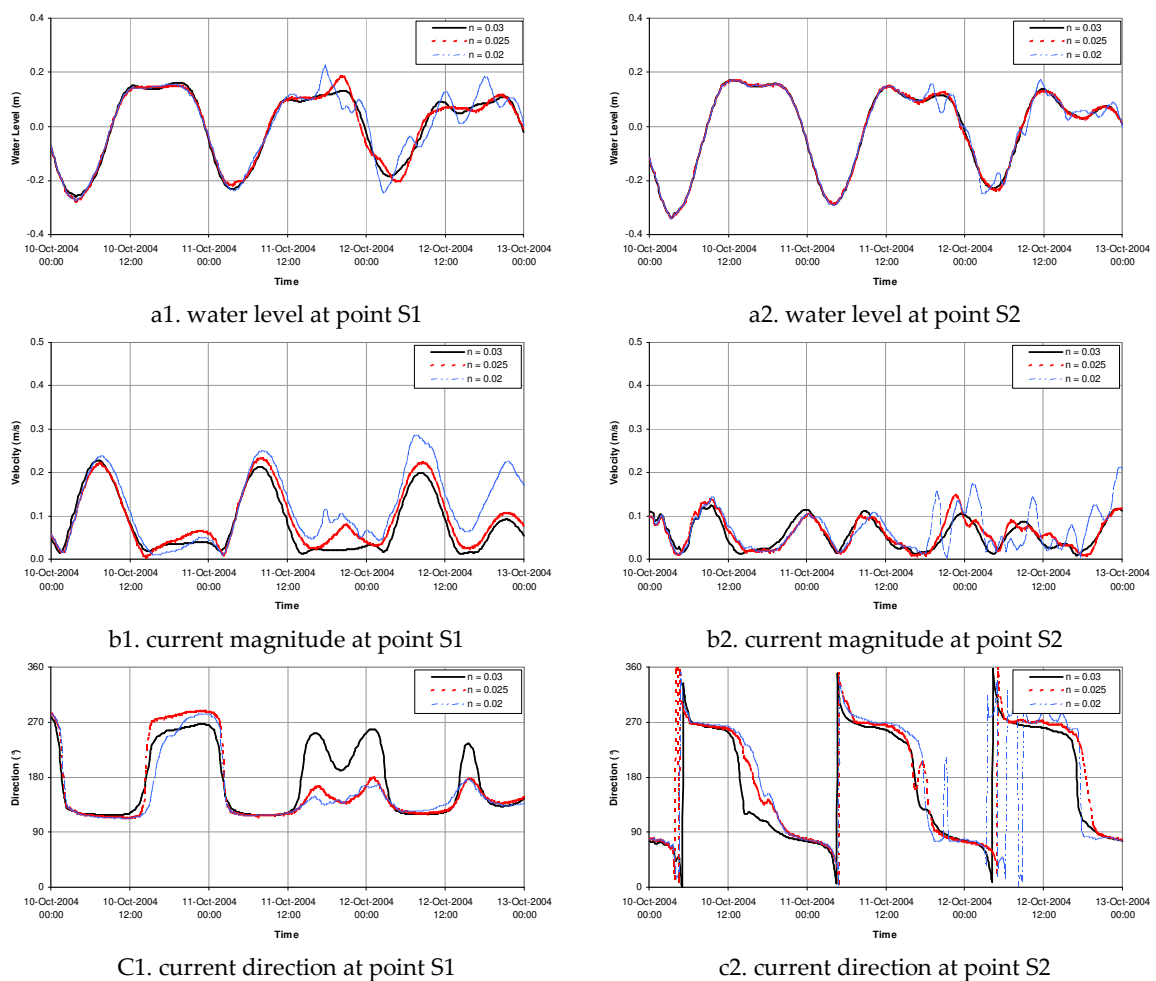


Figure 5.12: Sensitivity analysis due to change of bottom roughness

F. Verification and Calibration

There are four observation points in the domain (P1, P2, P3, P4, C1 and C2 in Figure 5.9) where the measurement data are available. These observation points are:

1. P1-Cikoneng ($6^{\circ}4'S$; $105^{\circ}53'E$), which is located on the western part of Java Island, close to the west open boundary. The data is in the form of tidal harmonic constituents.
2. P2-Teluk Bawang ($4^{\circ}25'S$; $105^{\circ} 51' E$), which is located on Sumatera Island, close to the upper part of the eastern open boundary. The data is in the form of tidal harmonic constituents.
3. P3-Tanjung Priok ($6^{\circ}6'S$; $105^{\circ} 52' E$), this observation point is located at Jakarta (Java Island) close to the lower part of the eastern open boundary.
4. P4-Pramuka Island ($5^{\circ}44'S$; $106^{\circ}36'E$), water level data for this point is available in the form of a time series taken from the tide-gauge measurement (8th – 17th October 2004)
5. Close to the Pramuka Island, current velocity profile data from several measuring transects are available. Measurement of current velocity was done by ADCP (Acoustic Doppler Current Profiler). Current velocity data are available from 43 ADCP transects at four locations. Two points were taken from two locations (C1 and C2) for the purpose of verification, the data from one ADCP transect formed one set of time series data for that location. Since the ADCP measurements were done several times for the same transect line, time series data can be created. The ADCP measured current velocity profiles at each defined depth interval along the transect line. Since the model results are given as 2-dimensional depth averaged current velocities, ADCP data must be depth-averaged as well.

Periods of simulation for verification and calibration were taken for 34 days (29th September – 1st November 2004). A long period of verification was intended to develop tidal astronomical constituents at the observation points in addition to time series data. Based on the sensitivity results, it is important to include wind data in the simulation, even though the wind condition was relatively calm during this period (Figure 5.13). Wind data is provided by National Centre for Environmental Prediction (NCEP) (Table 5.1).

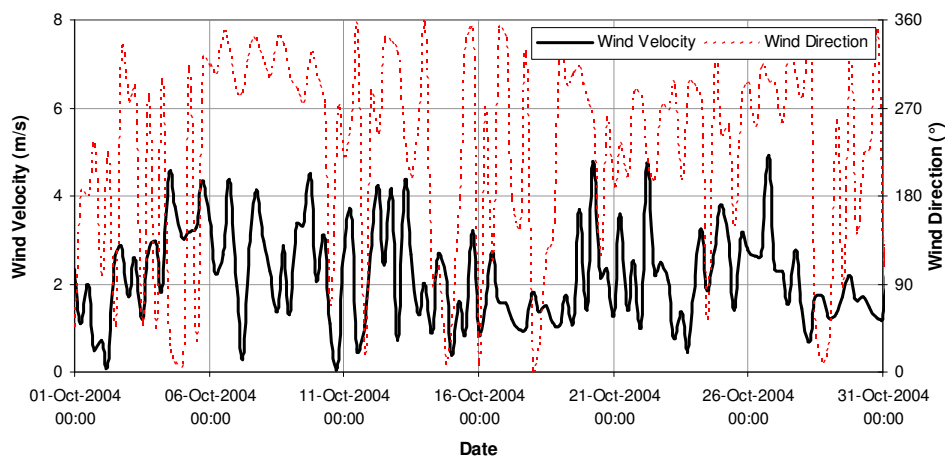


Figure 5.13: Wind condition at Seribu Islands during verification period

Figure 5.14 shows the verification results of the water level time series at four observation points (P1, P2, P3, and P4). This data for the observation points P1, P2 and P3 for the verification period were derived from the astronomical constituents since there were no available time series data during this period. It is clear that there are still some discrepancies in terms of water level. Therefore the model calibration must be done.

The strategy for calibration is to adjust the open boundary values. Since three observation points (P1, P2, and P3) are located close to the boundary, measurement data from these three points can be used for the calibration process. As described before, imposed open boundary values of the model were astronomical constituents derived from the Global Ocean Model TPXO. In the calibration process, these values were adjusted by astronomical constituents from the measurements.

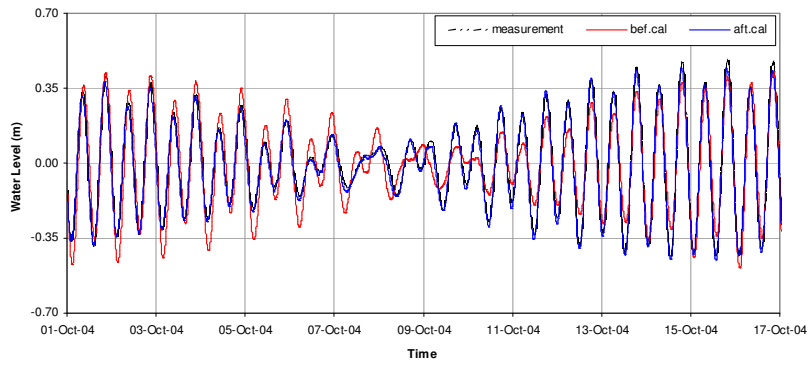
The first step was to derive astronomical constituents from the model results. Since the simulation was taken for 34 days, all harmonic constituents in the open boundary input can be derived for the three observation points (P1, P2 and P3). The comparison of the tidal astronomical constituents from the model results and measurements is presented in Table 5.4.

The next step is to calculate the correction factor of amplitude and phase. In Delft3D, correction for the amplitude is a multiplicative factor and for the phase is an additive factor. Correction factors of amplitude and phase resulted from calculations were then applied to the open boundary near to the observation point for the new simulation. Correction factors for P1, P2 and P3 were applied to the western boundary, the upper part of the eastern boundary and lower part of the eastern boundary, respectively. Figure 5.14 shows the comparison of the model results before and after calibration of open boundary values. Figure 5.14 presents a significant improvement of model results after the calibration process.

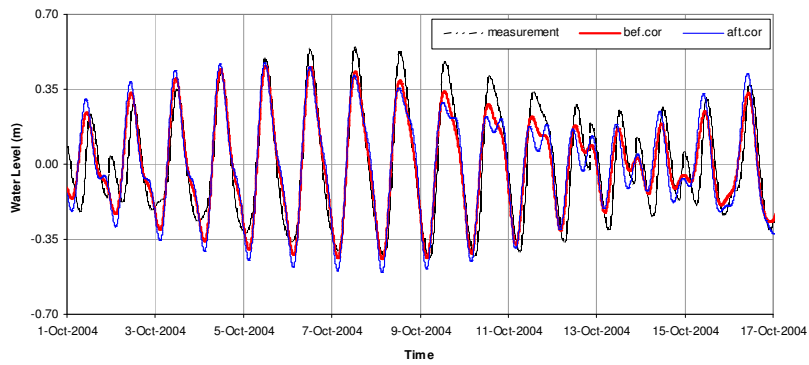
Table 5.4: Comparison of tidal astronomical constituents

| P1-Cikoneng | | | | | | |
|------------------|-----------|-------|-------------|-------|----------------|----------------|
| Constituents | Model | | Measurement | | C _A | C _P |
| | Amplitude | Phase | Amplitude | Phase | | |
| M2 | 0.247 | 199 | 0.245 | 200.8 | 0.992 | 1.800 |
| S2 | 0.125 | 271.9 | 0.13 | 232 | 1.040 | -39.900 |
| K1 | 0.035 | 271.9 | 0.037 | 232 | 1.057 | -39.900 |
| O1 | 0.083 | 218.9 | 0.081 | 249.9 | 0.976 | 31.000 |
| N2 | 0.027 | 218.9 | 0.027 | 249.9 | 1.000 | 31.000 |
| P1 | 0.04 | 206.4 | 0.016 | 187.8 | 0.400 | -18.600 |
| K2 | 0.05 | 167 | 0.041 | 203.5 | 0.820 | 36.500 |
| Q1 | 0.008 | 185.9 | 0.001 | 303.7 | 0.125 | 117.800 |
| P2-Teluk Bawang | | | | | | |
| Constituents | Model | | Measurement | | C _A | C _P |
| | Amplitude | Phase | Amplitude | Phase | | |
| M2 | 0.021 | 110.5 | 0.035 | 66.4 | 1.667 | -44.100 |
| S2 | 0.069 | 327.8 | 0.109 | 8.1 | 1.580 | -319.700 |
| K1 | 0.02 | 327.8 | 0.031 | 8.1 | 1.550 | -319.700 |
| O1 | 0.314 | 140.6 | 0.484 | 146.5 | 1.541 | 5.900 |
| N2 | 0.103 | 140.6 | 0.159 | 146.5 | 1.544 | 5.900 |
| P1 | 0.157 | 97.5 | 0.223 | 76.9 | 1.420 | -20.600 |
| K2 | 0.027 | 62.2 | 0.018 | 61.9 | 0.667 | -0.300 |
| Q1 | 0.032 | 82 | 0.014 | 194.2 | 0.438 | 112.200 |
| P3-Tanjung Priok | | | | | | |
| Constituents | Model | | Measurement | | C _A | C _P |
| | Amplitude | Phase | Amplitude | Phase | | |
| M2 | 0.052 | 8.2 | 0.05 | 352 | 0.962 | 343.800 |
| S2 | 0.036 | 311.5 | 0.051 | 292.9 | 1.417 | -18.600 |
| K1 | 0.01 | 311.5 | 0.014 | 292.9 | 1.400 | -18.600 |
| O1 | 0.249 | 147.3 | 0.245 | 144.6 | 0.984 | -2.700 |
| N2 | 0.082 | 147.3 | 0.08 | 144.6 | 0.976 | -2.700 |
| P1 | 0.122 | 112.7 | 0.129 | 123.2 | 1.057 | 10.500 |
| K2 | 0.015 | 306.6 | 0.017 | 311 | 1.133 | 4.400 |
| Q1 | 0.028 | 93.5 | 0.026 | 130.6 | 0.929 | 37.100 |

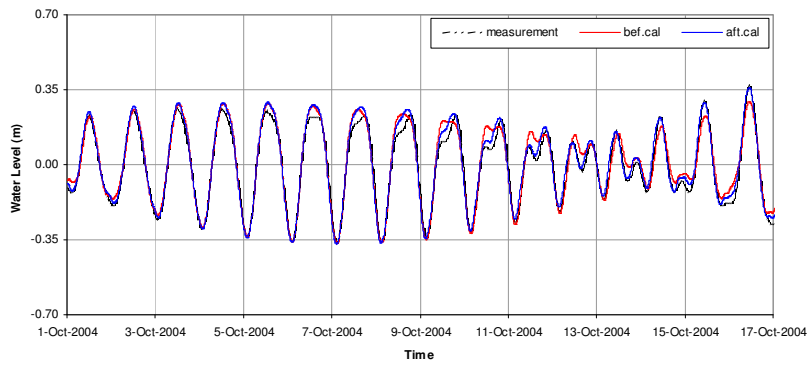
Note : C_A = correction factor of amplitude = modelled amplitude/measured amplitude
C_P = correction factor of phase = modelled phase – measured phase



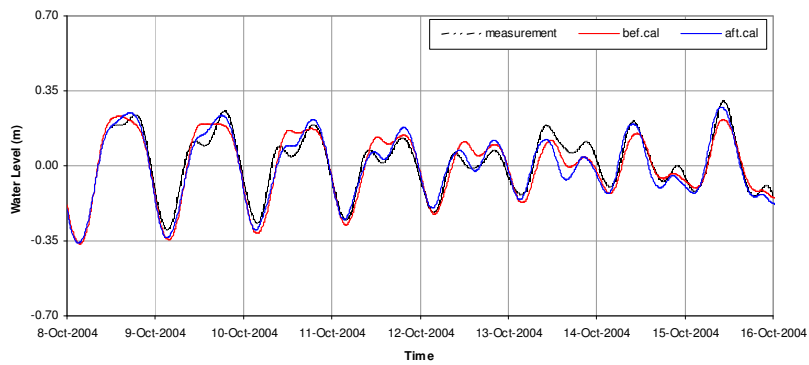
a) P1-Cikoneng



b) P2-Teluk Bawang



c) P3-Tanjung Priok

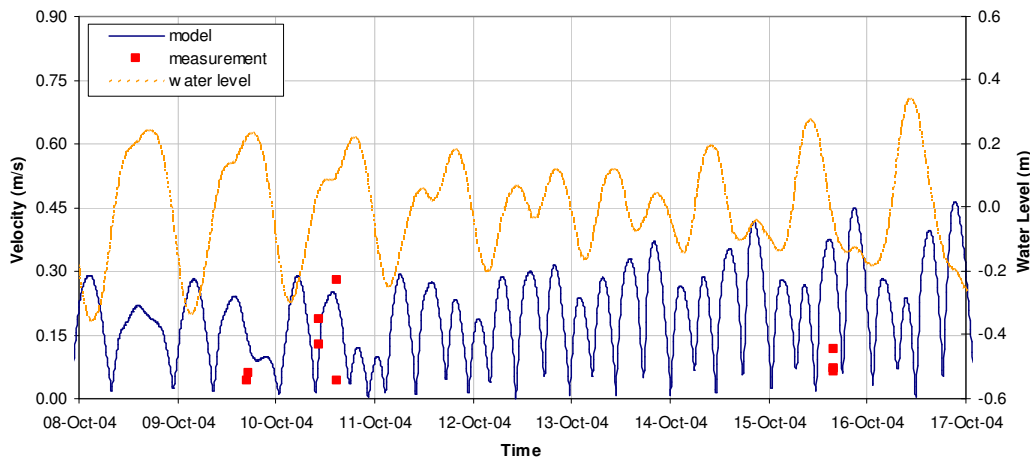


d) P4-Pulau Pramuka

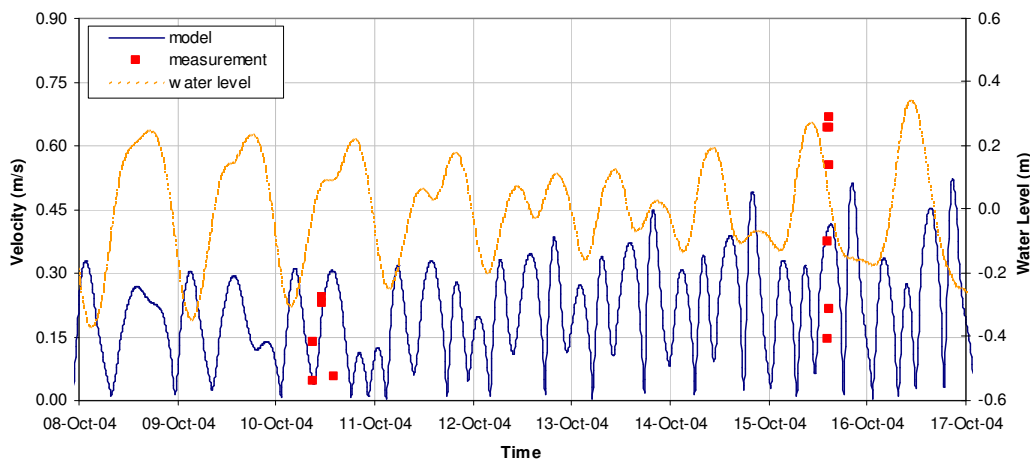
Figure 5.14: Verification of water level from model results to measurement data before and after calibration

In the verification of current velocity results, the model resolution cannot capture the ADCP transect in a proper way. One transect of the ADCP measurement is located only in one or two cells of model domain, therefore the comparison of velocity data cannot be made along the transect. The verification is done by a comparison of time series data of the depth averaged model results at point C1 and C2 to the depth averaged time series data taken from the nearest point to C1 and C2 from the ADCP profiles.

Verification of the depth averaged current velocity from the model results after calibration to the measurement data is presented in Figure 5.15. The results show some discrepancies, which are probably due to different positions of the observation points from the model (with 170 m grid resolution) and the points taken from the ADCP measurement transects. Comparison at point C1 is in good agreement to the measurement data. At C2 some of the results are also in good agreement, except for the data on 15th October 2004, where the highest discrepancies up to 0.25 m/s occurred during ebb current.



a) C1-Panggang Island



b) C2-Pramuka Island

Figure 5.15: Verification of current velocity from calibrated model results to measurement data

The discrepancies in the current velocity results do not actually represent the model performance due to model resolution and measurement data availability. Therefore since the water level and some of the current velocity results are in good agreement, it is concluded that the model exhibits good performance in capturing the natural phenomena of the modelled domain area.

G. Validation

The same observation points were used for the validation as well as for the verification. The simulation period for validation is 9th – 18th April 2004, since another measurement in Seribu Islands was collected during this period.

Validation in terms of water level at four observation points is presented in Figure 5.16. The validation results show a good agreement between model results and measurement, especially close to the western boundary (P1) and southern part of the eastern boundary (P2), where the calibrations were previously made.

Figure 5.17 presents the validation in terms of current velocity. The validation shows better results in point C1 and C2 compared to the verification results. It is probably due to water level conditions when the measurements were taken and more available ADCP measurement data during this period. In the verification period, the measurements were taken when the water level conditions were dominated by mixed conditions of diurnal and semidiurnal, which provide two separate peaks of water levels in one day (Figure 5.15). In the validation period, the water level conditions were more dominated by the diurnal period, which provides more stable conditions with one water level peak each day. Better agreement at this point can also be seen in the water level comparison (Figure 5.16d).

Validation results support the first conclusion after verification that the model is sufficient to provide the information of hydrodynamic conditions in the entire model domain. Therefore the information from the model simulations can be used as data input for the development of the Decision Support System as it is discussed before in Chapter 4.

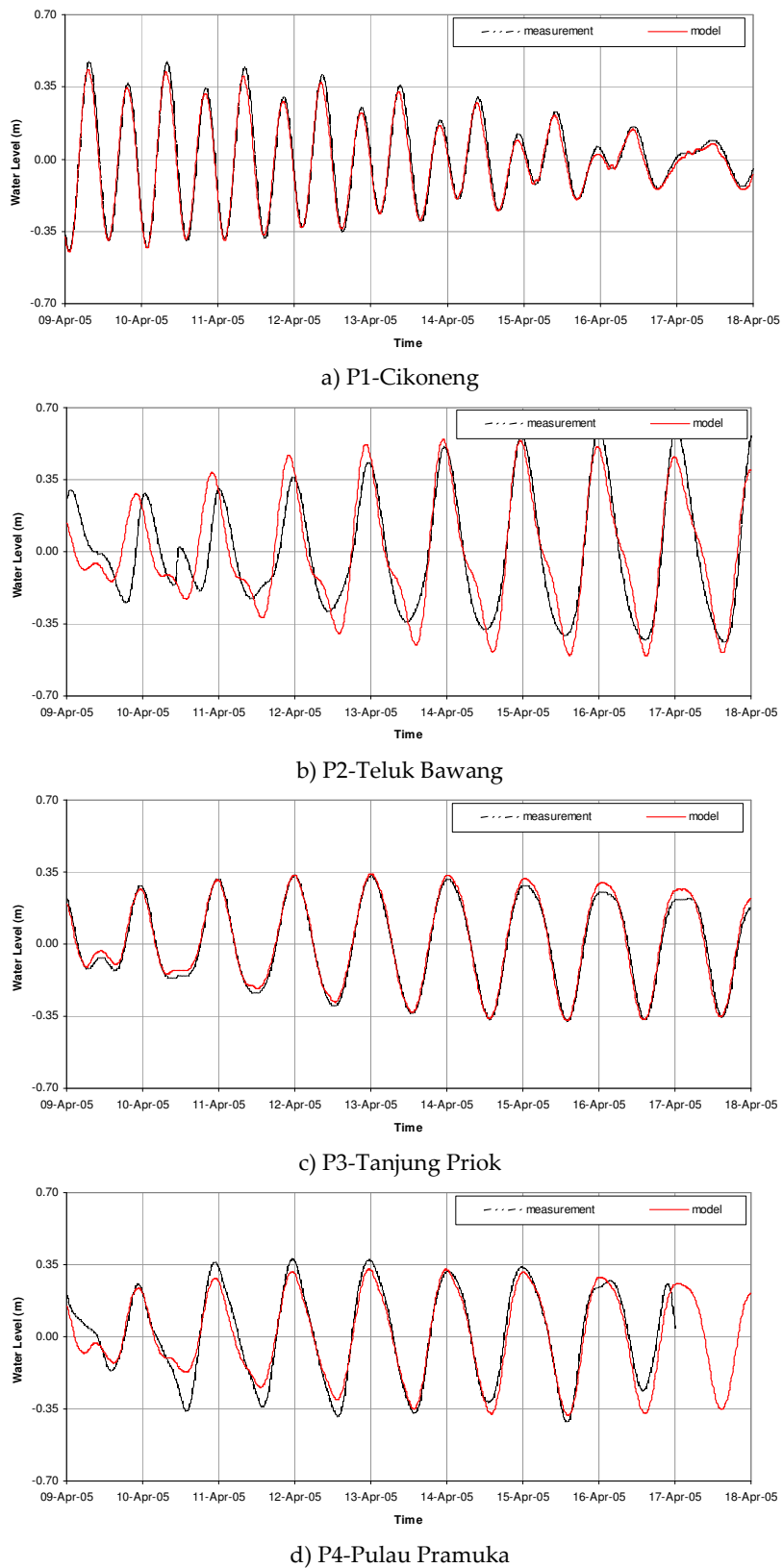


Figure 5.16: Validation of water level model results versus field data

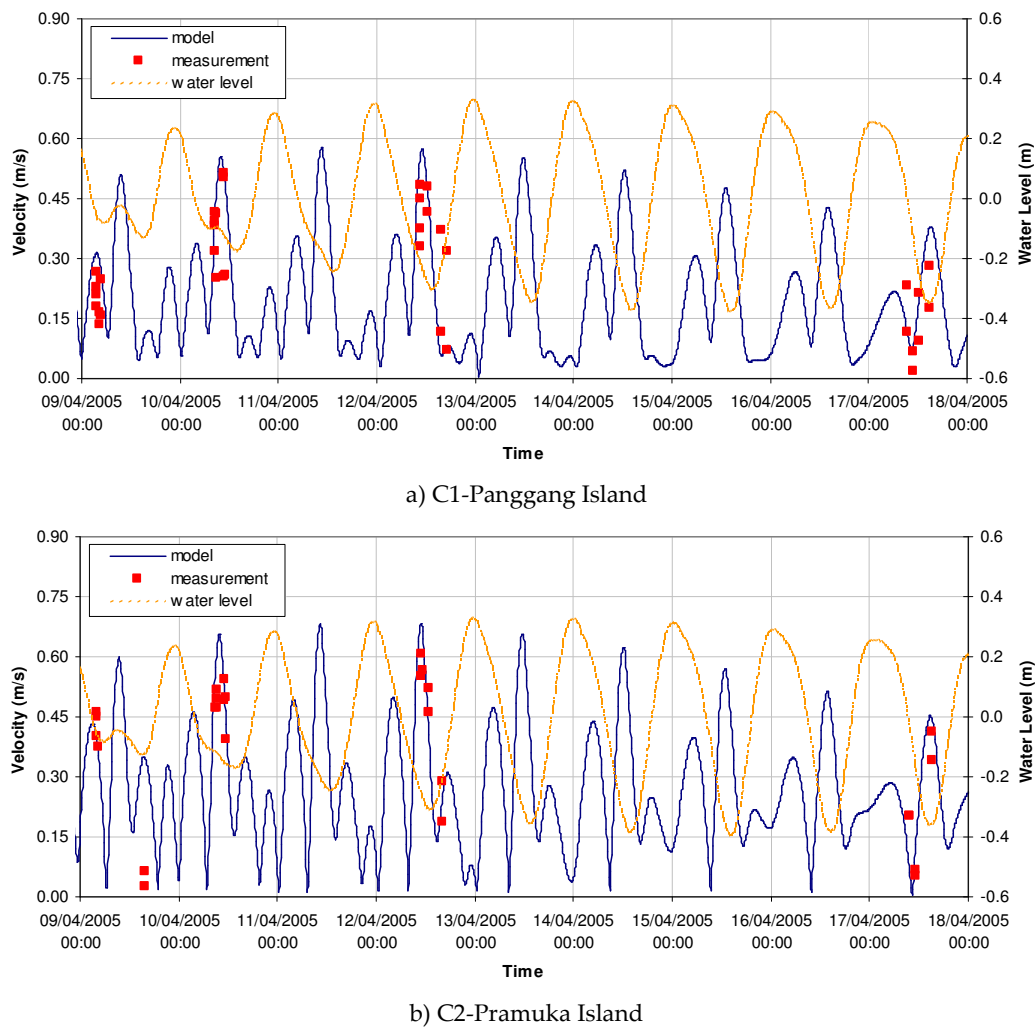


Figure 5.17: Validation of current velocity model results versus field data

H. Wave Modelling

Wave modelling was also done in this study to provide information of wave conditions in the domain. Hydrodynamic model results were coupled to the wave model. The wave themselves were driven by wind. Required information for the DSS input is the possible maximum wave height in the area, which is related to possible highest wind speed. To analyze the possible highest wind speed in the area, NCEP wind data (Table 5.1) was used. Wind data for over 25 years (1980 – 2005) were analyzed. Figure 5.18 shows the wind rose and wind class frequency distribution of the wind data for this period. From statistical analysis, where the wind speeds are divided into 7 classes and wind directions into 8 classes, 50% of the wind speeds are in the range of 2 - 4 m/s and the main wind directions are blowing to northwest and north-northwest (13.6% and 13.9% of the wind directions respectively). It clearly shows the Java Sea area is in the relatively calm weather area, only 0.1% of wind data shows the wind speed over 8 m/s. Maximum wind over this period is 9.5 m/s. Maximum wind speed (9.5 m/s) and main wind direction (315°) were then used to drive the wave conditions over the domain. Figure 5.19 presents the wave simulation results using the selected maximum wind speed and main direction of the wind.

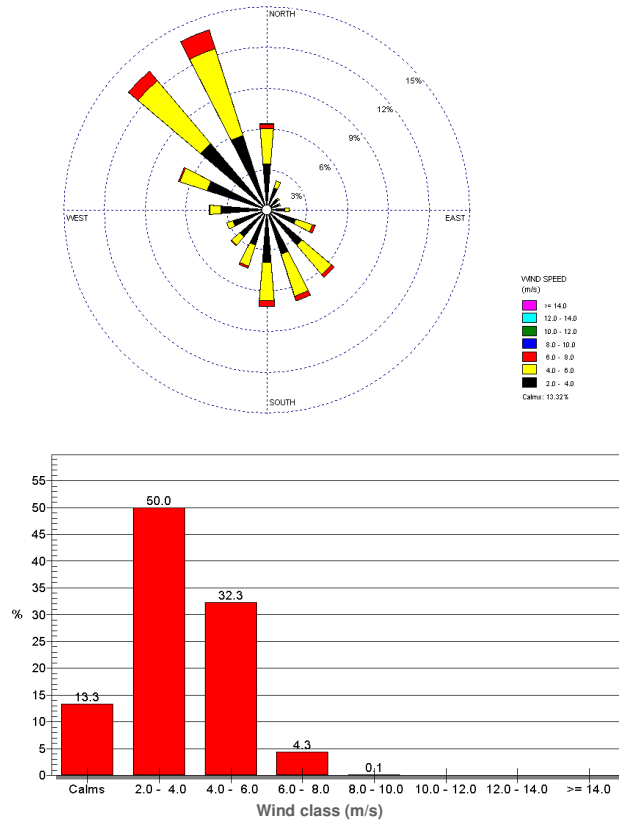


Figure 5.18: Wind rose and class frequency distribution at Java Sea from NCEP wind data 1980 - 2005

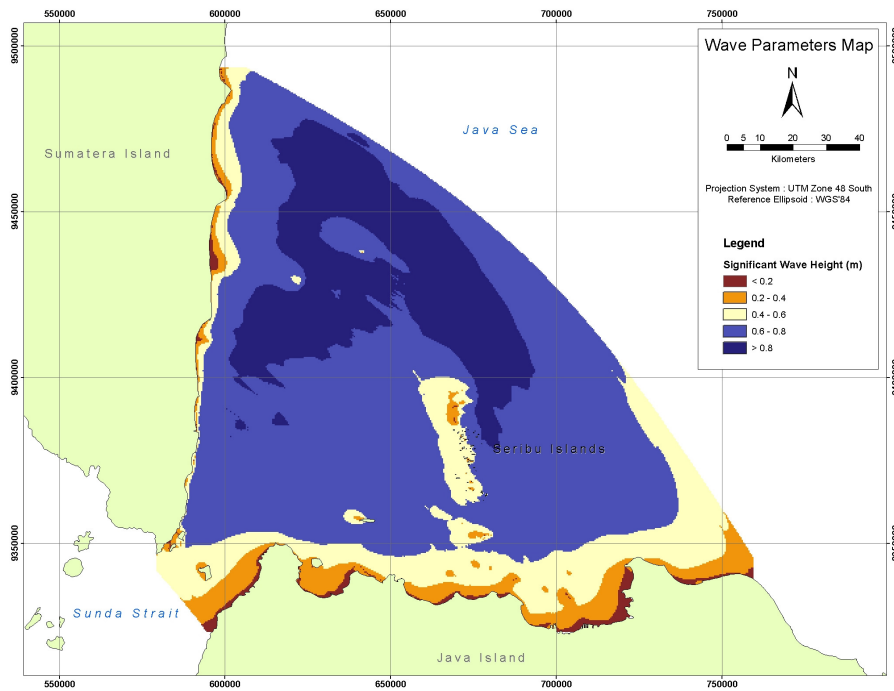


Figure 5.19: Significant Wave Height from the Java Sea Wave Model Result

Based on significant wave heights and mean wave period distributions resulting from the wave model, the Dean number distribution can be derived respectively. To obtain the Dean number (equation 2.1), it is necessary to calculate the falling velocity based on the grain size distributions of the intended sediment. The equations for the falling velocities (w_s) are expressed below [Van Rijn, 1989]:

$$w_s = \frac{(s-1)gd^2}{18\nu} \quad \text{for } d \leq 0.1 \text{ mm} \quad \dots (5.2)$$

$$w_s = \frac{10\nu}{d} \left[\left(1 + \frac{0.01(s-1)gd^3}{\nu^2} \right)^{0.5} - 1 \right] \quad \text{for } 0.1 < d \leq 1 \text{ mm} \quad \dots (5.3)$$

$$w_s = 1.1[(s-1)gd]^{0.5} \quad \text{for } d \geq 1 \text{ mm} \quad \dots (5.4)$$

where w_s = falling velocity (m/s)
 g = gravity acceleration coefficient (= 9.81 m/s²)
 s = specific gravity (= 2.65 m/s²)
 d = grain size (m)
 ν = kinematic viscosity coefficient (= 1x10⁻⁶ m²/s)

The grain size used in the calculation is for fish feed pellet used in the fish farm, which is 0.55 mm [Landeta, 2005]. Thus using equation 5.3, the falling velocity is 0.706 m/s. Based on this falling velocity value and wave characteristics from the wave model, Figure 5.20 represents the Dean number distribution for the Java Sea.

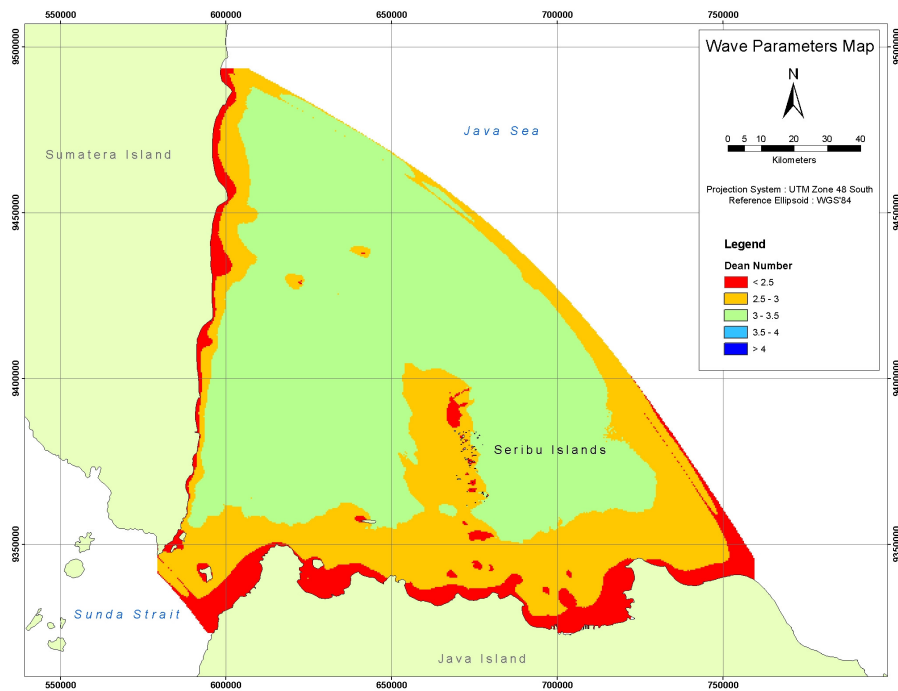


Figure 5.20: Dean number distributions for the Java Sea

5.3.2 Riau Islands Model

Following the same procedure as in the development of Java Sea Model, the numerical model for Riau Islands was developed. The model for this area is called the Riau Islands Model.

The following description will only refer to the model domain, input parameters and presentation of model results after sensitivity, calibration, verification and validation.

A. Model Domain

The area of Riau Islands Model covers Riau Islands waters between 1°30' S - 1°30' N and 103° E - 106° E. The bathymetry of the model domain was digitised from the nautical chart nr. 3946 (Port Klang to Malacca), nr. 3947 (Malacca to Singapore), nr 3949 (Riau Strait) and nr.941A (Singapore Strait to Java Sea).

The model grid is curvilinear with the grid size of 400 - 1250 m. There are 499 x 376 cells in total. The grid and its position relative to Sumatera and Malaysia Peninsular are shown in Figure 5.21.

The grid was made with respect to the modified Universal Transverse Mercator Coordinate Systems zone 48 South with the central meridian of 105°E, central latitude at the equator and 5,000,000 m of false northing (instead of 10,000,000 m, due to location of the model, which is located in two zones of UTM, 48 north and 48 south).

The model domain is located in the Riau Islands waters with the maximum depths of 70 m. The domain is mainly influenced by the flow conditions of Malacca and Karimata Strait. The tidal range is around 1 - 2 m with a mixed diurnal type.

B. Model Setup

As for the Java Sea Model, the open sea boundaries for the Riau Islands model are also imposed by astronomical tides derived from TPXO 3.0. Eight harmonic components (M2, S2, K2, N2, O1, K1, P1, and Q1) are selected. A list of the astronomical constituents input for the first and last segment at the northern, eastern and southern boundary is presented in Table 5.5. The initial velocity was taken to be zero and the water surface elevation was set to zero relative to the mean sea level. Table 5.6 summarises the physical and numerical parameters selected as base input parameters for the Riau Islands Model.

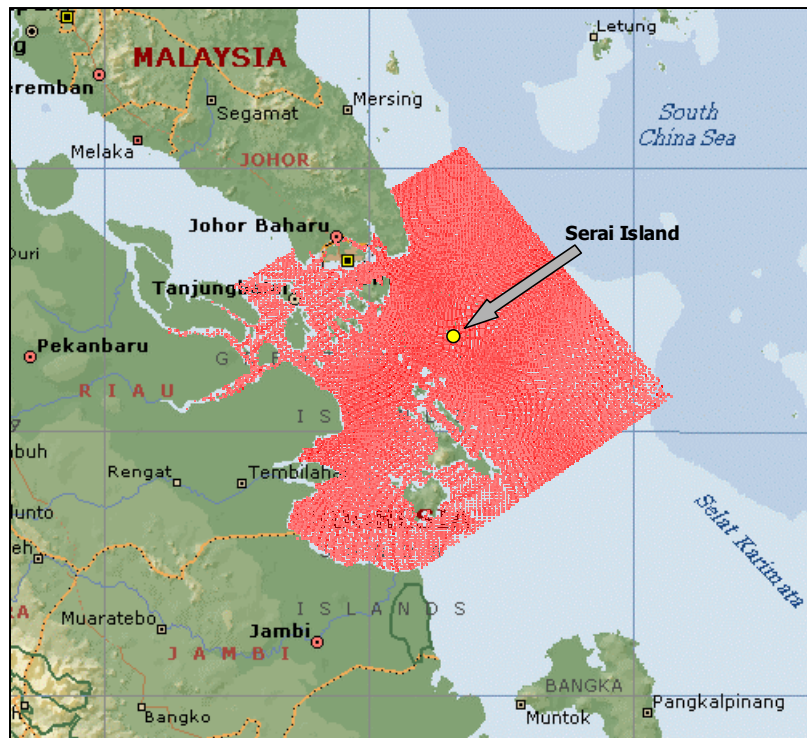


Figure 5.21: Numerical grid of Riau Islands model domain

Table 5.5: Astronomical constituent input for Riau Islands Model

| Constituent | Northern Boundary | | | |
|-------------|----------------------------|---------|---------------------|---------|
| | Beginning of First Segment | | End of Last Segment | |
| | Amplitude | Phase | Amplitude | Phase |
| M2 | 0.818 | 298.489 | 0.818 | 298.489 |
| S2 | 0.304 | 356.200 | 0.304 | 356.200 |
| K1 | 0.113 | 295.478 | 0.113 | 295.478 |
| O1 | 0.079 | 346.175 | 0.079 | 346.175 |
| N2 | 0.162 | 139.687 | 0.162 | 139.687 |
| P1 | 0.105 | 119.201 | 0.105 | 119.201 |
| K2 | 0.052 | 150.213 | 0.052 | 150.213 |
| Q1 | 0.010 | 104.591 | 0.010 | 104.591 |
| Constituent | Eastern Boundary | | | |
| | Beginning of First Segment | | End of Last Segment | |
| | Amplitude | Phase | Amplitude | Phase |
| M2 | 0.113 | 247.089 | 0.465 | 253.989 |
| S2 | 0.019 | 278.300 | 0.126 | 299.500 |
| K1 | 0.022 | 224.078 | 0.084 | 229.778 |
| O1 | 0.010 | 189.375 | 0.025 | 247.975 |

| | | | | |
|-------------|----------------------------|---------|---------------------|---------|
| N2 | 0.318 | 118.287 | 0.392 | 26.187 |
| P1 | 0.320 | 43.501 | 0.340 | -17.999 |
| K2 | 0.104 | 107.213 | 0.126 | 29.913 |
| Q1 | 0.058 | 23.491 | 0.062 | -39.509 |
| Constituent | Southern Boundary | | | |
| | Beginning of First Segment | | End of Last Segment | |
| | Amplitude | Phase | Amplitude | Phase |
| M2 | 0.698 | 301.489 | 0.113 | 247.089 |
| S2 | 0.257 | 354.800 | 0.019 | 278.300 |
| K1 | 0.097 | 293.178 | 0.022 | 224.078 |
| O1 | 0.063 | 341.775 | 0.010 | 189.375 |
| N2 | 0.162 | 139.987 | 0.318 | 118.287 |
| P1 | 0.112 | 114.301 | 0.320 | 43.501 |
| K2 | 0.051 | 148.213 | 0.104 | 107.213 |
| Q1 | 0.010 | 93.091 | 0.058 | 23.491 |

Table 5.6: Physical and numerical parameters of Riau Islands Model

| Parameter | Setting |
|---------------------------|--|
| Gravity acceleration | 9.81 m/s ² |
| Water density | 1023 kg/m ³ |
| Manning Roughness | 0.03 m ^{1/2} /s |
| Horizontal Eddy Viscosity | 1 m ² /s |
| Wind | NCEP wind data |
| Threshold depth | 0.1 m |
| Marginal depth | -999.99 m |
| Smoothing time | 60 |
| Simulation Periods | September 1 st – October 1 st , 2004 |
| Time Step | 5 minutes |
| Interval Data Stored | 10 minutes |

C. Flow and Wave Model Results

As a results of the sensitivity, verification and validation process, Figure 5.22 shows the final flow simulation of the Riau Islands Model compared to field data obtained at Serai Island (see Figure 5.21). Wave model results for this area based on maximum wind velocity data and dominant wind direction from NCEP wind data are presented in Figure 5.23. Distributions of Dean number for the Riau Islands are presented in Figure 5.24.

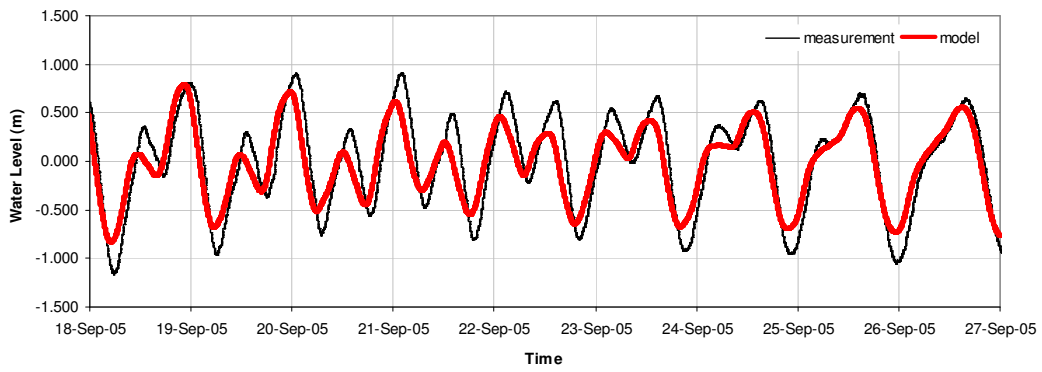
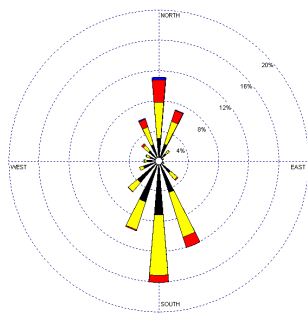
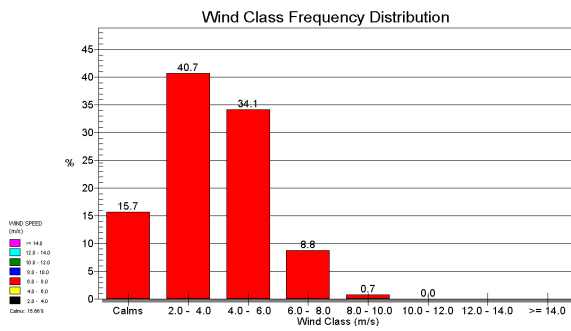


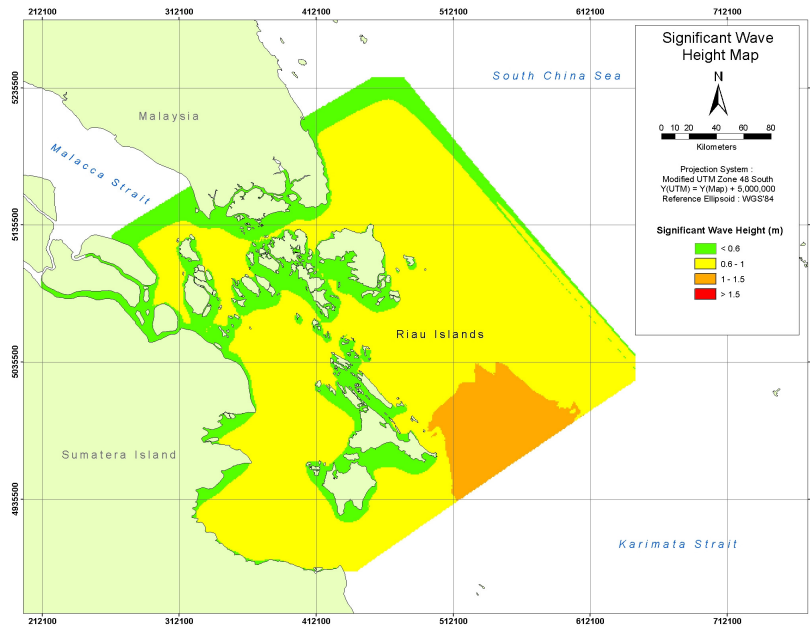
Figure 5.22: Riau Islands flow model results



(a) Wind rose



(b) Wind class frequency distribution



(c) Wave model result

Figure 5.23: Wind conditions and wave model results for Riau Islands

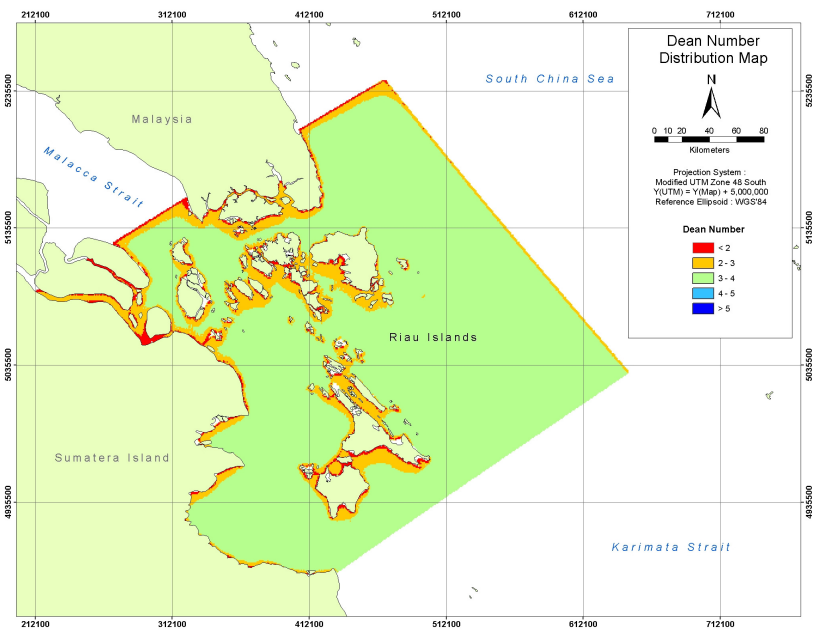


Figure 5.24: Dean number distributions for the Riau Islands

Chapter 6. Decision Support System for Mariculture Site Selection

In this chapter, the components of the developed Decision Support System (DSS), its implementation, some examples showing the spatial distribution of input parameters and the comprehensive DSS results are given.

6.1 Components of the Decision Support System

The components of the DSS for mariculture site selection are presented in Figure 6.1. Input data from various sources is fed to the system through an interface and are stored in the database component of the system. The instructions for data input or analysis to the system are given by the user through the interface that passes the type of analysis to be made by the model components of the DSS. The output data is presented in the form of map figures.

6.1.1 Interface

The interface component usually includes a graphical component called the *Graphical User Interface* (GUI), which is the part of the DSS that interacts with the user. GIS software is selected as a main interface for the systems since it provides the user with many additional features for handling spatial data of different types. The spatial data from the different parameters and types are uniformed and stored in the DSS database. ArcGIS version 8.3 has been used for building the interface.

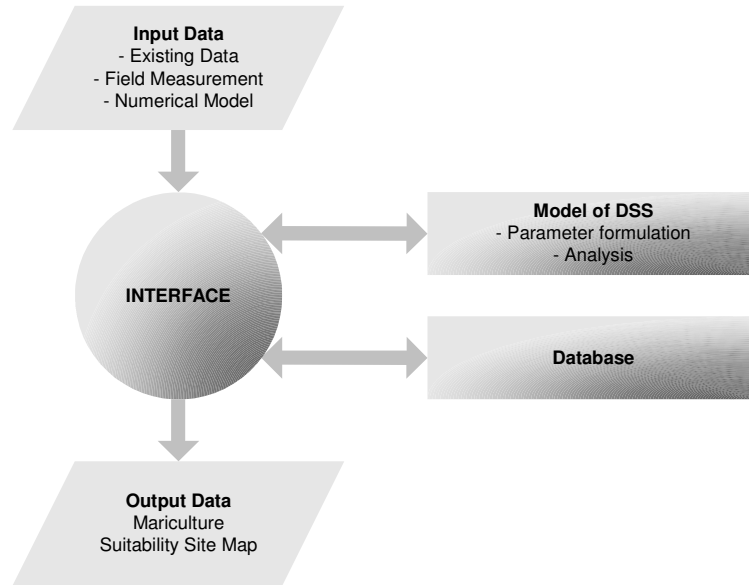


Figure 6.1: General Components of the DSS

6.1.2 Database

Success of the Decision Support System depends primarily on the quality and quantity of information available to decision makers. Selection of the criteria in this study was done by studying literature and screening the knowledge of experts. The data required for this study were available in the form of paper maps, tables and charts resulting from surveys and from the numerical models. One advantage of using GIS is the efficiency of integrating such a wide range of data types and information into a compatible format.

The spatial database is a critical part of the GIS-based DSS. Databases can be physically stored in files (File Management Systems, FMS) or in specialist software programs called Database Management Systems (DBMS) [Longley et al., 2005]. The DSS model structure for mariculture site selection was built using 16 parameters as presented in Table 4.2. Since the used data are not really complex, have less interrelationships and do not require large amounts of disk space, the FMS type of database is employed instead of DBMS. This type has several advantages in dealing with small amounts of data, being simpler to use and less expensive.

6.1.3 Model of the DSS

The other component of the system is the DSS model, which is designed to analyze, evaluate, and correlate the information from different sources available in the database and to reduce the information to make it easy for the user to understand the physical process.

The model of DSS for mariculture site selection is based on the Equation 4.1. Raster scored images from selected parameters are overlaid based on this equation, as described in section 4.3.3. Figure 6.2 presents the conceptual model structure for the study.

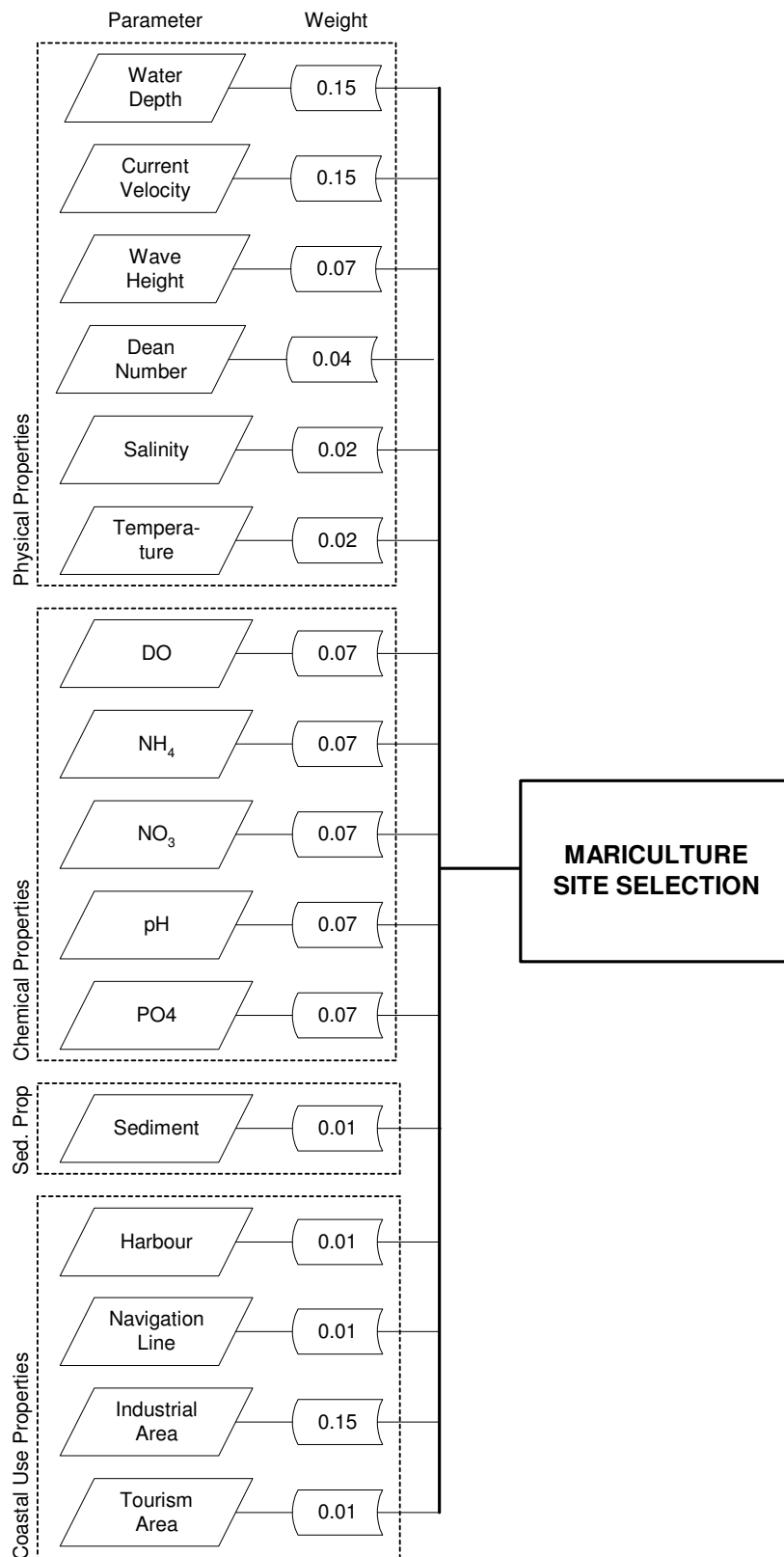


Figure 6.2: Conceptual model of mariculture site selection

6.2 Mariculture Site Selection

In this section input data and results of the DSS for mariculture site selection in the two study areas, the Java Sea and the Riau Islands are presented. For the site selection in the Java Sea, a raster image resolution of 100 m was selected, whereas in the Riau area the resolution was 200 m. The spatial resolution corresponds to that of the flow simulation made by the numerical model.

6.2.1 Java Sea

6.2.1.1 Input Data

Examples of data input for DSS mariculture site selection in the Java Sea are presented in the following figures. Figure 6.3 shows minimum water depth digitized from nautical charts. The depth in the nautical chart is considered as minimum depth since it represents the lowest depth with respect to the lowest astronomical tide. The maximum current velocities resulting from simulations of the Java Sea Model is displayed in the map of Figure 6.4. The maximum current velocity conditions are derived from the simulations for validation runs, where the velocity value has a good agreement with the measurement (see section 5.3.1). However, the time of the maximum current velocity may differ between locations in the same model domain. Therefore, the map of maximum current velocity was not taken from one time simulation, rather the results of the entire simulation period were screened to sort out maximum current velocity values in each cell. Maximum wave height conditions and Dean number distributions were derived from wave simulations as already presented in Figure 5.19 and Figure 5.20.

As an example of chemical parameters, a dissolved oxygen map of the area derived from WOA'01 is presented in Figure 6.5. Figure 6.6 shows the bottom sediment type of the area derived from the Indonesian sediment map (Figure 5.2), while Figure 6.7 displays a coastal and marine use map of the area.

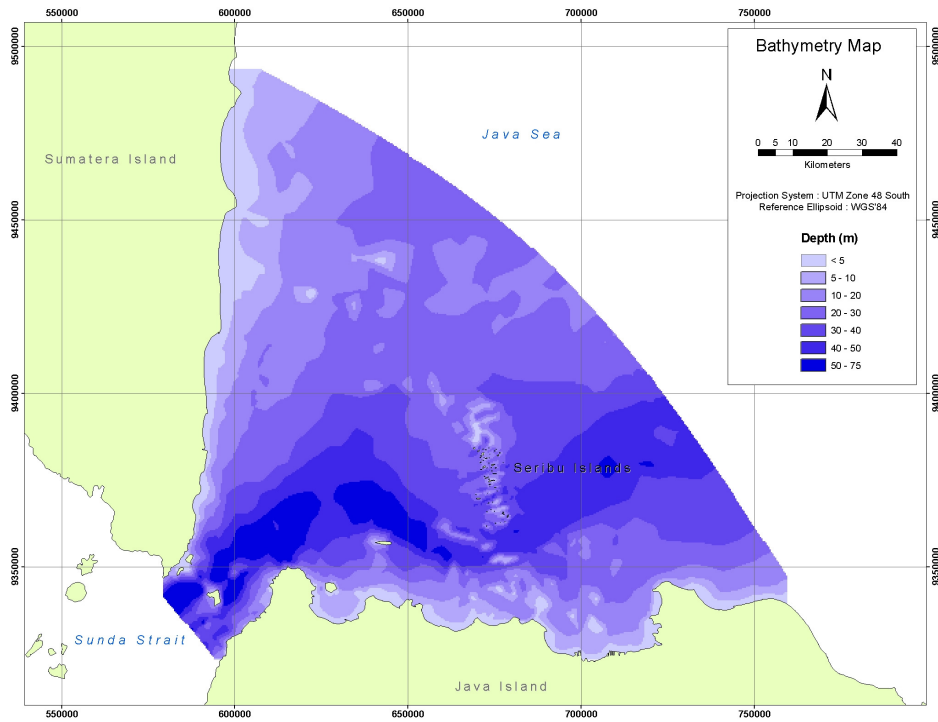


Figure 6.3: Minimum Depth Map of Java Sea area

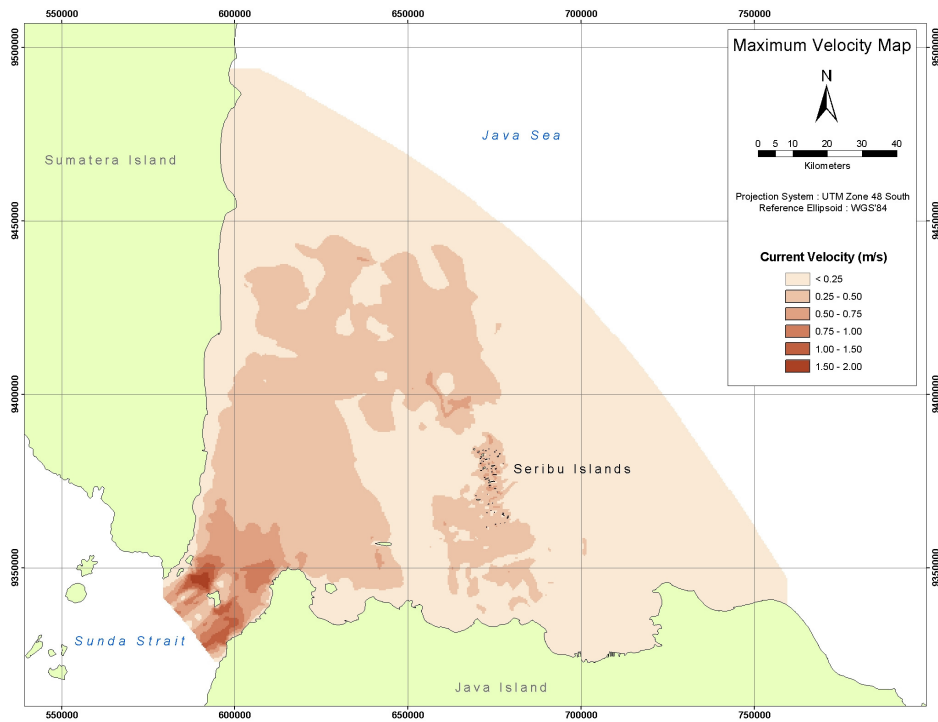


Figure 6.4: Maximum Current Velocity Map of Java Sea area

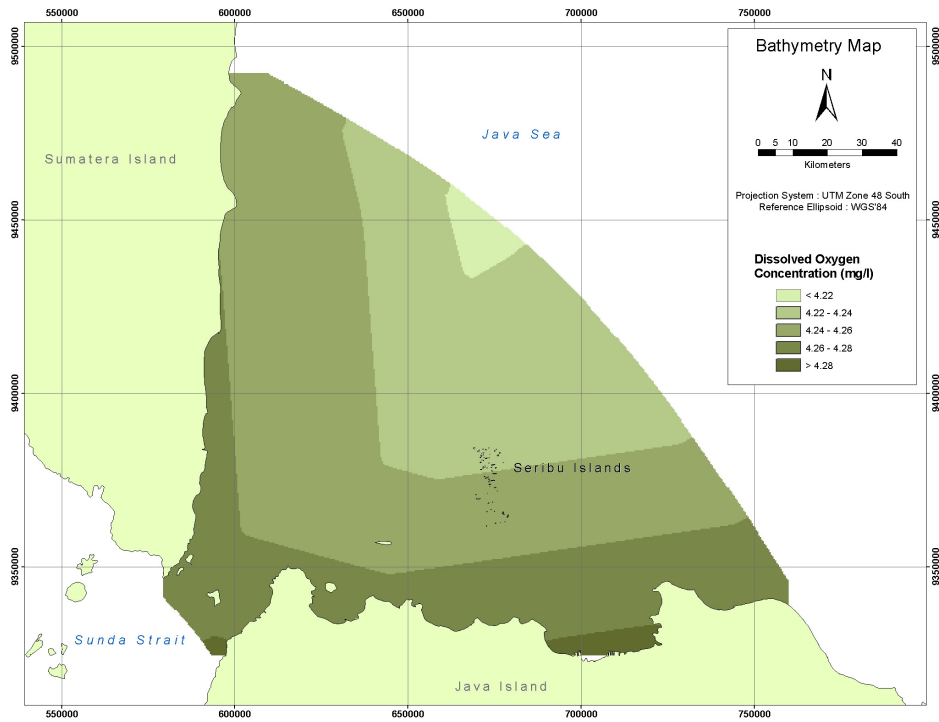


Figure 6.5: Dissolved Oxygen Map of Java Sea area

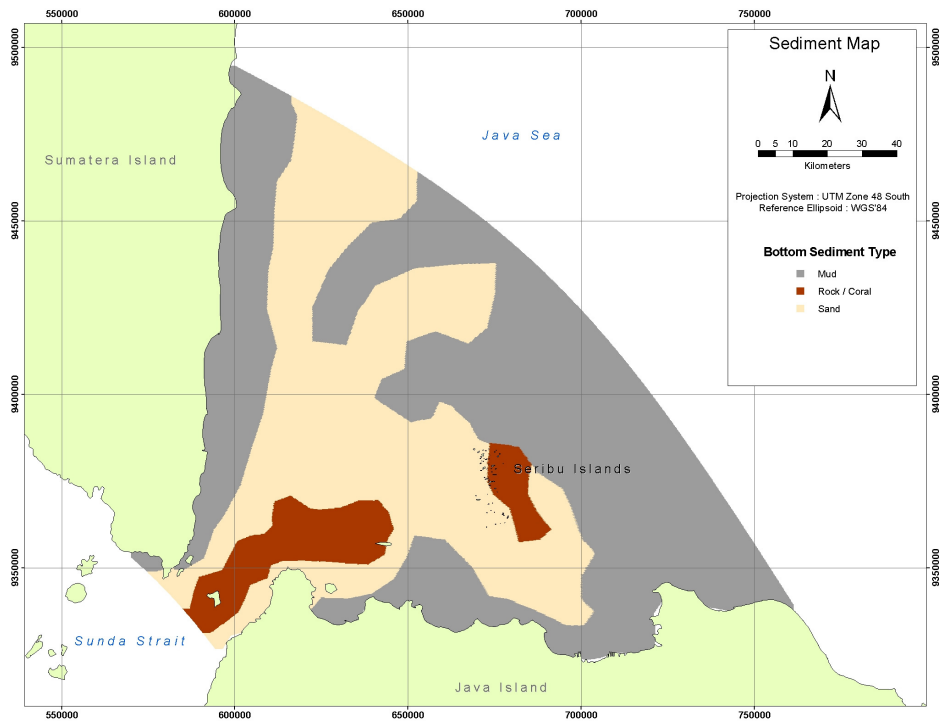


Figure 6.6: Sediment Map of Java Sea area

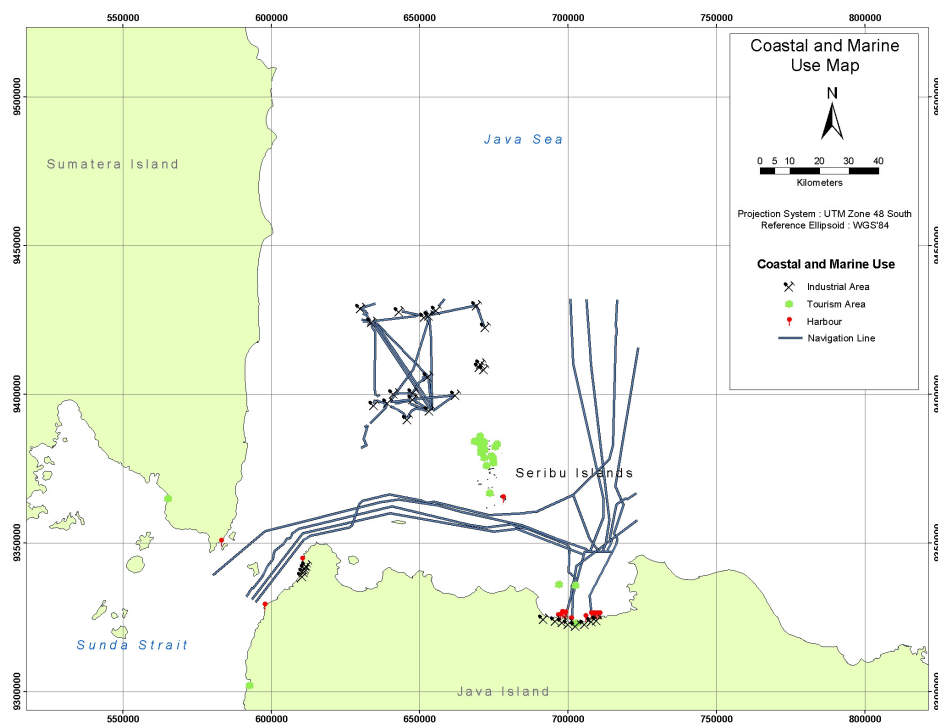


Figure 6.7: Coastal Use Map of Java Sea area

6.2.1.2 Output and Discussion

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 6.8 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 4.5).

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.

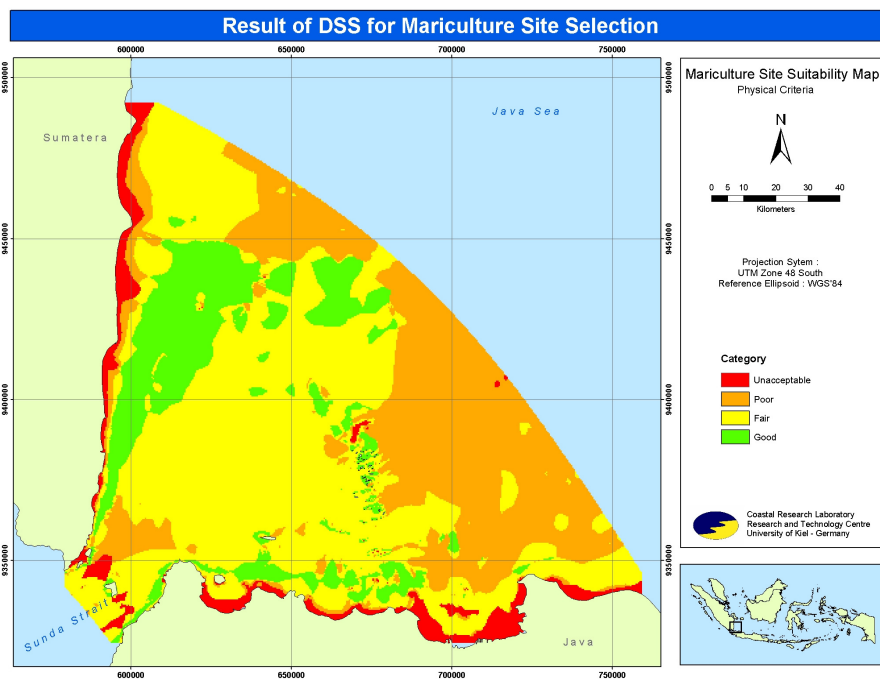


Figure 6.8: Java Sea Mariculture Suitability Map based on physical parameters

With respect to chemical criteria, the entire area is categorized as suitable (*good*) (Figure 6.9), since most of the chemical parameters indicate favourable 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*.

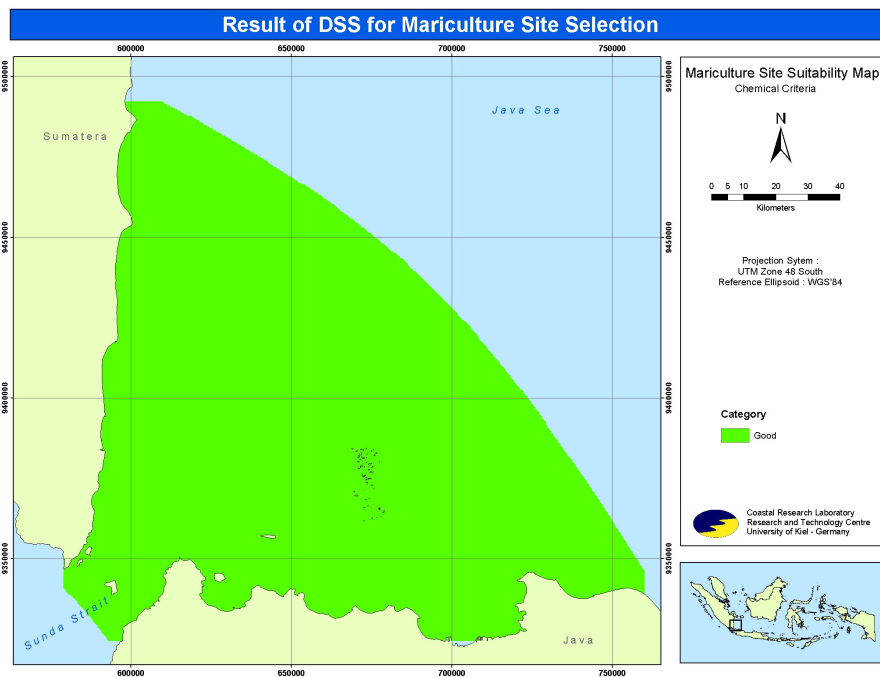


Figure 6.9: Java Sea Mariculture Suitability Map based on chemical parameters

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 6.6). 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. There is a direct correlation between Figure 6.6 and Figure 6.10, since muddy sediment is classified as *poor*, whereas rock/coral and sandy sediment is categorized as *fair* and *good* for mariculture respectively. 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.

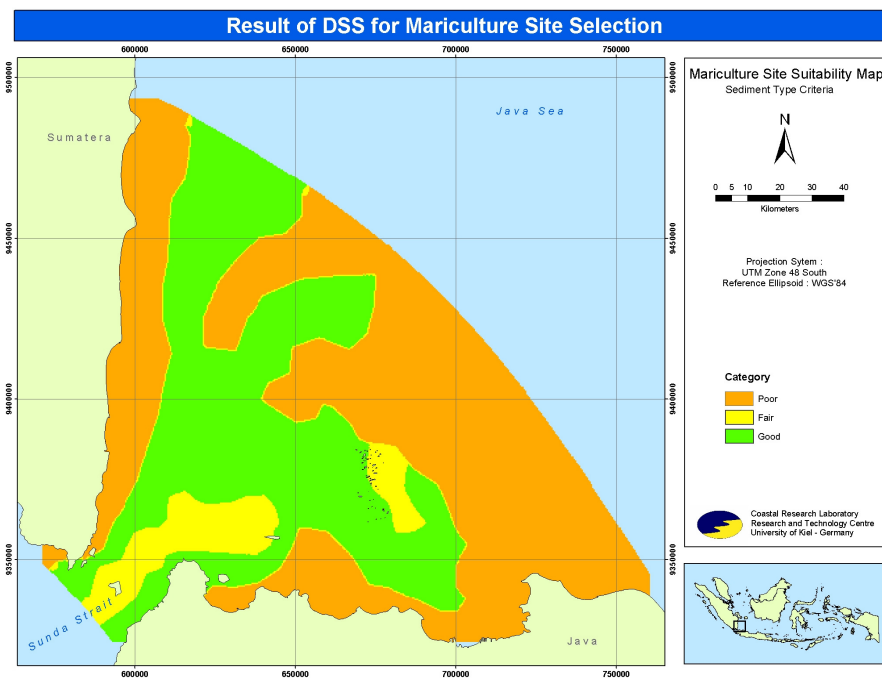


Figure 6.10: Java Sea Mariculture Suitability Map based on sediment type

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 (harbours, navigation line, industrial and tourism) are presented in Figure 6.11

There are four main harbours 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, lie 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.

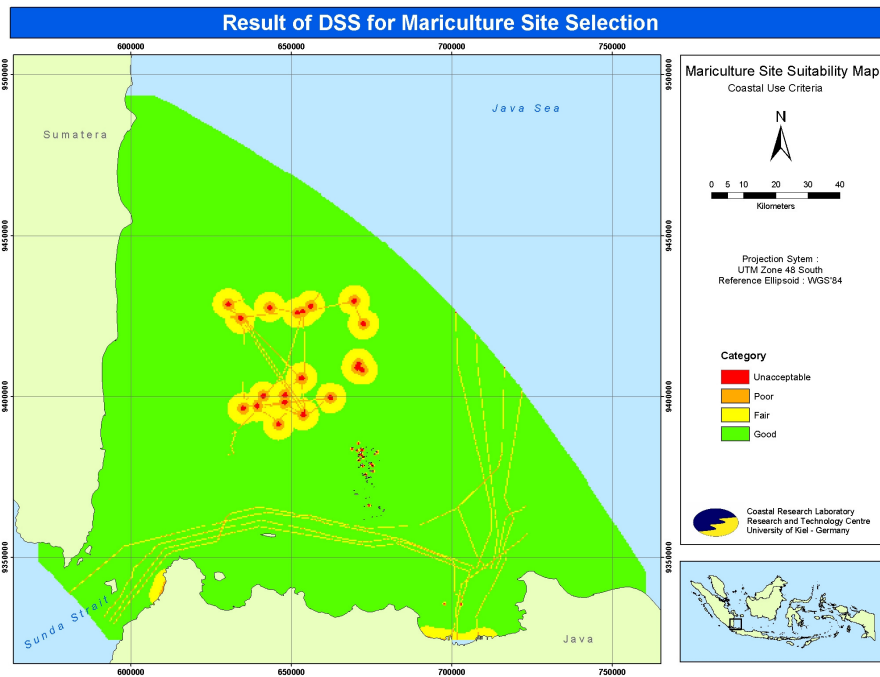


Figure 6.11: Java Sea Mariculture Suitability Map based on coastal use parameters

As a final result, a comprehensive mariculture suitability map for the Java Sea area is presented in Figure 6.12. 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 6.8). 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.

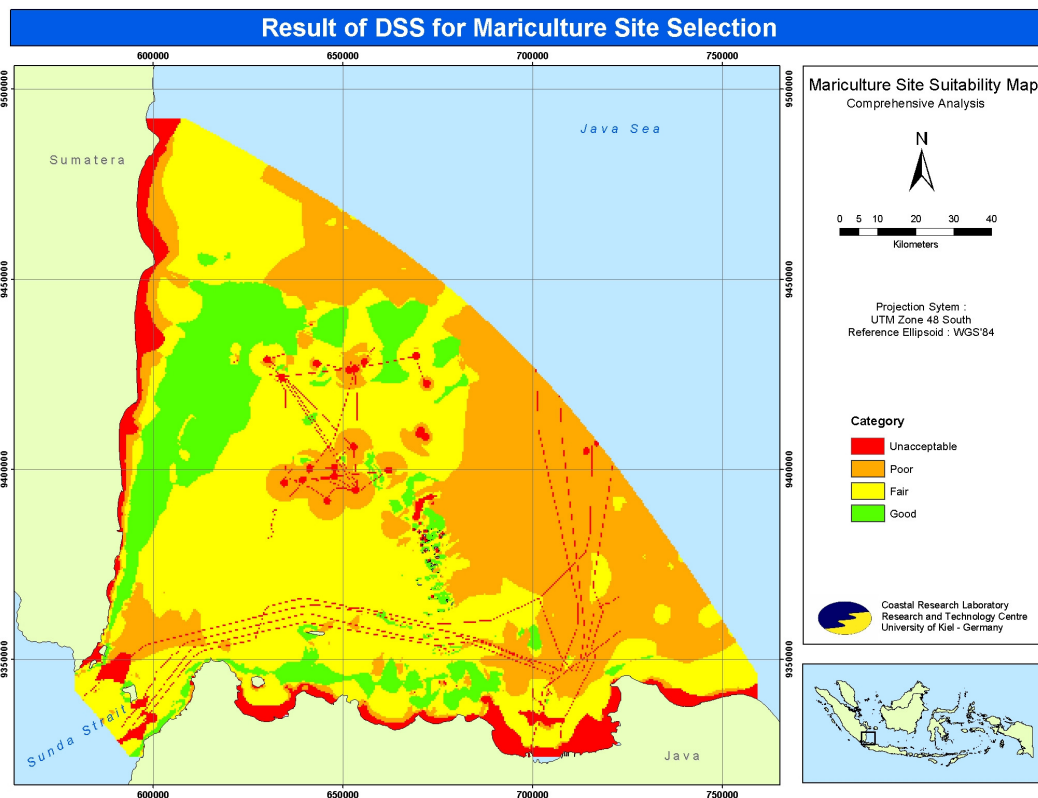


Figure 6.12: Comprehensive Mariculture Suitability Map for the Java Sea

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 colour 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 harbours, industrial and tourism sites.

6.2.2 Riau Islands

6.2.2.1 Input Data

Figure 6.13 shows the bathymetry of the study area digitized from nautical charts. A maximum current velocity map as derived from the numerical model simulations is presented in Figure 6.14. Figure 6.15 displays a nitrate concentrations map selected as one example of chemical input data. Sediment distribution of the study area is shown in Figure 6.16. Sites of harbour, navigation line, tourism and industrial areas are presented in the coastal use map (Figure 6.17).

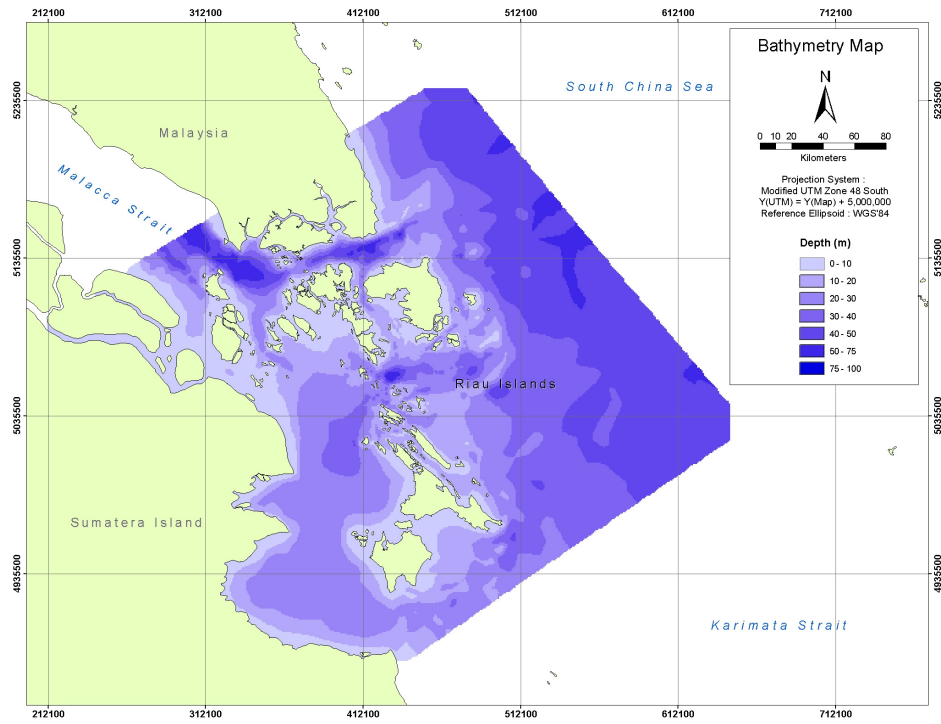


Figure 6.13: Bathymetry of Riau Islands

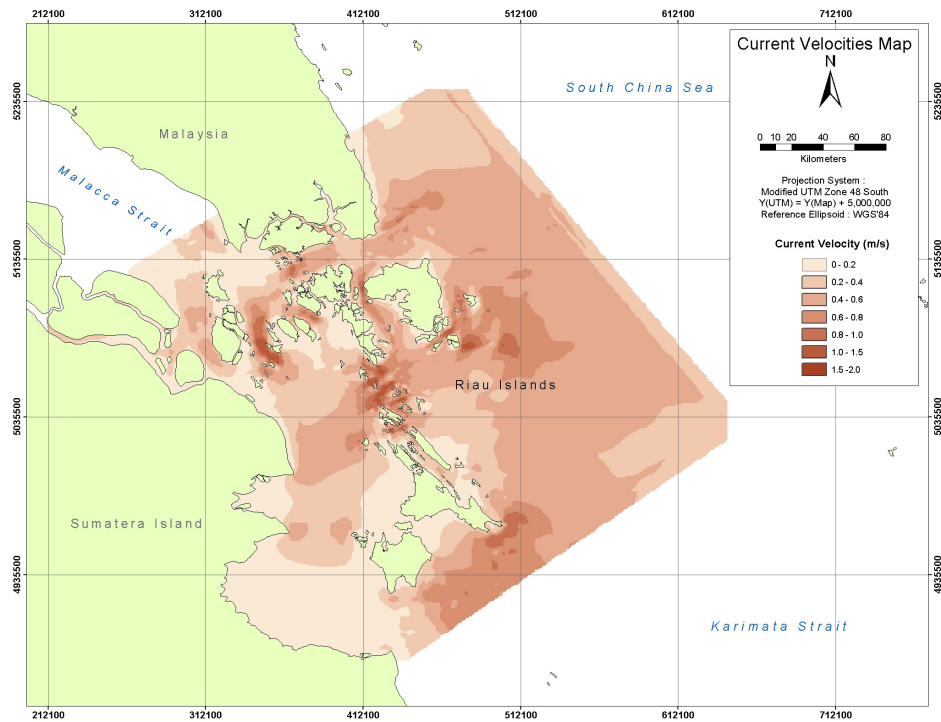


Figure 6.14: Maximum Current Velocity Map of Riau Islands

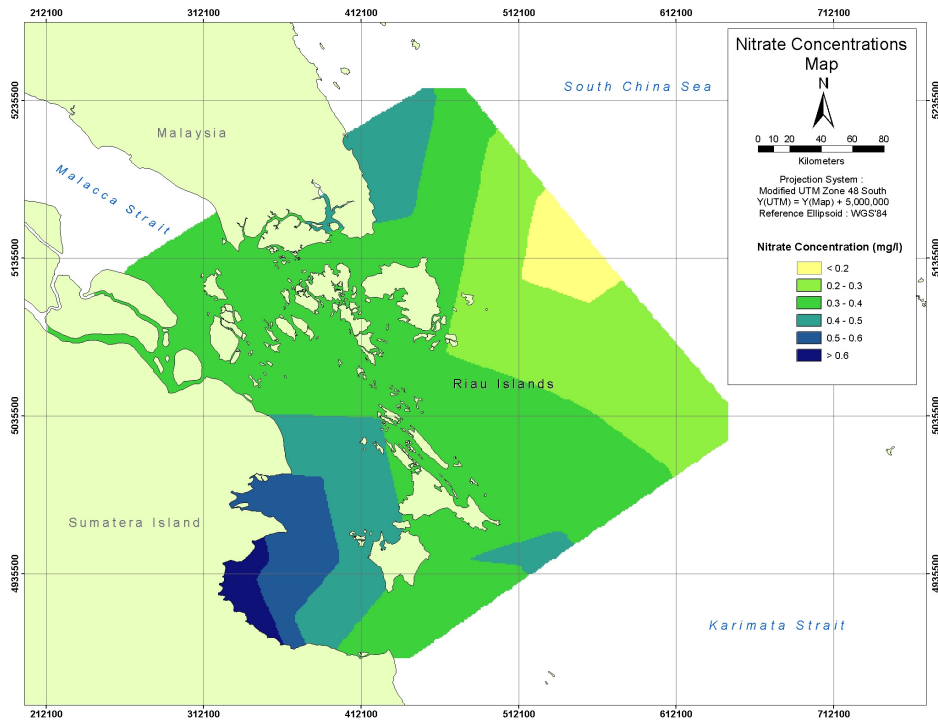


Figure 6.15: Nitrate Concentrations Map of Riau Islands

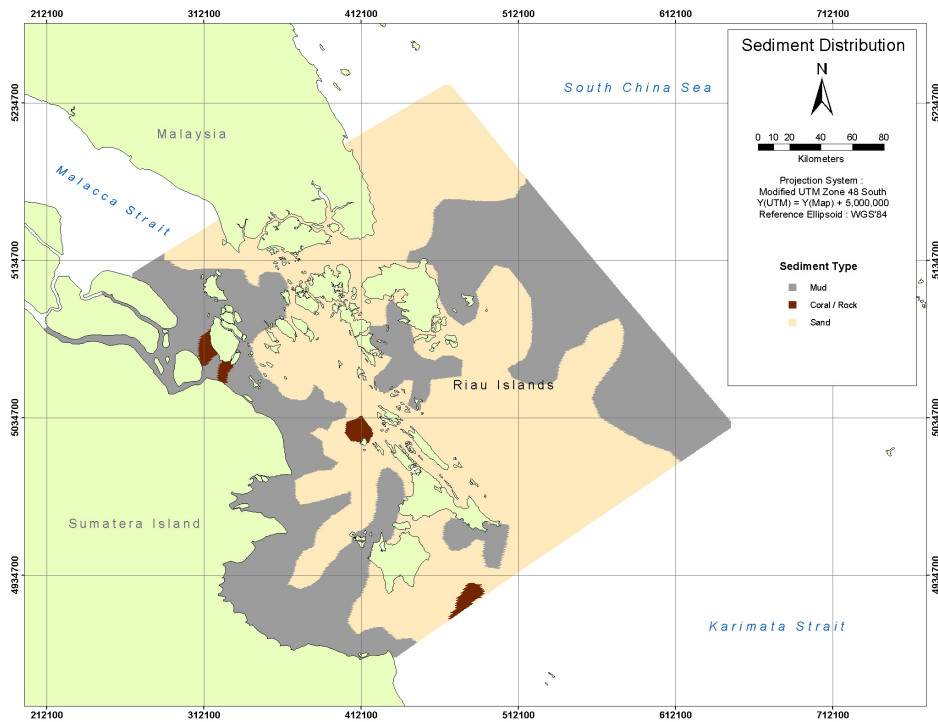


Figure 6.16: Sediment Map of Riau Islands

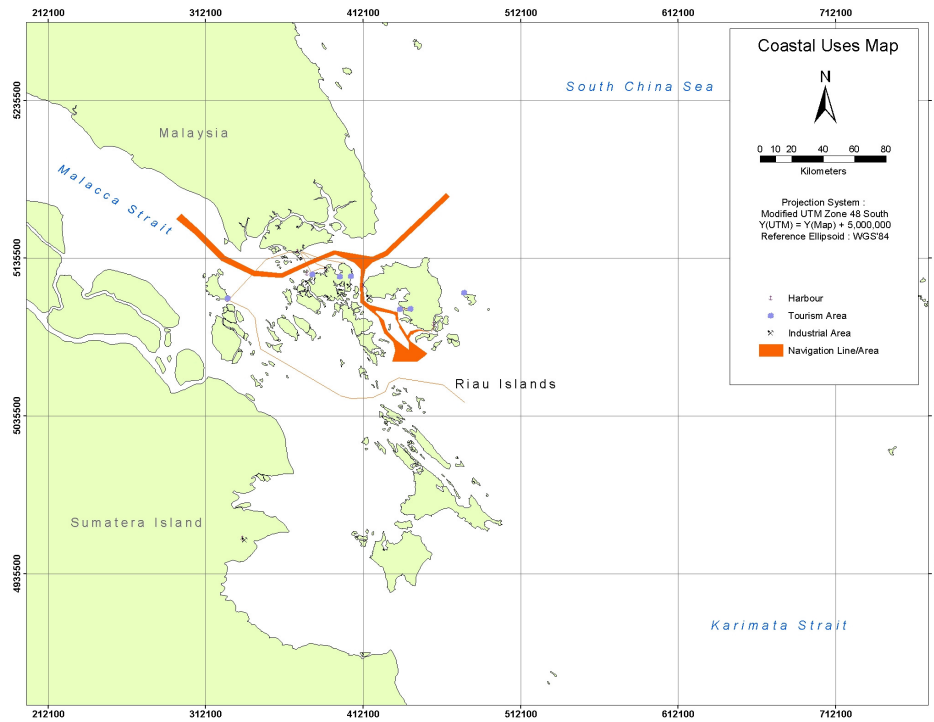


Figure 6.17: Coastal Use Map of Riau Islands

6.2.2.2 Output and Discussions

As for the Java Sea study, before the comprehensive analysis of the DSS is presented, thematic suitability maps for each group of criteria (physical, chemical, sediment type and coastal use) are described.

The first group considers physical criteria. The suitability map (Figure 6.18) classifies only 13.85% of the area as most suitable for farming (*good*), however, 44.44% of the area is in the *fair* category. *Poor* physical conditions for mariculture are found in 30.36% of the area. The remainder (11.35%) is classified as *unacceptable*.

The low representation of *good* conditions is essentially caused by the depth and current characteristics of the area, which to a wide extent exhibit water depth of more than 15 m (Figure 6.13) and high current velocities of more than 0.6 m/s (Figure 6.14). These conditions are assigned as *fair* in mariculture site selection.

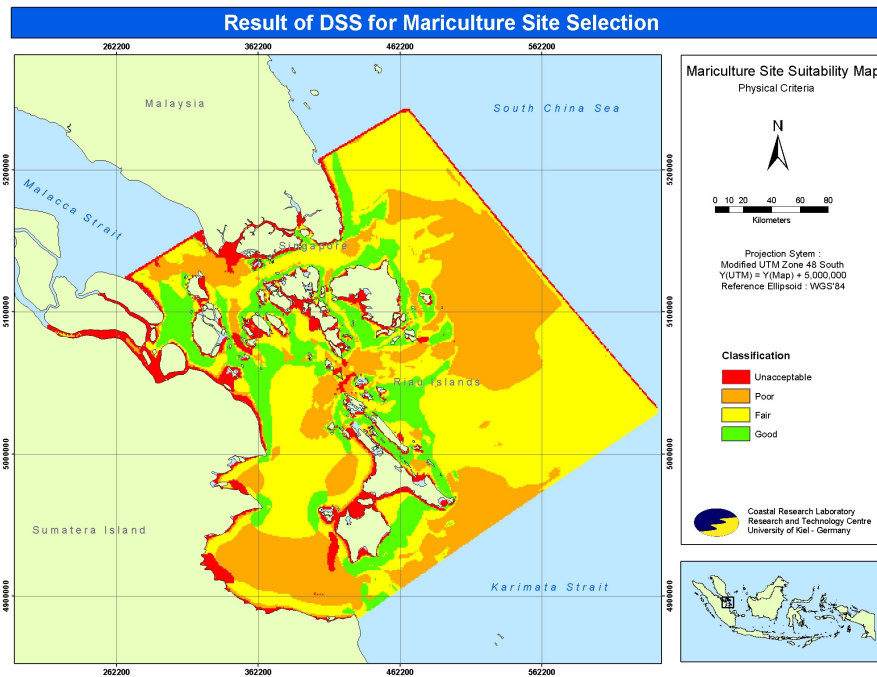


Figure 6.18: Riau Islands Mariculture Suitability Map based on physical parameters

Figure 6.19 represents a suitability map based on chemical parameters. The results show all *good* conditions for mariculture prevailing throughout the entire area. Only with respect to dissolved oxygen concentrations, is part of the area classified as *fair*.

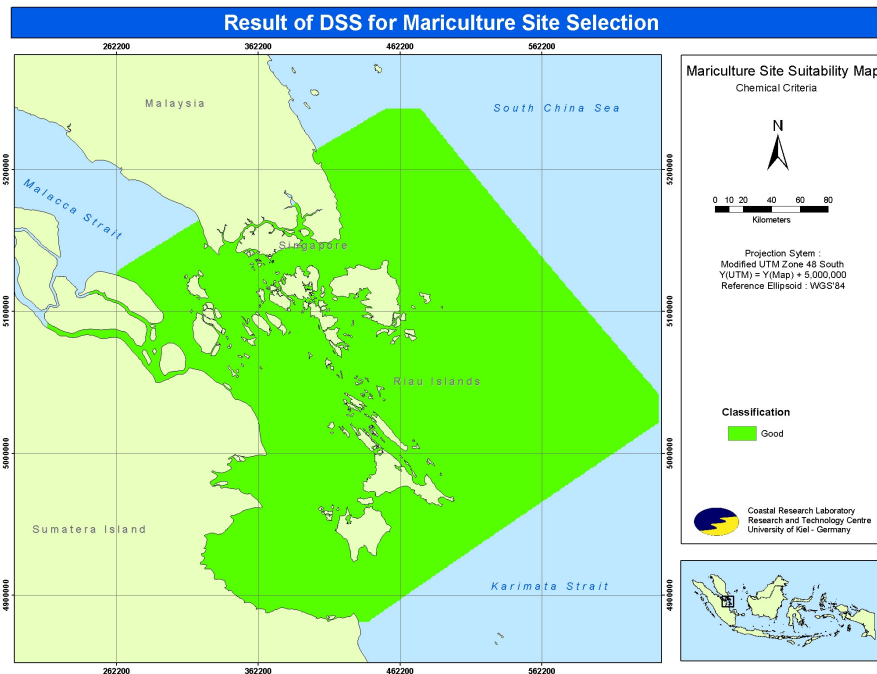


Figure 6.19: Riau Islands Mariculture Suitability Map based on chemical parameters

A mariculture site suitability map based on sediment parameters is presented in Figure 6.20. The study area in Riau Islands is mainly dominated by sandy sediments, which is the most suitable bottom sediment type for mariculture site. Sandy sediments cover an area of 53.02% of the total area. Muddy sediments, which are the least suitable for mariculture, are located on the east coast of Sumatera up to 27 km seaward. The mud may be due to elevated river discharge along this area. Another deposit of mud is located on the eastern part of the study area. In total 44.07% of the area is covered by mud. Only 2.91%, is covered by rock/coral, representing *fair* conditions for mariculture site.

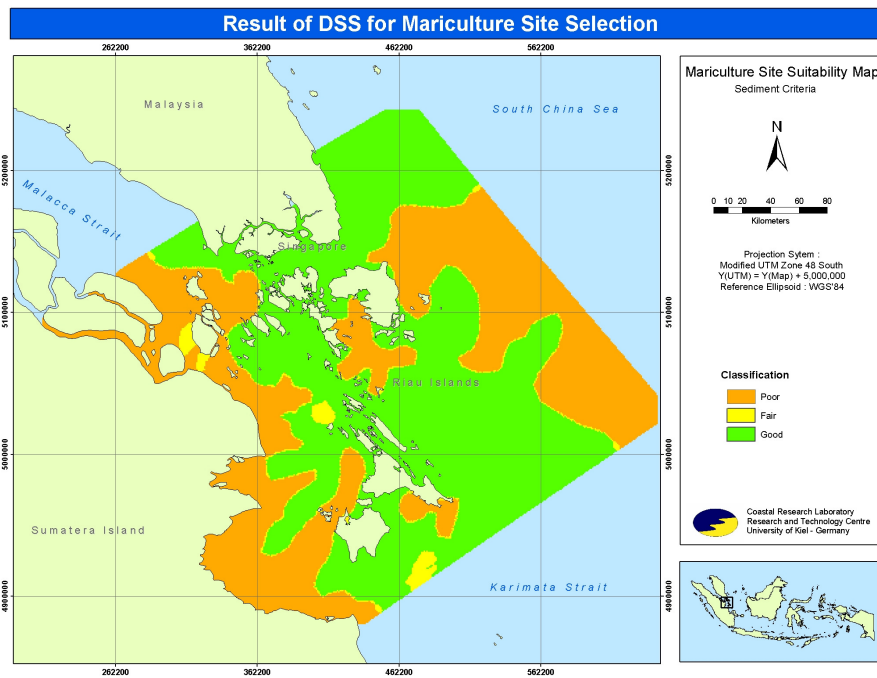


Figure 6.20: Riau Islands Mariculture Suitability Map based on sediment parameter

Figure 6.21 presents a suitability map for mariculture site suitability based on coastal use parameters. Batam and Bintan Island are the most developed islands in the region. Batam has been a free trade zone over the past years due to its strategic position near Singapore and Malaysia. Many industry and tourism areas have developed on the island during the last three decades. There are at least three main harbours, five industrial areas and two tourism sites (Figure 6.17). Malacca Strait, Singapore, Batam and Bintan waters are very busy shipping line zones. The nautical charts indicate some wide navigation lines in the area (red lines in Figure 6.21), which are combined in this analysis as buffer zones.

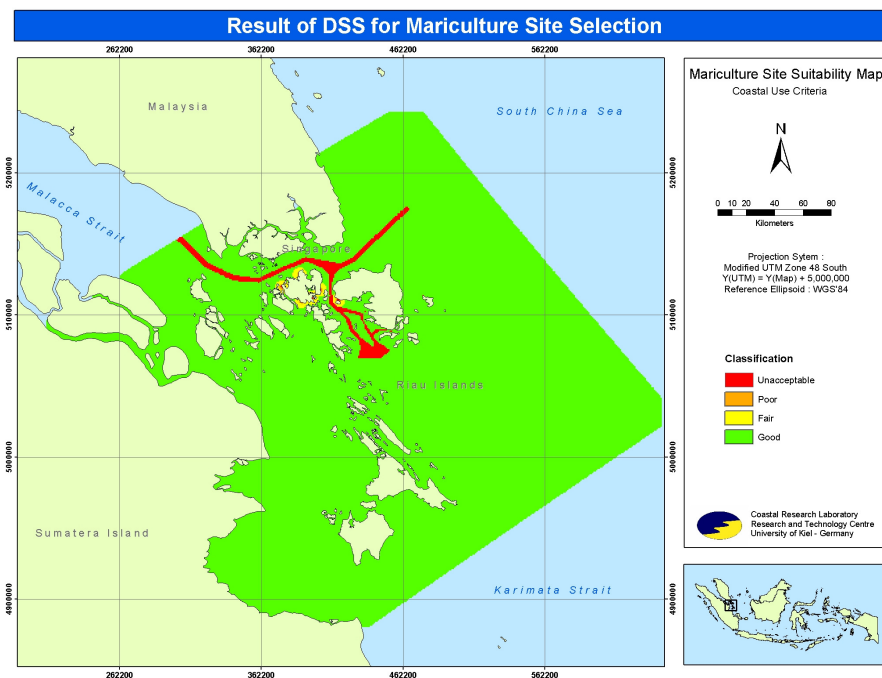


Figure 6.21: Riau Islands Mariculture Suitability Map based on coastal use parameters

The final results of the mariculture suitability analysis integrating all parameters is presented in Figure 6.22. The final map classifies only 13.43% of the total area as *good* (most suitable). The largest part of this category is located about 2 – 10 km offshore the coasts. The comprehensive classification of most suitable areas is mostly dominated by physical criteria, since these sites are consistent with those found in the physical suitability analysis. They are characterized by 5 – 15 m water depths and current velocities up to 0.5 m/s. Areas with *fair* conditions for mariculture cover almost half of the entire region (43.50%). They are generally characterized by 15 – 20 m water depth and maximum current velocity of more than 0.5 m/s. Poorly suited areas cover approximately 30.11% of the total area whereas *unacceptable* conditions for mariculture account for 12.96%. Areas with *unacceptable* conditions are generally characterized by shallow waters of less than 3 m depth and very small current velocities, or are located within the buffer zone around navigation lines, harbours, tourism and industrial activities.

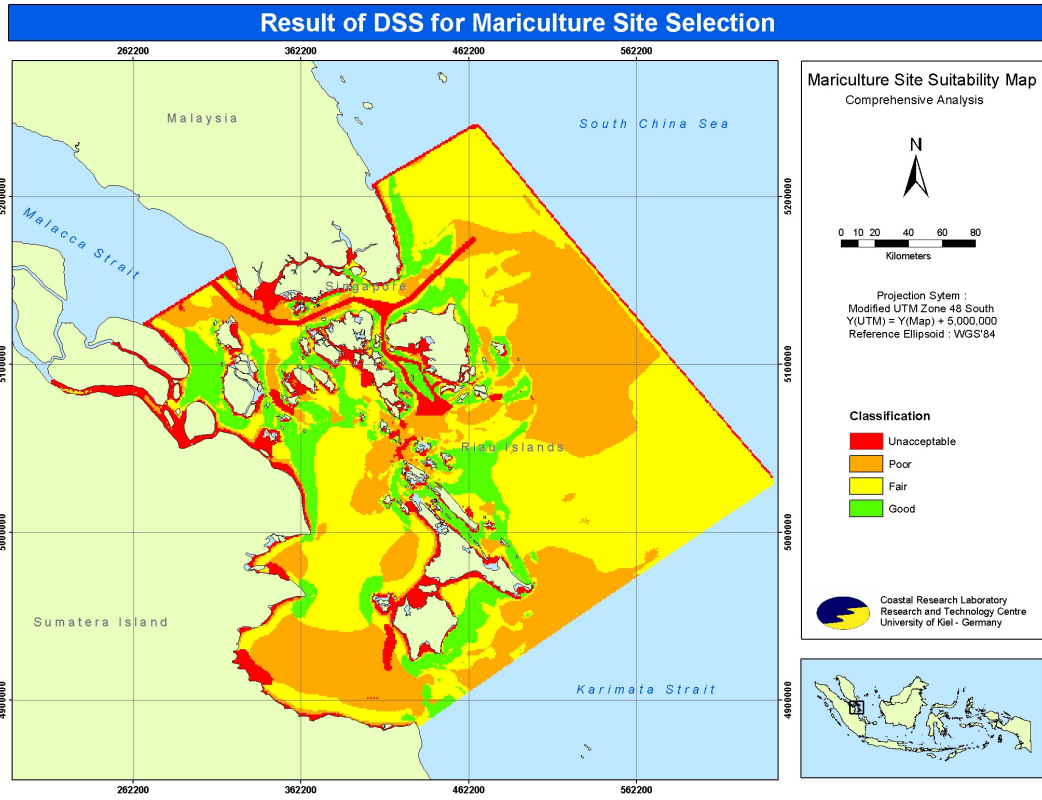


Figure 6.22: Riau Islands Mariculture Suitability Map

Chapter 7. Validation and Application of DSS for Small Scale Area

7.1 Introduction

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 two fish farm sites used for this study are located in Pramuka Island (Java Sea) and Serai Island (Riau). The Pramuka fish farm site is located in the Seribu Islands, about 60 km north west from the capital city of Indonesia, Jakarta, 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 Serai fish farm is located close to the equator in Riau Islands Province between Serai and Siulung Island, about 25 km south east of Tanjung Pinang, the main city of Bintan Island. Farming activities have been present since the eighties. The fish farm itself and the facilities are much bigger than those of Pramuka. The locations of both fish farms are presented in Figure 7.1

The field measurements were taken twice at both sites, during the dry and rainy season, according to the Southeast Asian monsoon conditions. The measuring campaigns cover the following parameters:

1. Physical
 - a. Bathymetry
 - b. Water level
 - c. Current velocity
 - d. Meteorological conditions (wind and air humidity)
 - e. Salinity
 - f. Temperature
2. Chemical
 - a. Turbidity/Suspended solids
 - b. Nutrients (N, P, Si)
 - c. PH
 - d. Dissolved Oxygen concentration and saturation
3. Bottom sediment type

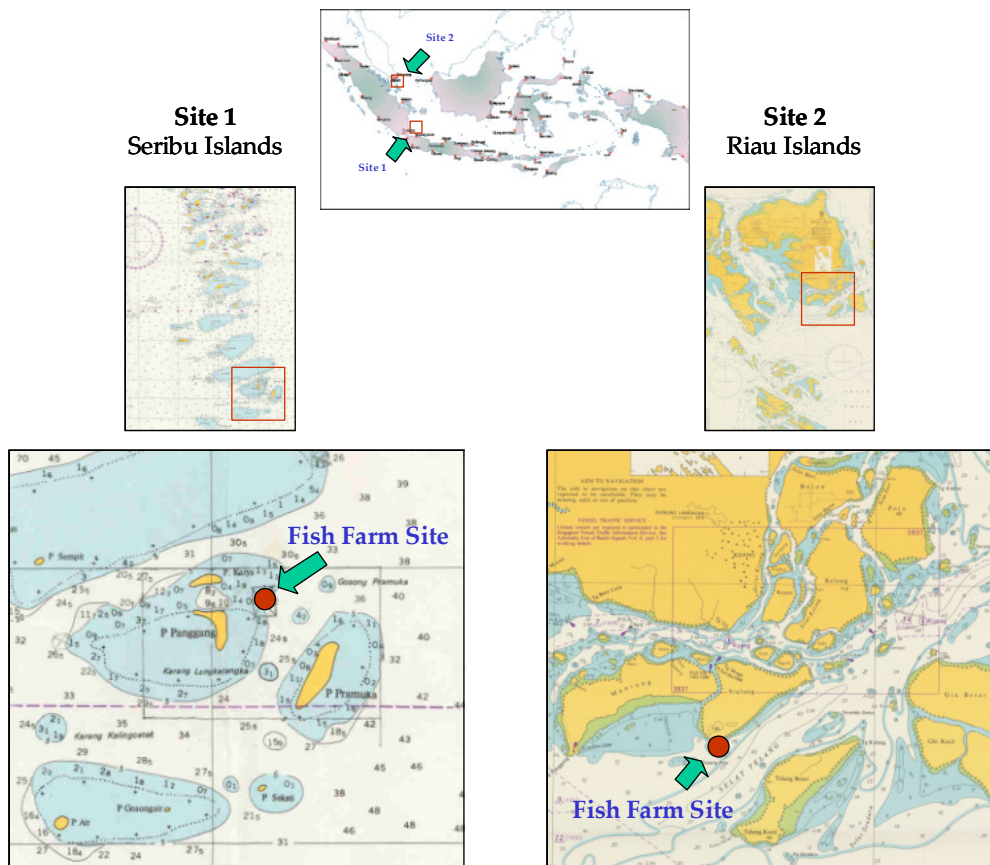


Figure 7.1: Location of the study area and the fish farms

7.2 Pramuka Island

The validation of DSS input parameters for the Java Sea area is done on the basis of measurements carried out near Pramuka Island. The DSS for Java Sea area uses input data in raster format with a resolution of 100 m.

Physical Parameters

A comparison of bathymetric data used for the DSS and the field measurements is presented in Figure 7.2. The bathymetry for the DSS input was derived from digitations of nautical charts and in combination with measurement data, including the measurement data used for this comparison, interpolated into raster image in 100 m resolution. The result 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. It can therefore be concluded that the bathymetry values from interpolation are appropriate as DSS input data.

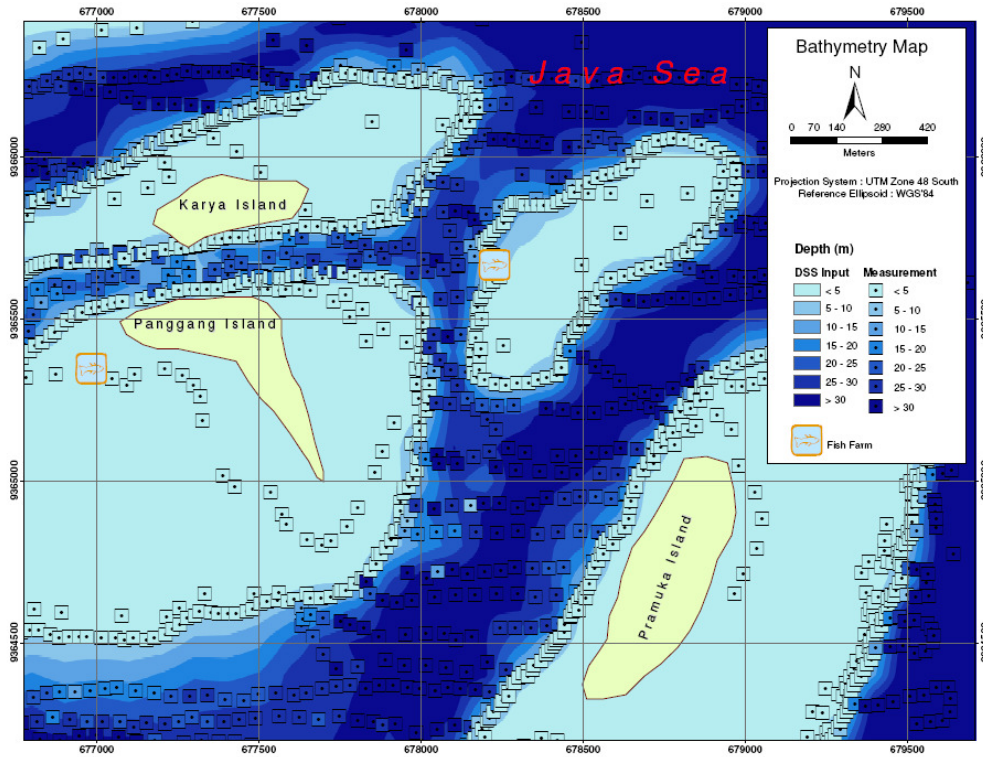


Figure 7.2: Comparison of bathymetry value from DSS input and field measurement

Current velocities used as DSS input were derived from numerical model results, as referred to in section 5.3.1. Spatial resolution of the model output and the DSS input is the same value of 100 meters. Figure 7.3 presents one of the validations of model results with the measurement data. It should be noted that DSS only requires maximum current velocities as input. Since the resulting time series of the model is in very good agreement with the measurements, it can be concluded that the maximal current velocity data used for the DSS represents the natural maximal current velocity.

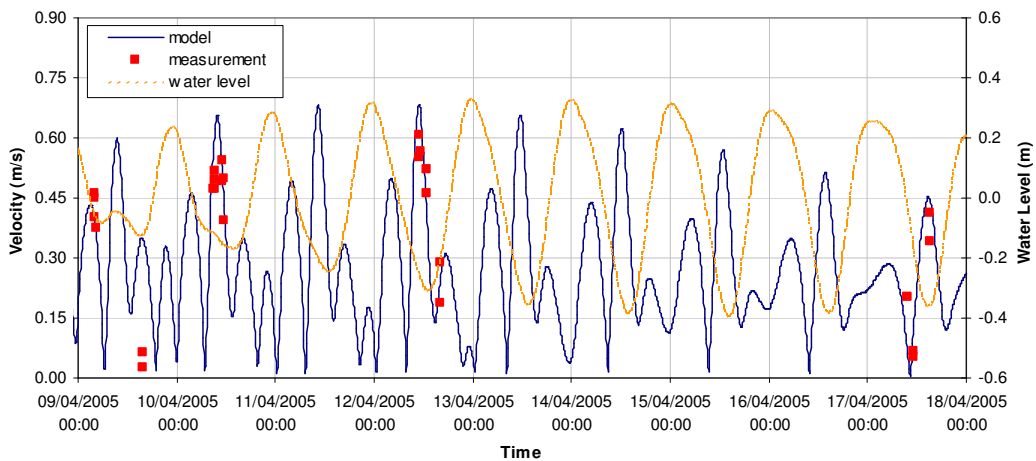


Figure 7.3: Comparison of model and field data for current velocity value from DSS input and field measurement near Pramuka Island

During both measuring campaigns in Pramuka Island, wave parameters were not measured. However, available wave data from the area during a survey in December 1999 (KK Hidrografi, 2000) indicates a maximal wave height of 0.5 m, whereas the wave model results delivered a value of 0.6 m. The difference may be due to the wind input data for the wave model. Wave values of 0.6 and 0.5 are in the same category range in the DSS analysis (waves up to 0.6 m are categorized as *good* condition for mariculture site). Therefore the difference does not significantly change the analysis results related to this parameter.

Water Temperature, Salinity and Nutrients Parameters

Data for water temperature, salinity and all nutrients for the DSS input were derived from WOA'01. A comparison between the data taken from the WOA'01 and direct field measurements is presented in Table 7.1. Although the comparison reveals some discrepancies, they did not affect the scoring value in DSS.

Table 7.1: Comparison of chemical parameters in Pramuka Island Fish Farm Area

| Parameter | DSS Input | | Measurement | |
|-------------------------|-----------|-------|-------------|-------|
| | Value | Score | Value | Score |
| Water Temperature (°C) | 28 | 3 | 29 | 3 |
| Salinity (psu) | 32 | 3 | 34 | 3 |
| Dissolved Oxygen (mg/l) | 4.23 | 2 | 4.37 | 2 |
| Ammonium (mg/l) | 0.3 | 3 | 0.13 | 3 |
| Water pH | 7.9 | 3 | 7.93 | 3 |
| Nitrate (mg/l) | 0.36 | 3 | 0.11 | 3 |
| Phosphate (mg/l) | 0.36 | 3 | 0.02 | 3 |

Sediment Parameters

The available sediment map used for the DSS input data reveal that the sediment type in Pramuka Island area is rocky sediment (coral reef) (Figure 7.4). This type of sediment was also found during the measuring campaign. There are 3 sampling locations (Figure 7.4) the results of which are presented in Table 7.2. Coral reef sediment was found in the channel and on the reef platform. Sandy sediment was restricted to the bottom beneath the fish farm site. The sand, however, was added during the installation period as a foundation for the fish farm.

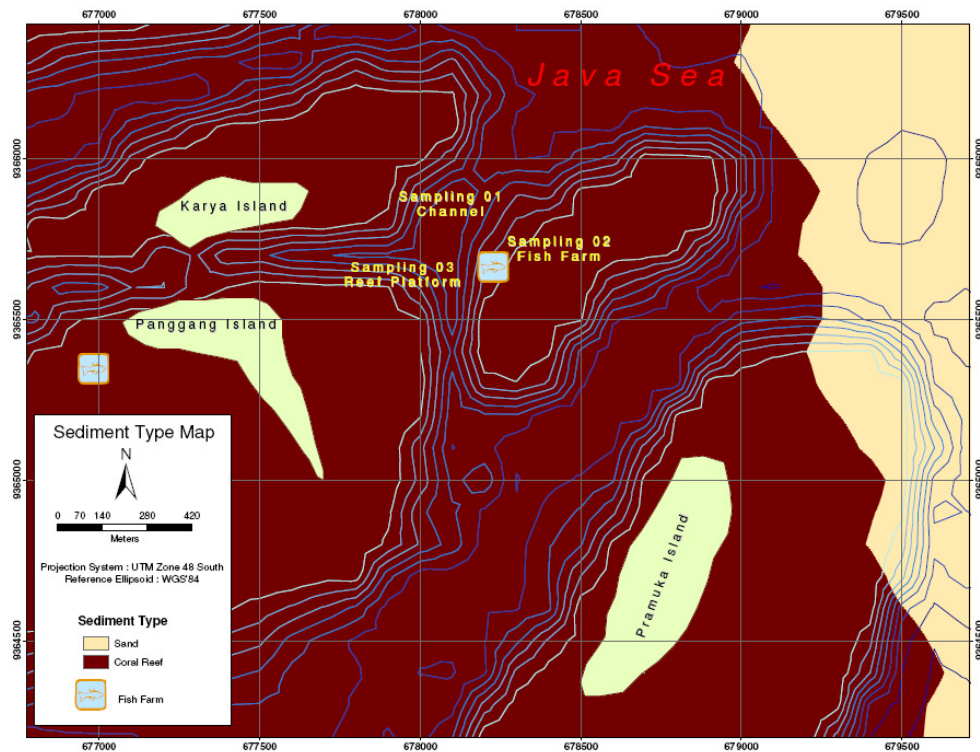


Figure 7.4: Sediment Map of Pramuka Island based on DSS input

Table 7.2: Recorded sediment parameters [FTZ, 2005]

| Sediment parameter | Channels (long & cross sections) | Fish farm (sea floor underneath) | Reef platform (east of the fish farm) |
|---------------------------------|--|--|--|
| Mean grain size (mm) | 0.75 range 0.35 – 2.31 | 0.41 range 0.22 – 0.78 | 0.93 range 0.44 – 1.57 |
| median d50 grain size (mm) | 0.75 range 0.32 – 2.31 | 0.41 range 0.18 – 0.84 | 1.04 range 0.49 – 2.05 |
| Sorting Standard dev. (mm) | 2.31 range 1.67 – 2.83 | 2.45 range 1.90 – 3.24 | 2.20 range 1.83 – 2.52 |
| Porosity loosest packing (%) | 54.87 | 55.28 | - |
| Porosity Densest packing (%) | 47.05 | 48.35 | 51.25 |
| Density loosest packing (kg/m3) | 2630 | 2610 | - |
| Density Densest packing (kg/m3) | 2760 | 2810 | 2680 |
| Permeability (m ²) | 1.13*10 ⁻¹⁰ range 1.34*10 ⁻¹¹ - 8.53*10 ⁻¹⁰ | 2.54*10 ⁻¹¹ range 8.00*10 ⁻¹² - 7.78*10 ⁻¹¹ | 1.69*10 ⁻¹⁰ range 2.96*10 ⁻¹¹ - 5.24*10 ⁻¹⁰ |

Coastal Use Parameter

There is one passenger harbour on Pramuka Island that is included in the DSS. The available nautical charts did not reveal any navigational lines in this area. They were however inaccurate since inspection during the measuring campaigns showed the channels between the three islands are used heavily as navigational channels for local transportation and fishing boats.

DSS Result

Figure 7.5 presents the enlarged results from the comprehensive mariculture suitability map for the Java Sea on the Pramuka site in a coarse resolution of 100 m. 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 7.3. 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.

Table 7.3: Comparison of DSS and measurement results for the Pramuka Island fish farm site

| 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 (km) | > 1.5 | Good | > 1.5 | Good |

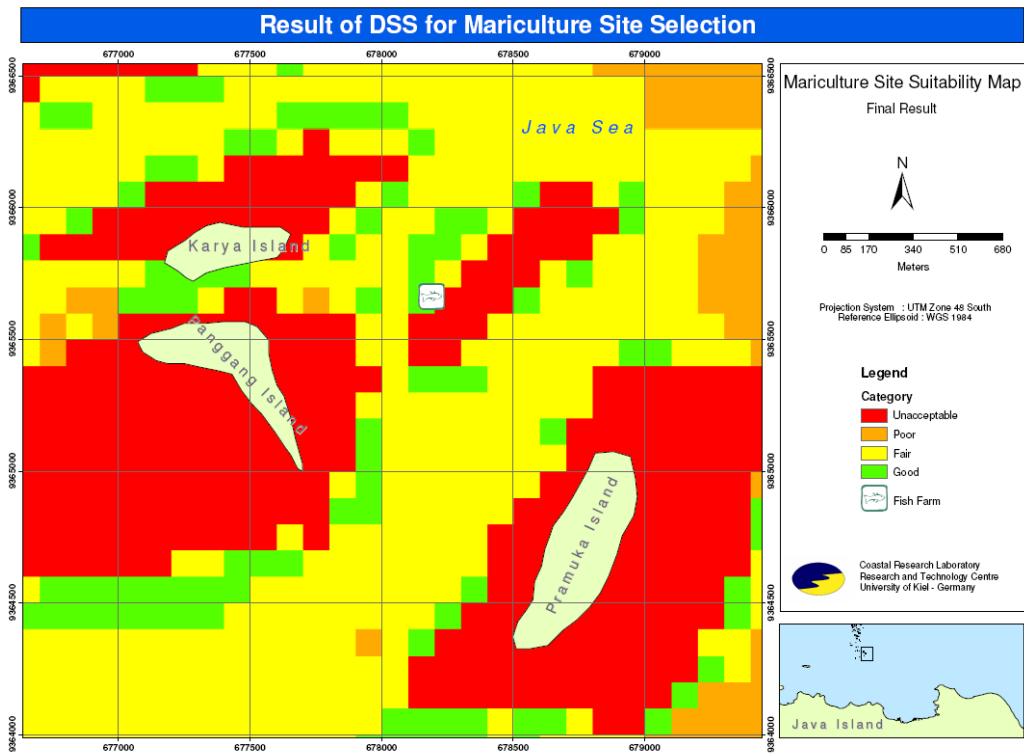


Figure 7.5: Final Result of DSS for the Pramuka Island area

7.3 Serai Island

Validation of the DSS input and output data for the Riau Islands area was done with field measurements near the Serai Island. The measuring campaign in the area was conducted in September 2005. The spatial resolution of the raster image for the DSS input data in Riau Islands is 200 m.

Physical Parameters

Bathymetry and wave parameters were not assessed during the measuring campaign at Serai Island, therefore the validation of the DSS input for Riau Islands is restricted to the current velocity. The validation of the current velocity data was part of the development of the numerical model for Riau Islands. Figure 7.6 shows one of the validation results for an observation point in the channel between Serai and Siulung Island. Some discrepancies were found between field and model data which may be due to the resolution of the model, as it places the channel between Serai and Siulung Islands (Figure 7.7) in one grid cell. However, maximal current velocities resulting from the model and measurements were in good agreement.

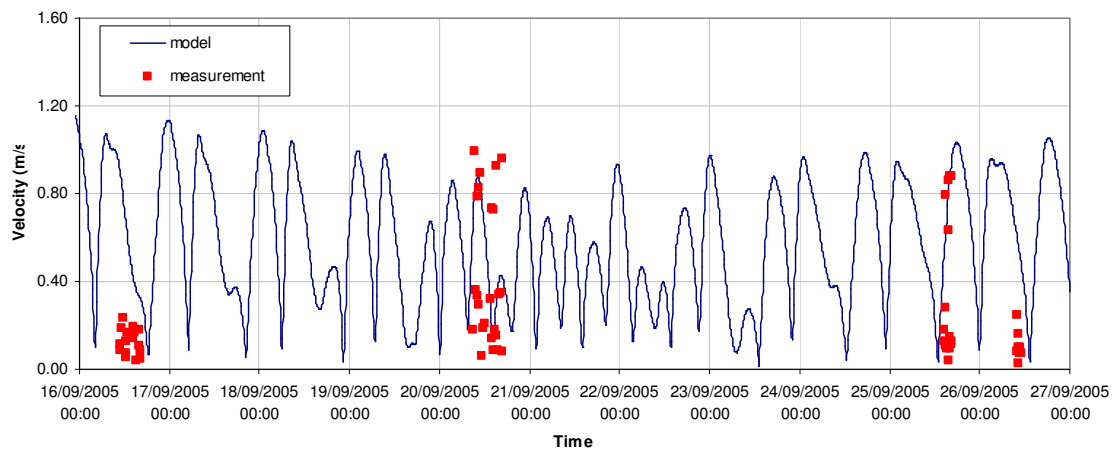


Figure 7.6: Current Velocity Validation at Serai Island

Water Temperature, Salinity and Nutrients Parameters

A comparison of water temperature, salinity and nutrient input data derived from WOA'01 and field data for Serai Island area is displayed in Table 7.4. The discrepancies in some parameters did not affect the scoring value and analysis results in DSS. It can thus be concluded that appropriate data inputs for nutrients parameters have been applied for the DSS.

Table 7.4: Comparison of chemical parameters in Serai Island Fish Farm Area

| Parameter | DSS Input | | Measurement | |
|-------------------------|-----------|-------|-------------|-------|
| | Value | Score | Value | Score |
| Water Temperature (°C) | 30 | 3 | 30 | 3 |
| Salinity (psu) | 32 | 3 | 33 | 3 |
| Dissolved Oxygen (mg/l) | 4.4 | 2 | 6.8 | 3 |
| Ammonium (mg/l) | 0.4 | 3 | 0.04 | 3 |
| Water pH | 8.1 | 3 | - | - |
| Nitrate (mg/l) | 0.21 | 3 | 0.06 | 3 |
| Phosphate (mg/l) | 0.25 | 3 | 0.04 | 3 |

Sediment Parameters

The DSS input data assumed that the Serai Island area is characterized by sandy sediments as shown in Figure 7.7. Results of a grain size analysis from bottom sediment samples close to the fish farm area reveal a sediment grain size around 0.15 – 0.45 mm (Figure 7.8) [Niederndorfer, 2006]. Ahmad et al. (2002) categorized this grain size as fine to medium sand. Hence, the DSS input data reflects appropriate values.

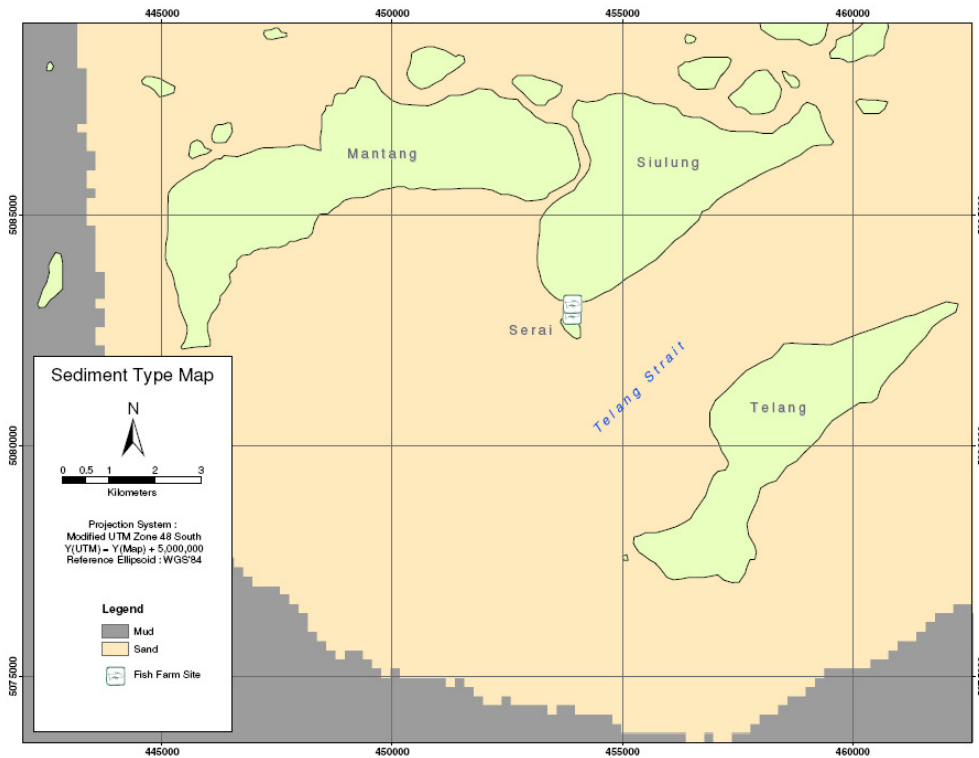


Figure 7.7: Sediment Map of Serai Island based on DSS input

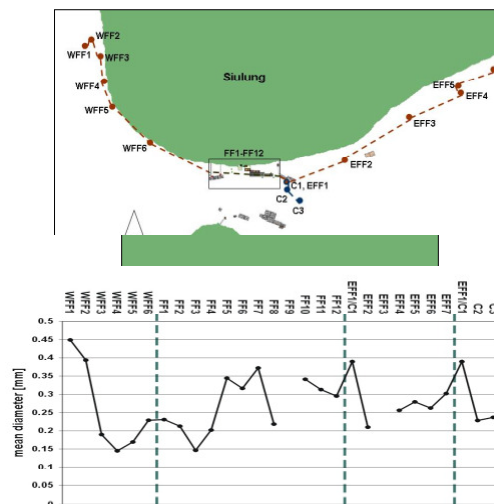


Figure 7.8: Serai Island sediment sampling positions and results of grain size analysis results [Niederndorfer, 2006]

Coastal Use

The channel between Serai and Siulung Island is a short channel about 700 m long and 300 m wide. The channel is mainly used by the local communities as mariculture site. The area is far from any navigational lines, harbour areas, tourism and industrial activities. These conditions were confirmed by the field survey applied as DSS input.

DSS Result

Figure 7.9 presents the final analysis results of the DSS. Accordingly, the Serai Island fish farm is located in the good category for mariculture implementation. Table 7.5 compares the DSS input data to the field measurement data resulting from the measuring campaign in September 2005. Both the DSS input and the measurement data reveal the same conditions for the mariculture site.

Table 7.5: Comparison of DSS and measurement results for the Serai Island fish farm site

| Parameter | DSS | | Measurement | |
|----------------------------------|-------|----------|-------------|----------|
| | Value | Category | Value | Category |
| Minimum Depth at Spring Tide (m) | 13 | Good | 8 – 15 | Good |
| Maximum Current Velocity (m/s) | 0.6 | Fair | 0.5 – 1 | Fair |
| Maximum Wave Height (m) | 0.4 | Good | - | - |
| Dean Number | 2.9 | Fair | - | - |
| Water Temperature (°C) | 30 | Good | 30 | Good |
| Salinity (psu) | 32 | Good | 33 | Good |
| Dissolved Oxygen (mg/l) | 4.4 | Fair | 6.8 | Good |
| Ammonia (mg/l) | 0.4 | Good | 0.04 | Good |
| Water pH | 8.1 | Good | - | - |
| Nitrate (mg/l) | 0.21 | Good | 0.06 | Good |
| Phosphate (mg/l) | 0.25 | Good | 0.04 | Good |
| Bottom sediment type | Sand | 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 (km) | > 1.5 | Good | > 1.5 | Good |

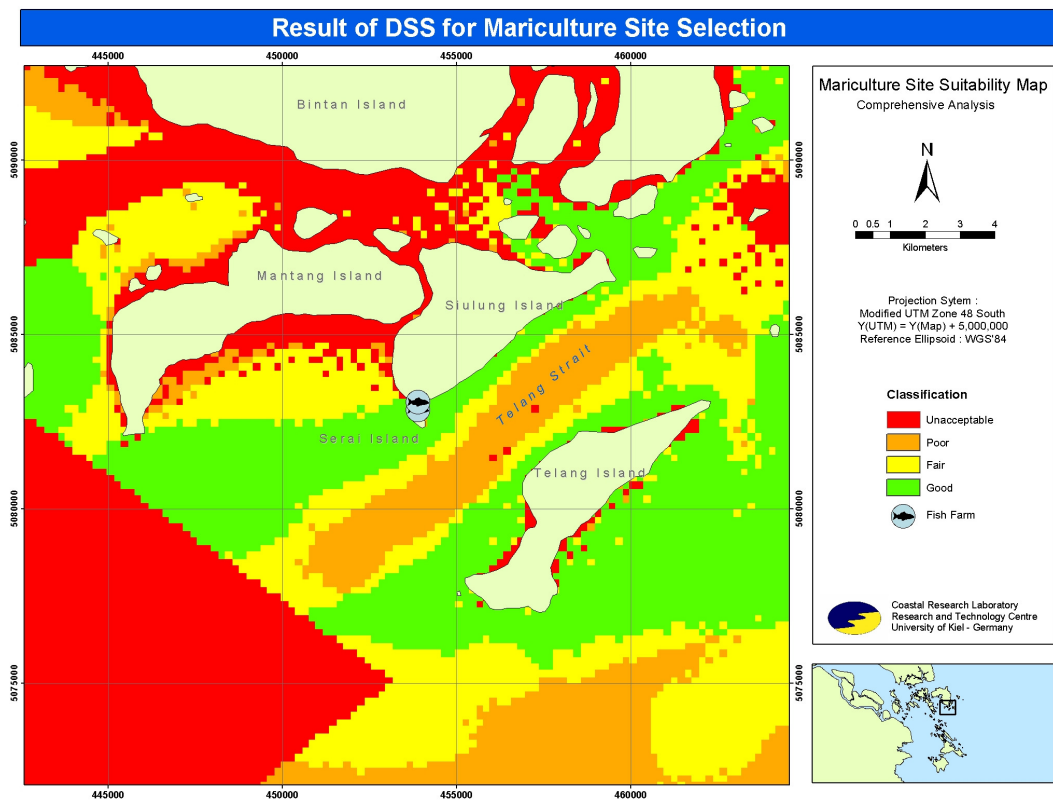


Figure 7.9: Final Result of DSS for the Serai Island area

Chapter 8. Conclusions and Recommendation

8.1 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 v8.3 GIS 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.

Generally, mariculture site selection is based on two criteria, suitability and sustainability. Suitability is related to the required proper conditions of the location that support the living environment of the fish in the farm. Sustainability is associated to the continuation of the farming itself due to environmental impact of the fish farm.

There are two case studies of coastal area in this research, Seribu Islands (the southwestern part of the Java Sea) and Riau Islands (the western part of Karimata Strait and South China Sea). Validation of the DSS input was made based on measuring campaign data in both study areas. Based on the validation results, almost all of the parameters input into the DSS represents good agreement values compared to recent field measurement data. In general, both of the study areas have chemical conditions that are close to the natural tropical seawater conditions, therefore the suitability of the mariculture site location for both areas is dominated by physical, sediment and coastal use factors.

The results of the DSS for mariculture site selection in Seribu Islands/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.

In the Riau Islands about 13.43% of the area is in *good* condition for mariculture site, this includes the area about 2 – 10 km from the islands' coastlines. Most of the area, covering 43.50% of the seawater space is in *fair* condition. Mariculture site is not recommended in 30.11% of the area due to *poor* condition. Unacceptable conditions for mariculture site were found in 12.96% of the area, located in areas up to 2 km from the islands and in areas close to the industrial area, navigational line, harbour and tourism sites.

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.

Validation results presenting appropriate values were given to the DSS for both study areas. Existing fish farms at Pramuka and Serai Islands were classified as belonging to the most suitable areas for mariculture sites based on the developed DSS's result.

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.

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.

8.2 Recommendations

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.

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.

References

- Adisukresno, S. & Perbowo, N., (1996). Indonesian Fisheries Development Overview. Proceeding of making efficient use of technology application on marine environmental monitoring for supporting sustainable development. Directorate for Human Settlement and Environmental Technology-BPPT. Jakarta, 3rd July, 1996.
- Ahmad, A., Jamaludin, I., Mahyam, M.I. & Solahuddin A.R., (2002). Sedimentological properties of the coastal waters of the East Coast of Peninsular Malaysia. In: Mansor, M.I. (ed.). Thirteenth Trawl Survey of the Coastal Waters off the East Coast of Peninsular Malaysia (April-June 2001). Ministry of Agriculture Malaysia. 138pp.
- Ahmad, T., (2001). Analysis of Sea Farming's Development in Indonesia. Warta Penelitian Perikanan Indonesia, Centre of Research and Development of Marine Exploration and Fisheries, Jakarta. Vol. 7 Nr. 1, 2000. Special Edition, pp. 9 – 14. In Indonesian.
- Aguilar-Manjarrez, J. & Ross, L.G., (1995). Geographical information systems (GIS), environmental models for aquaculture development in Sinaloa state, Mexico. *Aquaculture Int.* 3, pp. 103-115.
- Ali, C.Q., Ross, L.G. & Beveridge, M.C.M., (1991). Microcomputer spreadsheet for the implementation of geographical information systems in aquaculture. A case study on carp in Pakistan. *Aquaculture*, Vol. 92, pp. 199-205.
- Alver, M.O., Alfrredsen, J.A. & Sigholt, T. (2004). Dynamic modelling of pellet distribution in Atlantic salmon (*Salmo salar* L.) cages, *Aquacultural Engineering*, Vol. 31, pp. 51 -72.
- APEC/NACA/BOBP/GOI (2002). Report of the Regional Workshop on Sustainable Seafarming and Grouper Aquaculture, Medan, Indonesia, 17-20 April 2000. Collaborative APEC Grouper Research and Development Network (FWG 01/99). Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand. 224 pp.
- Arnold, W.S., White, M.W., Norris, H.A. & Berrigan, M.E., (2000). Hard Clam (*Mercenaria* spp.) aquaculture in Florida, USA: Geographic Information System applications to lease site selection. *Aquacultural Engineering*, Vol. 23, pp. 203 – 231.
- BAKOSURTANAL (Badan Koordinasi Survey dan Pemetaan Nasional), (1998), Marine Resource Atlas Scale 1:5,000,000. National Coordinating Agency for Surveys and Mapping. Cibinong – Indonesia.
- Bergheim, A. & Asgard, T. (1996). Waste production from aquaculture. In: *Aquaculture and Water Resource Management*, Baird, D.J., Beveridge, M.C.M, Kelly, L.A. and Muir, J.F. (eds). Blackwell Science, Oxford, pp. 50-80.

-
- Berry, J.K., (2004), Bridging GIS and Map Analysis: Identifying and Utilizing Spatial Relationships, ASPRS Annual Conference, May 23-28, 2004, Denver, Colorado.
- Best, B.A., (2002). Trade in coral reef animals, algae and products: An overview. In: Best B.A, Pomeroy, R.S., and Balboa C.M. (eds.), Implications for coral reef management and policy, relevant findings from the 9th International Coral Reef Symposium, Bali, Indonesia- October 2000, U.S. Agency for International Development.
- Bolte, J.P. & Nath, S.S., (1995). Decision support for pond aquaculture: parameter estimation for simulation models. Technical Reports: Global Studies and Activities, Thirteen Annual Report. Work Plan 7, DAST Study 5, Department of Bioresource Engineering, Oregon State University, Corvallis.
- Bolte, J.P. & Hillyer, C., (2001). Decision support systems for fish population management and scheduling in commercial pond aquaculture operations. In: A. Gupta, K. McElwee, D.Burke, J.Burright, X.Cummings & Egna, H. (Editors), Eighteen Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis.
- Boyd, C. E., (1979). Water quality in warm water fish ponds. Auburn University, Agriculture Experiment Station, Alabama, 359 pp.
- BPPT (Badan Pengkajian dan Penerapan Teknologi) (2001). Technical guide of marine fish cage culture, Agency for the Assessment and Application of Technology, Jakarta - Indonesia. In Indonesian.
- BPS (Badan Pusat Statistik) (2002). Results of population census 2000. Indonesian Centre of Statistical Agency, Jakarta.
<http://www.bps.go.id/releases/files/hasilsp2000-03jun02.pdf>
- Burrough, P.A., (1986). Principles of Geographic Information Systems, 1st Edition, Oxford University Press, New York, 336 pp.
- Caine, G.C., (1987). Biophysical criteria for siting salmon farms in British Columbia. B.C. Ministry of Agriculture and Fisheries. Food, Aquaculture and Commercial Fisheries Branch.
- Cheah, S.H. & Chua, T.E., (1979). A preliminary study of the tropical marine fouling organisms on floating net cages. Malaysian National Journal, Vol. 33, pp. 39-48.
- Chou, R., (1988). Singapore Report on Site Selection Criteria of Seafarming. UNDP/FAO Regional Seafarming Development and Demonstration Project, RAS/86/024.
- Chua, T.E., J.N. Paw and F.Y. Guarin, (1989). The environmental impact of aquaculture and the effects of pollution on coastal aquaculture development in Southeast Asia. Marine Pollution Bulletin, Vol. 20(7), pp. 335-378
- Conkright, M.E., Locarnini, R.A., Garcia, H.E., O'Brien, T.D., Boyer, T.P., Stephens, C., and Antonov, J.I., (2002). World Ocean Atlas 2001: Objective Analyses, Data Statistics, and Figures CD-ROM documentation, Ocean Climate Laboratory. National Oceanographic Data Centre, U.S.A.
- Coppola, S. & Crosetti, D., (2001). Decision-support systems for fisheries. The ITAFISH case study. Studies and Reviews. General Fisheries Commission for the Mediterranean. No. 72. Rome, FAO, 50 pp.

- Cromey, C.J, Nickell, T.D. & Black, K.D., (2002). DEPOMOD-modelling the deposition and biological effects of waste solids from marine cage farms, *Aquaculture*, Vol. 214, Issues 1-4, 15 November 2002, pp. 211-239.
- Dahdouh-Guebas, F. (2006). Mangrove forests and tsunami protection. In : 2006 McGraw-Hill Yearbook of Science & Technology, McGraw-Hill Profesional, NewYork, USA, pp. 187-191.
- Darmawan, R.A., Erowati, D.A., Setiawan, A. & Santosa A.D., (1998). Application of SEAWATCH Indonesia information system technology for environmental management of mariculture. Proceeding of the 3rd International Symposium on Advanced and Aerospace Science Technology in Indonesia, Vol. 2. Jakarta, August 31st – September 3rd 1998. Indonesian Aeronautics and Astronautics Institute.
- Dean, R. G. (1973). Heuristic models of sand transport in the surf zone. Proceeding of Conference on Engineering Dynamics in the Surf Zone, Institution of Engineers, pp. 208-413.
- DITJEN PERIKANAN (Direktorat Jenderal Perikanan), (1982). Technical guide of mariculture, Directorate General of Fisheries, Department of Agriculture, Jakarta. 24 pp. In Indonesian.
- DITP3K (Direktorat Pemberdayaan Pulau-pulau Kecil), (2002). Profiles of Indonesian Small Islands, Vol. I, Directorate of Small Islands Development, Ministry of Marine and Fisheries, Jakarta-Indonesia. In Indonesian.
- DKP (2005a). Statistic of Indonesian Fish Production 1997 – 2002, Ministry of Marine and Fisheries, Jakarta – Indonesia. In Indonesian. <http://www.dkp.go.id/main.php?m=6>
- DKP (2005b). Production statistic of Indonesian mariculture 2004, Ministry of Marine and Fisheries, Jakarta – Indonesia. In Indonesian. http://www.perikanan-budidaya.go.id/index.php-show=2&filter=1&spec_segment=001.htm
- Doglioli, A.M., Magaldi, M.G., Vezzulli, L. & Tucci, S., (2004). Development of a numerical model to study the dispersion of wastes coming from a marine fish farm in the Ligurian Sea (Western Mediterranean). *Aquaculture Journal*, Vol. 231, pp. 215 – 235.
- Ervik, A., Hansen, P.K., Aure, J., Stigebrandt, A., Johannessen, P. & Jahnsen, T., (1997). Regulating the local environmental impact of intensive marine fish farmin I. The concept of the MOM system (Modelling.Ongrowing fish farms-Monitoring). *Aquaculture*, Vol. 158, Issues 1-2, 1 December 1997, pp. 85-94.
- FAO, (1989). Site selection criteria for marine finfish net cage culture in Asia, UNDP/FAO Regional Seafarming Development and Demonstration Project, Network of Aquaculture Centres in Asia. Food and Agricultural Organization Documentation NACA-SF/WP/89/13.
- FAO Fisheries Department, (1997). Aquaculture development, FAO Technical Guideline Responsible Fisheries, No. 5, pp. 7
- FAO, (2003). FISHERIES GLOBAL INFORMATION SYSTEM. FI Programme Websites. FAO - Rome. Updated Wed Jun 28 16:25:34 CEST 2006. Available via FIGIS from: http://www.fao.org/figis/servlet/static?dom=org&xml=FIGIS_org.xml.
- Falconer, R.A., Cox, I.C.S., (1989). Numerical modelling of the vertical tidal current and salinity structure in a deep water Scottish Loch, *Ocean and Shoreline Management*, Vol. 12, Issue 1, 1989, pp. 61 – 80.

- FTZ (Forschung und Technologiezentrum, Westküste), (2005). Interim Report of SPICE Project Cluster 3.2, Development of a Decision Support System for the Sustainable Management of Coastal Living Resources. Kiel University, Germany.
- GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). (2001). Planning and management for sustainable coastal aquaculture development. Report and Studies No. 68. Food and Agriculture Organization of The United Nations.
- Glude, J.B., (1982). The potential for seafarming in the Riau Archipelago district of Indonesia, Work plan implementation, South China Sea Fisheries Development and Coordinating Programme, FAO Document, SCS/82/WP/110.
- Gordon, R.L., (1996). Acoustic Doppler Current Profiler: Principles of operation, A practical Primer. Second Edition. RD Instruments, San Diego, USA.
- Hargrave, B.T., (2002). A traffic light decision system for marine finfish aquaculture siting, Ocean and Coastal Management, Vol. 45, pp. 215 – 235.
- ICES (International Council for the Exploration of the Sea), (2003). Report of the Working Group on Environmental Interactions of Mariculture, Vigo, Spain, 31 March – 4 April 2003, 118 pp.
- Ilahude, A.G., (1980). The oceanographic features of the coastal region between Jakarta and Cirebon, Oceanographic section. In : Bird, C.F and Soegiarto, A. (Editors). Proceeding of the Jakarta Workshop on Coastal Resources Management. 11 – 18 September 1980. LIPI – Jakarta.
- Kapetsky, J.M., Hill, J.M & Worthy, D.L., (1988). A geographical information system for catfish farming development. Aquaculture, Vol. 68, pp. 311-320.
- Kapetsky, J.M., (1989). A geographical information system for aquaculture development in Johor State, FAO Field Document, FI:TCP/MAL/6754, Malaysia, January 1989.
- Kapetsky, J.M. & Travaglia, C., (1995). Geographical information systems and remote sensing: an overview of present and potential applications in aquaculture. In: Nath, S.S., Bolte, J.P., Ross, L.G. & Aguilar-Manjarrez, (2000). Application of geographical information systems (GIS) for spatial decision support in aquaculture. Aquacultural Engineering, Vol. 23, pp. 233-278.
- Kapetsky, J.M, Hill, J.M., Worthy, D.L. & Evans, D.L., (1990a). Assessing potential for aquaculture development with a geographic information system. Journal of World Aquaculture Society, Vol 21, pp. 241-249
- Kapetsky, J.M., Wijkstrom, U.N., MacPherson, N.J., Vicnke, M.M.J., Ataman, E. & Caponera, F., (1990b). Where are the best opportunities for fish farming in Ghana? The Ghana aquaculture geographical information system as a decision-making tool. FAO Field Technical Report 5, FI:TCP/GHA/0051, FAO, Rome.
- Karthik, M., Suri, J., Saharan, N. & Biradar, R.S., (2005). Brackish water aquaculture site selection in Palghar Taluk, Thane district of Maharashtra, India, using the techniques of remote sensing and geographical information system. Aquacultural Engineering, Vol. 32, pp. 285-302.
- Kishi, M.J., Uchiyama, M. & Iwata, Y., (1994). Numerical simulation model for quantitative management of aquaculture, Ecological Modelling, Vol. 72, Issues 1-2, March 1994, pp. 21 – 40.

- KK Hidrografi, (2000). Measurement of oceanography and meteorology parameters in Pramuka, Panggang and Karya Island waters, Seribu Islands. Report. Hydrography Working Groups, Faculty of Civil Engineering and Planning, Bandung Institute of Technology.
- KLH (Kantor Menteri Negara Kependudukan dan Lingkungan Hidup). (1984). Water quality standard for tourism, marine fisheries and culture of marine fisheries. In: Romimohtarto, K., (1985). Water quality in mariculture, Seafarming workshop report, Bandar Lampung, Indonesia. FAO Documentation, WBL/85/WP-13.
<http://www.fao.org/docrep/field/003/AB882E/AB882E13.htm>
- Krant, J., Motzkin, F. & Gordin, H., (1981). Modelling temperatures and salinities of mixed seawater fish ponds. *Aquaculture*, Vol. 27, Issue 4, May 1982, pp. 377-388.
- Kraus, N.C., Larson, M. & Kreibel, D.L., (1991). Evaluation of beach erosion and accretion predictors. *Proceeding of Coastal Sediments 1991*, ASCE, pp. 572-587.
- Landesman, L., (1994). Negative impacts of coastal tropical aquaculture developments. *World Aquaculture*, Vol. 25. pp 12-17.
- Landeta, F., (2005). Development of a wave model for a fish farm in archipelago Seribu, Indonesia. Master of Science Thesis. Coastal Geosciences and Engineering. Kiel University.
- LAPAN (Lembaga Penerbangan dan Antariksa Nasional), (2005). Socialisation and field survey of "Application of remote sensing and geographical information systems for development of mariculture" project. Preliminary results. The National Institute of Aeronautics and Space of Indonesia, Jakarta. 19 pp.
- Lee, J.H.W. & Qu, B., (2001). Hydrodynamic modelling and algal bloom tracking in Hong Kong's coastal waters in March-April 1998, *Hydraulics for Maritime Engineering*, Proceedings of the 29th IAHR Congress, Beijing, China, September 2001
- Lee, J.H.W., Choi, K.W. & Arega, F., (2003). Environmental management of marine fish culture in Hong Kong, *Marine Pollution Bulletin*, Vol. 47, Issues 1-6, January-June 2003, pp. 220-210.
- Legault, J.A., (1992). Using a geographic information system to evaluate the effects of shellfish closure zones on shellfish leases, aquaculture and habitat availability. Canadian Technical Report of Fisheries Aquaculture Science 1882E:iv+10
- Longley, P.A., Goodchild, M.F., Maguire, D.J., and Rhind, D.W., (2005). *Geographical Information Systems and Science*. 2nd Edition, John Wiley & Sons Ltd., West Sussex, England.
- Lovegrove, T., (1979). Control of fouling in farm cages. *Fish Farming International*, Vol. 6.
- LUCO, (1998). Guide to spatial land and resource information in LRMP. Land Use and Coordination Office, British Columbia. Internet website
<http://www.luco.gov.bc.ca/lrmp/spatial/marine.htm>
- Meaden, G.J., (1987). Where should trout farms be in Britain? *Fish Farmer* March/April, pp. 33-35.
- Meyers, G., (1996). Variation of Indonesian Throughflow and the El Niño – Southern Oscillation, *Journal of Geophysical Research*, Vol. 101, No. C5, pp. 12,255-12,264.

-
- Nath, S.S., (1996). Development of a decision support system for pond aquaculture. PhD Dissertation, Oregon State University, Corvallis.
- Nath, S.S., Bolte, J.P. & Ernst, D. H., (1996). Decision support for pond aquaculture planning and management, Department of Bioresource Engineering, Oregon State University, Corvallis.
- Nath, S.S., Bolte, J.P., Ross, L.G. & Aguilar-Manjarrez, (2000). Application of geographical information systems (GIS) for spatial decision support in aquaculture. *Aquacultural Engineering*, Vol. 23, pp. 233-278.
- Niederndorfer, K.R., (2006). Investigation on the dynamics of particulate matter emissions from Hiang Fisheries Fish Farm Pulau Serai, Indonesia. Master of Science Thesis. Coastal Geosciences and Engineering. Kiel University.
- Pérez, O.M., Telfer, T.C., Beveridge, M.C.M. & Ross, L.G., (2002). Geographical Information Systems (GIS) as a simple tool to aid modelling of particulate waste distribution at marine fish cage sites, *Estuarine, Coastal and Shelf Science*, Vol. 54, pp. 761 – 768.
- Pérez, O.M., Telfer, T.C. & Ross, L.G., (2003a). Use of GIS-based models for integrating and developing marine fish cages within the tourism industry in Tenerife (Canary Islands). *Coastal Management*, Vol. 31, pp. 355 – 366.
- Pérez, O.M., Telfer, T.C. & Ross, L.G., (2003b). On the calculation of wave climate for offshore cage culture site selection: a case study in Tenerife (Canary Islands). *Aquacultural Engineering*, Vol. 29, pp. 1 – 21
- Pérez, O.M., Ross, L.G., Telfer, T.C. & del Campo Barquin, L.M, (2003c). Water quality requirements for marine fish cage site selection in Tenerife (Canary Islands): predictive modelling an analysis using GIS, *Aquacultur Journal*, Vol. 224, pp. 51 – 68.
- Pérez, O.M., Telfer, T.C. & Ross, L.G., (2005). Geographical information systems-based models for offshore floating marine fish cage aquaculture site selection in Tenerife, Canary Islands. *Aquacultural Research*, Vol. 36, pp. 946-961
- Populus, J., Hastuti, W., Martin J.M., Guelorget O., Sumartono, B. & Wibowo, A.,(1995). Remote sensing as a tool for diagnosis of water quality in Indonesian seas. *Ocean & Coastal Management*, Vol. 27, Issue 3, pp. 197-215.
- Power, D.J., (2000). Supporting Decision-Makers: An Expanded Framework, World Wide Web. <http://dssresources.com/papers/supportingdm/sld001.htm>
- Power, D.J., (2004). Decision Support Systems Web Tour, World Wide Web, <http://dssresources.com>, version 4.3, January 11, 2004.
- Praseno D.P., (1980). The oceanographic features of the coastal region between Jakarta and Cirebon, Biology section. In : Bird, C.F and Soegiarto, A. (Editors). Proceeding of the Jakarta Workshop on Coastal Resources Management. 11 – 18 September 1980. LIPI – Jakarta.
- Purwaka, T. and Sunoto.1999. Coastal and marine resources management in Indonesia: legal and institutional aspects. PRIAP-ICLARM Working Paper Series 2, Manila, Philippines, pp. 60-90.
- Ramelan, S.H., (2000). Present status and strategy of Indonesian mariculture development, Proceeding of Regional Workshop on Sustainable Seafarming and Grouper Aquaculture, Asia-Pacific Economic Cooperation (APEC), Medan, Indonesia.

- Riqqi, A., (2001). Prototype of geographic information systems application for pond aquaculture management (case study: Kabupaten Serang). Master thesis. Biology Department. Bandung Institute of Technology. In Indonesian.
- Riyadi, A. & Adibroto, T.A., (1999). SEAWATCH buoy monitoring and zoning for monitoring in coastal area development plan. Proceeding International Seminar on "Application of Seawatch Indonesia Information System for Indonesian Marine Resources Development". March 10-11, 1999. BPPT-Jakarta, pp. 163-181.
- Ross, L.G., Mendoza, E.A. & Beveridge, M.C.M., (1993). The application of geographical information systems to site selection for coastal aquaculture: an example based on salmonid cage culture. *Aquaculture*, Vol. 112, pp. 165-178.
- Saaty TL, 1980, *The Analytic Hierarchy Process*, NY, McGraw Hill.
- Santoso, A.D., Aboejoewono, W., Bilal, J. & Bachtiar, I., (1977). Inventory of surface water quality of Jakarta Bay. National Oceanographic Agency. Jakarta
- Santoso, A.D. & Nursetiarso, B.C., (1999). The application of SEAWATCH Indonesia monitoring system for environmental management of mariculture. Proceeding International Seminar on "Application of Seawatch Indonesia Information System for Indonesian Marine Resources Development". March 10-11, 1999. BPPT-Jakarta, pp. 208-215.
- Scott, P.C., Cansado, S. & Ross, L.G., (1998). A GIS-assisted mollusc culture potential determination for Sepetiba Bay, Brazil. Paper presented at the GIS Planet'98 Conference, 7 – 11 September, 1998. Lisbon, Portugal.
- Scottish Executive, (1999). Policy guidance note: Locational guidelines for the authorisation of marine fish farms in Scottish waters, Scottish Executive.
<http://www.scotland.gov.uk/library2/doc06/mff-00.htm>
- SETNEG (Sekretariat Negara), (2005). Indonesian Profil, Indonesian Government website.
<http://www.indonesia.go.id/navigasiDetail.php?navId=1&content=0>
- Shepherd, D.P., (2001). Assessment of the potential to develop mariculture in Western Australia, *Geospatial Information and Agriculture 2001*, Australia
<http://www.regional.org.au/au/gia/26/842shepherd.htm>
- Silvert, W., (1994). A decision support system for regulating finfish aquaculture, *Ecological Modelling*, Vol. 75, pp. 609 – 615.
- Silvert, W., (1994). Decision support systems for aquaculture licensing, *Journal of Applied Ichthyology-Zeitschrift für Angewandte Ichthyologie*, Vol. 10(4), pp. 307 – 311.
- Silvert, W., (2001). Fuzzy logic modelling of traffic light indicators, Final report of project "Fuzzy Logic Modelling of Traffic Light Indicators". Instituto de Investigação das Pescas e do Mar, Departamento de Ambiente Aquático, Avenida de Brasília. Portugal.
<http://ciencia.silvert.org/models/fuzzy/ftlm/index.html>
- Sim, S.Y., Rimmer, M.A., Toledo, J.D., Sugama, S., Rumengan, I., Williams, K.C., Phillips, M.J., (2005). A guide to small-scale marine finfish hatchery technology. NACA, Bangkok, Thailand, 17 pp.
<http://library.enaca.org/Grouper/Publications/grouper-hatchery-guide.pdf>
- Sprague, R.H. & Carlson, E.D., (1982). *Building Effective Decision Support Systems*, Prentice Hall International.

-
- Stigebrandt, A. & Aure, J., (1995). The MOM model for the benthic holding capacity of a fish farm site, Report on International Workshop on Modelling Environmental Interactions of Mariculture, Bedford Institute of Oceanography, Dartmouth, NS, Canada, 6-8 September 1995.
- STREAM (Support to Regional Aquatic Resources Management), (2005). Pond Construction: Selecting Good Places for Ponds, Better-practice guidelines (No. 2).
<http://www.streaminitiative.org/Library/pdf/bpg/worlp/WBPG2.pdf>
- Sugama, K., (2002). Status and development of mariculture in Indonesia, Regional Workshop on Sustainable Marine Finfish Aquaculture for the Asia-Pacific, Halong City, Vietnam. 30th September – 3rd October 2002.
<http://library.enaca.org/Grouper/HalongWorkshop/Indonesia.pdf>
- Suhey, J.D., Kim, N.H. & Niezrecki, C., (2005). Numerical modelling and design of inflatable structures-application to open-ocean-aquaculture cages, *Aquacultural Engineering*, Vol. 33, Issue 4, October 2005, pp 285-303.
- Svirezhev, Y.M., Krysanova, V.P. & Voinov, A. A., (1983). Mathematical modelling of a fish pond ecosystem. *Ecological Modelling*, Vol. 21, Issue 4, pp. 315-337.
- Swann, L.D., (1992). A Basic Overview of Aquaculture, Technical Bulletin Series # 102, Iowa State University, Ames, Iowa.
- TCMP (Tanzania Coastal Management Partnership), (2001). Tanzania mariculture guidelines source book, Working Document # 5048 TCMP.
http://www.crc.uri.edu/download/TAN_0046.PDF
- Tiensongrusmee, B., (1986). Site Selection for the Culture of Marine Finfish in Floating Netcages, FAO Documentation, INS/81/008/Manual/1
- Trick M., (1996), Multiple Criteria Decision Making for Consultants, Internet Article, <http://mat.gsia.cmu.edu/mstc/multiple/multiple.html>
- Wallis, I.G., (1974). Modelling the impact of waste on a stable fish population, *Water Research*, Vol. 9, Issue 12, pp. 1025-1036.
- WCED (World Commission on Environment and Development), (1987). *Our common future*, Oxford UK, Oxford University Press, pp. 383.
- Wibowo, A., (1994). Application of Remote Sensing and GIS for monitoring of brackish water aquaculture. Internal article, BPPT – Jakarta.
- WL | Delft Hydraulics, (2005). DELFT3D-FLOW, Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments. WL | Delft Hydraulics, The Netherlands
- Wu, R. S. S., (1995). The environmental impact of marine fish culture: Towards a sustainable future. *Marine Pollution Bulletin*, Vol. 31, Issues 4 – 12, pp. 159 – 166.
- Wu, R.S.S., Shin, P.K.S., MacKay, D.W., Mollowney, M. & Johnson, D. (1999). Management of marine fish farming in the sub-tropical environment: a modelling approach, *Aquaculture*, Vol. 174, Issues 3-4, 20 April 1999, pp. 279 – 298.
- Wyrski, K., (1961). Scientific Results of Marine Investigations of the South China Sea and the Gulf of Thailand 1959 – 1961. Naga Report, 2. University of California, Scripps Institute of Oceanography, La Jolla, California.

Erklärung

Hiermit erkläre ich, dass die Abhandlung -abgesehen von der Beratung durch meine akademischen Lehrer- nach Inhalt und Form meine eigene Arbeit ist. Diese Arbeit hat an keiner anderen Stelle im Rahmen eines Prüfungsverfahrens vorgelegen. Außerdem erkläre ich, dass diese mein erster Promotionsversuch ist.

Kiel, den 16.12.2006

Wiwin Windupranata

About the Author

Wiwin Windupranata was born in Bandung, Indonesia on May 4th, 1974. From 1992 the author start his academic study in Geodetic Engineering at the Bandung Institute of Technology. He graduated in 1998 to receive his Bachelor of Engineering. He took a final project as his thesis on hydrography. In the same year he affiliated with the Hydrographic Science and Engineering Working Group, Faculty of Earth Science and Engineering (formerly in the Faculty of Civil Engineering and Planning) and works there as a researcher and lecturer until today.



In 2000 he continued his study to the Master of Science program in Physical Oceanography and Meteorological Science, Bandung Institute of Technology. He completed his study with master project on *Analysis of Sea Surface Topography in Indonesian Waters, Pacific and Indian Oceans and their Relationships with El Nino and La Nina Phenomenon*.

From December 2003 until February 2007 he conducted his doctorate study at the Coastal Research Laboratory, the Research and Technology Centre, Westcoast, Kiel University, Germany. His research on the *Development of Decision Support Systems for Sustainable Management of Coastal Living Resources* was funded by the German Academic Exchange Service (Deutscher Akademischer Austauschdienst - DAAD) as part of the Marine Science Program for the SPICE Project 2003 - 2007.