SPATIAL MODELING FOR MARICULTURE SITE SELECTION BASED ON ECOSYSTEM PARAMETERS AT KUPANG BAY, EAST NUSA TENGGARA INDONESIA

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Abstract. The aims of the study were: (a). to identify the physical, chemical and biological parameters at the utilization zone-coastal water of Kupang Bay, East Nusa Tenggara, (b). to analyze the value of coastal water suitability from the physical, chemical and biological parameters for the development for mariculture at the utilization zone of Kupang Bay, East Nusa Tenggara, (c). to select the sub zone for sea weed culture, grouper fish culture site using the system of floating net cage and the culture of pearl oyster. The method used in the study is a spatial approach by conducting the direct measurement of the physical, chemical, and biological parameters. Mapping and spatial model was processed and analyzed through a geo-statistic method. The site selection for mariculture sub-zones were constructed through a spatial scoring and spatial interaction- RGB model and based on the matrix of ecosystem parameters suitability score and weighting. With consideration that any numerical, mathematical or spatial model related to the surface of the earth or an ecosystem should take into account the concept of 4D function of its spatial distribution (x,y,z) and temporal consideration (time) such as seasonal data. The result showed that the range values of the physical, chemical, and biological parameters at utilization zone of the Kupang Bay are as follow: (1). Variable of physical parameters were: (a). depth 5–25 m, (b). transparency 3.00-11.00 m, (c). temperature 26-28.45ºC, (d). salinity 31.50-38.20 ppt, (e). Substrate consist of: sand, sandy clay, clay sand, silt clay, silt, sand, and coral, (f). current velocity 0.059-0.238 m/s, and (g) Total Suspended Solid 180-305 mg/l. (2). Variable of chemical parameters were: (a). dissolved oxygen 6.85-8.74 ppm, (b). pH 7.97-8.59, (c) phosphate is 0.081-0.435 mg/l, and (d). nitrate 0.145-4.134 mg/l, (3). Variable of biological parameter were: (a) abundance of phytoplankton 106,760-210,380 cell/l, and (b) chlorophyll-a 0.033-0.037 mg/m^3. Sub zone for seaweed culture identified mainly almost at all area of the middle of the Kupang Bay width about 7,544 hectares. The most-suitable sub-zone for grouper fish culture was 2,803 hectares wide and width of 1,336 hectare of moderately-suitable. Sub zone for pearl culture exist especially at the north part of Kupang Bay and at some area nearby at the mouth of the Kupang Bay wide about 4,383.8 hectares. The approach with the above concept had proved that with a significance difference of 'scoring-weight' on each specific and important ecosystem parameters for each spatial analysis purposes (i.e. 50% scoring-weight of nitrate and phosphate for sea weed culture sub zone; 40% scoring-weight of Dissolved Oxygen for fish culture sub zone and 40% scoring-weight of plankton abundance for oyster pearl culture sub zone), had resulted in a distinctive and specific delineation for each culture sub zones, thus avoiding and less on sub zonal overlapping.

Keywords: *Ecosystem parameters, Kupang Bay, Mariculture, Spatial model*

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1. Introduction

Attention of the Government of Indonesia in the Export Development Program of Fisheries in 2003 is mainly on Mariculture. It is hoped that with high productivity from Mariculture in the future will take over gradually the rely on capture fishery especially with optimalization of marine resources and science and technology applications (Widodo, 2001). Inline with the spirit of local autonomy, the government of East Nusa Tenggara Province (NTT) was eager to increase community income. The program launched is called GEMALA (Gerakan Masuk Laut / Go To the Sea Movement). This was supported with the designation of Kupang Bay as the potential coastal zone for Mariculture development. The site selection is an important factor in Mariculture suitability as well as to guaranty for the success (Milne, 1979; Muir and Kapetsky, 1988). Some important considerations need to be taken into account in the site selection are the specific performance of local ecosystem : physical, chemical and biology parameters (Hartoko and Helmi, 2004) as well as the non technical factors such as the market demand for the culture commodity, security and human resources (Milne, 1979; Pillay, 1990). In general, the failure of Mariculture product is unsuitable coastal ecosystem.

Most of the failures occurred because the site selection for Mariculture zones was determined based on feeling or trial and error. Therefore, data, information and spatial analysis for site suitability for marine area are essential (Hartoko and Helmi, 2004). The paper is expected can be used as a spatial analysis guide for more specific site-selection for Mariculture purposes. Otherwise, the misguided site selection zones will resulted in the incompatibility for a real Mariculture or other coastal use.

2. Method

The method used for this research was in-situ measurement of ecosystem parameters, such as physical, chemical and biological parameters. Temperature, dissolved oxygen, salinity, and pH were measured by using the water quality checker Horiba U-10-A. The water depths are measured using a digitized bathymetric map, while the water transparency is measured using a seichi disk and the water current using the current meter. Other variables, such as bottom substrate (sampled with grab sampler), nitrate, phosphate, and chlorophyll-a are measured using the spectrophotometer method, whereas the plankton (counted using sedge wick rafter) were analyzed in the laboratory. The research zone was a marine area of Kupang Bay designated by local government of East Nusa Tenggara Province 10°00′–10°20 S and 123°23′–123°45′ E. Field measurement and sampling station were based on a purposive sampling (Nasution, 2001), as referred to the geographical, physiological and aim of the research. The sampling station coordinate was derived by Garmin Global Positioning System (GPS). Samples of physical, chemical, and biological parameters were taken from 8.00 am to 17. 00 pm local/ east Indonesia time. Data analysis was mainly transformation from point into a spatial layers, followed by spatial modeling based on geo-statistic gridding known as ‘kriging-method’ (Hartoko, 2000). The coordinate data transformation was carried out from Geodetic data (Degree, Minute, Second) into a single numeric coordinate based on the formula (Hartoko and Helmi, 2004):

Numeric Value (Lat;Long) =
Degree + {Minute + (Second/ 60)} / 60

Spatial gridding was carried out to obtain about 13 ecosystem parameters spatial layers. The next step was analysis of water-suitability based on the spatial scoring matrix of all ecosystem parameters as in Table 1. In this study, the scoring process (determination of value and weight of each ecosystem parameters) should be based on the "understanding on the function of each parameter in the ecosystem, with respect to the specific goal of its use, i.e. for fish, sea weed or bivalve Mariculture".

The suitability levels of the coastal water were divided into four classes namely S1: Highly Suitable, S2: Moderately Suitable, S3: Marginally Suitable, and N: Not Suitable. Class evaluation was based on guideline by Hartoko and Widowati (2008b); DKP-RI (2002) where S1 (85–100%), S2 (75–84%), S3 (65–74%) and N (<65%). Since the goals of this Mariculture site selection spatial model were for the sea weed culture; groupers/ polka dot grouper; and for oyster pearl (Bivalve), then a specific consideration must be taken for the weighted parameters in the 'spatial scoring' process, that is we had to give a high score specific ecosystem parameter for each kind of commodity being cultured. As an example, we can put about 40–50% of score-weight of nitrate, phosphate and water transparency for sea weed culture; DO, water current for fish culture and water current and phyto-plankton for pearl culture (Bivalve) culture zone. This significance weight-score for specific purposes would help in the spatial separation of the classes and zonation for Mariculture being clearer and more accurate, and will not give ambiguous and biased or overlapping zones.

3. Results and Discussion

3.1. Geographical Conditions of the Site

The coastal zone of Kupang Bay was moderately large, semi enclosed, and relatively protected from the ocean waves located between Semau and Kera islands. The inhabitant area was mostly centered at the south of the Kupang Bay. The accessibility to the coastal area was relatively in a good condition with the road network to most area of Kupang Bay. Beside, it was also supported by the marine port, air port, cold strorage, fish processing zone, easy access for fish fry as well as for marketing facilities.

3.2. Ecosystem Parameters

The in-situ ecosystem parameter measurements and sampling were obtained during the east monsoon (May 2006) at 16 well distributed sample coordinates in the Kupang Bay. The depths of sample stations were range from 5-25 m, with average of 9.59 m±SD 5.057. The deepest station exists at the coordinate of about 10º03'11.2"S / 123º36'53.6"E, and the shallowest one is at coordinate of about 10º05'49.6"S / 123º42'13.2"E. The range of depth was found especially suitable for sea weed, grouper and pearl-bivalve culture site. Water transparency ranges from 3.00 to 11.00 m with average of 7.00 m±SD 3,033. Highest transparency exist at coordinate at of about 10º08'04.7"S / 123º27'58.2"E and 10º09'32.4"S / 123º28'46.6"E. Meanwhile, the lowest transparency exists at the coordinate of about 10º03'11.2"S / 123º36'53.6"E. This data would help in identifying suitable location for the sea weed culture which especially needs high water transparency.

The water temperature in Kupang Bay ranged from 26ºC to 28.45ºC with the average of 27.58ºC±SD 0.636. The water currents vary from 0.059 m/sec to 0.238 m/sec with the average of about 0.122 m/sec±SD 0.067. Low currents were found at coordinate of about 10º09'15.0″S / 123º35'01.1″E and the highest ones at 10º05'46.6"S / 123º33'20.8"E. Water current varies because of turbulence and impact of stronger current from the adjacent open seas. Total suspended solid

(TSS) ranged from 180 mg/l to 305 mg/l with the average of about 252 mg/l±SD 42.703. Lowest TSS exists at coordinate of about 10º08'23.2"S / 123º38′10.0″E, whereas the highest one exists at 10º01′32.7″S / 123º38′41.6″E. Variations in TSS were caused by difference of bottom material composition and water mass movement such as tidal fluxes.

Analysis on samples the bottom material or substrate revealed the occurrence of some cluster of bottom substrate, namely (a) Predominant silt with clay, silt-clay. This kind of substrate is located in the inner part of Kupang Bay which is assumed coming from the coastal and river run-off (b) Sandy substrate located at the outer part of the Kupang Bay. The occurrence of water mass flowing into the bay was assumed bringing colloid and lighter particles and leaving sandy particles which are heavier; and (c) Coralline substrate type and sandy and coralline mixed substrate at front of the outer bay, which is relatively closer to open seas. Water salinity ranges from 31.50-38.20 ppt with the average of 34.33 ppt±SD 2.782. Lowest salinity exist at 10º08'04.7"S / 123º27'58.2"E and highest salinity at 10º03'42.0"S / 123º42'38.5"E. The variation of water salinity occurred was caused by the seawater discharge from the shrimp culture pond along the coastal area into the Kupang Bay. The specific ecosystem case happened in the area that the seawater discharge from the ponds had a higher water salinity, thus had impact into the water salinity of the Kupang Bay. Value of pH varies from 7.97-8.59, with the average of 8.35±SD 0.190. The lowest pH exist at coordinate of about 10º08'04.7"S / 123º27'58.2"E and the highest one exists at the coordinate of about 10º03'42.0"S / 123º42'38.5"E. Dissolved Oxygen (DO) varies from 6.85-8.74 mg/l with the average of 7.58 mg/l±SD 0.531. The lowest DO occurs at 10º03'42.0"S / 123º42'38.5"E and the highest one exists at 10º08'23.2"S/ 123º38'10.04"E.

Concentration of phosphate varies from 0.081-0.435 mg/l, with the average of 0.181 mg/l±SD 0.082. The lowest phosphate concentration exists at coordinate of about 10º01'52.1"S / 123º40'01.3"E and the highest concentration occurs at 10º08'35.0" S / 123º36'51.1"E. Concentration of nitrate ranges from 0.145-4.134 mg/l with the average of 1.091 mg/l±SD 1.311. The lowest nitrate exists at the coordinate of 10º01'52.1"S / 123º40'01.3"E and the highest one occurs at coordinate 10º02'59.7"S / 123º35'28.4"E. Chlorophyll-a varies from 0.033-0.037 mg/l with the average of 0.035 mg/l±SD 0.001. Spatial variation of chlorophyll-a at the Kupang Bay is assumed in association with distribution of phytoplankton both to density occurrence or its composition and to type of pigment. Phytoplankton density varies from 106,760 cells/l to 210,380 cells/l with average of 149,935 cells/l±SD 29.622.

Lowest phytoplankton density exist at coordinate of about 10º01'52.1"S / 123º40'01.3"E and the highest ones occurs at coordinate of about 10º02'59.7"S / 123º35'28.4"E. Spatial distribution of phytoplankton was assumed due to current, nutrient, chlorophyll-a as well as water transparency pattern. Species spatial distribution of phytoplankton varies due to seasonal changes (Newell and Newell, 1963), light, temperature, and mineral concentration (Hartoko, 2000), run off, current and grazing activity (Hartoko, 2004). Nontji (2005) postulated that distribution of chlorophyll-a due to location and plankton density. In general average value of sea water ecosystem parameters of the Kupang Bay were in a the good range for Mariculture zone.

Three of ecosystem data combined in RGB-layer method as shown in Figure 1 should be regarded as indicators of spatial interaction of the three ecosystem parameters. A step-wise three ecosystem RGB spatial interaction than could then be made in order to study and consider any specific ecosystem parameters interactions and lead to the pre zonation on each location. As an example the three spatial ecosystem interaction of DO–Plankton and chlorophyll-a as in Figure 1 (above) can be used for the identification of fish-culture sub zone. Any combination using plankton data layer could be used for the identification of oyster pearl (Bivalve) culture sub zones. While as in Figure 1 (below) in the spatial interaction of nutrient (nitrate and phosphate) to chlorophyll-a can be considered as an indication for sea water productivity as well as that this three specific ecosystem parameters interaction can be used to especially identify sea weed culture sub zone. This paper purposes to introduce the necessary for combining and taking into account the interactions among Mariculture with geodetic science and in which this matter was the weaknesses in this kind of process so far.

3.3. Spatial Model for Mariculture Zone of Kupang Bay

3.3.1. Site Selection for Sea Weed Culture Sub Zone

Study on spatial analysis of ecosystem parameters of the Kupang Bay results in a class of Highly Suitable-S1 and Moderately Suitable-S2 for sea weed culture. The spatial analysis and site selection for sea weed culture was characterized with consideration of important limiting factors especially nutrient: nitrate (25% scoring-weight) and phosphate (25% scoring-weight) which is in order to maintain sustainable growth and withhold of sea-weed culture. Other supporting ecosystem parameters to be considered in the scoring-weight for sea weed culture site-selection sub zone are water current, suspended-solid, and especially transparency, water depth and chlorophyll-a, as indicated in Figure.1 (below). Results of 'spatial-scoring' as in Figure 2 shows that the suitable proposed sub zone was almost the middle inside part of the Kupang Bay with area about 18,974.6 hectare (orange and red colors).

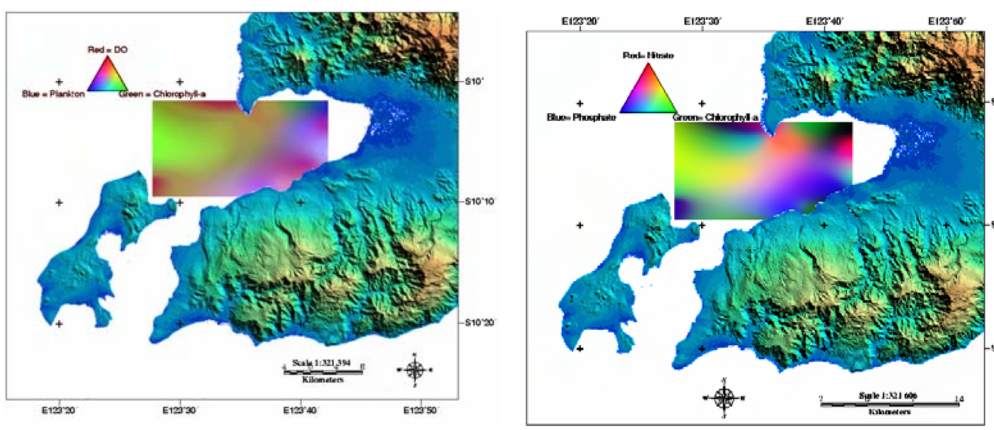

Figure 1. Spatial interaction RGB model of DO, chlorophyll-a, plankton (left) and nitrate, phosphate and chlorophyll-a (right) of Kupang Bay, East Nusa Tenggara

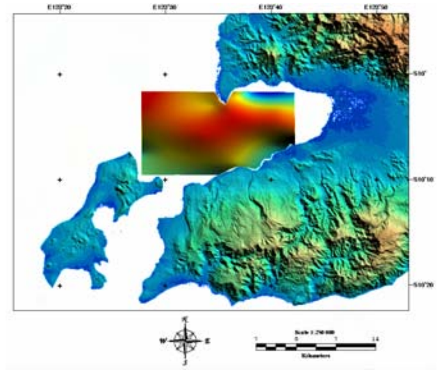

Figure 2. Suitable spatial model after 'spatial-scoring analysis' for Sea Weed Culture Zone (orange and red colors).

3.3.2. Site Selection for Grouper Fish Culture Sub Zone

Evaluation and analysis of ecosystem parameters of the Kupang Bay resulted two classes of fish culture sub zone, namely a class of Highly Suitable-S1 with wide area of 2,803 hectare (orange color zone) and Moderately Suitable-S2 with wide area of 1,336 hectare for fish culture sub zone (Figure 3). Suitability classes have some limiting factors of the ecosystem parameters, in which 40 percent special scoring weight on Dissolved Oxygen (DO), and secondary consideration on water current, depth, type of bottom substrate as on 'spatial-scoring analysis' as shown in Figure 3. The recommended sub zone for grouper fish culture sub-zone is mainly at the northern part of the Kupang Bay associated with Highly-Suitable sub zone and at the south part inside the Kupang Bay nearby to the local people settlement, which is characterized by best conditions of DO and water currents. The highly-suitable sub-zone spreading (orange color) at the mouth of Kupang Bay would not be considered being importantly since those are had been designated as fishing-vessel traffic line into and out of the Kupang Bay, although it can be considered as an alternative for Mariculture sub-zone further coastal zone and management adjustment.

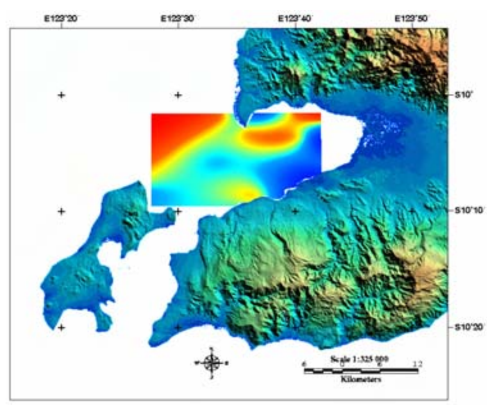

Figure 3. Result of 'Spatial – scoring' for Grouper Fish Culture Sub Zone, Highly-Suitable (Orange color) and Moderately-Suitable (Yellow color).

3.3.3. Site Selection for Bivalve (Pearl) Culture Zone

Results on spatial analysis of ecosystem parameters of the Kupang Bay show that there are 2 (two) classes used for oyster (Bivalve) pearl culture zone, namely Highly-Suitable-S1 and S2 Moderately Suitable. Spatial model based on spatial-scoring of ecosystem parameters with respect to conditions of plankton abundance which was considered with 40 percent weight. Meanwhile water current, water transparency, bottom substrate and depth was treated as secondary considerations, whereas nitrate, phosphate and chlorophyll-a was considered as tertiary variable. The identified suitable zone for oyster pearl culture sub zone was mainly at the northern part inside the Kupang Bay as in Figure 4 with wide area of 4,383.8 hectare at north bay of Semau Island and at outer mouth part of the Kupang Bay as shown in Figure 4.

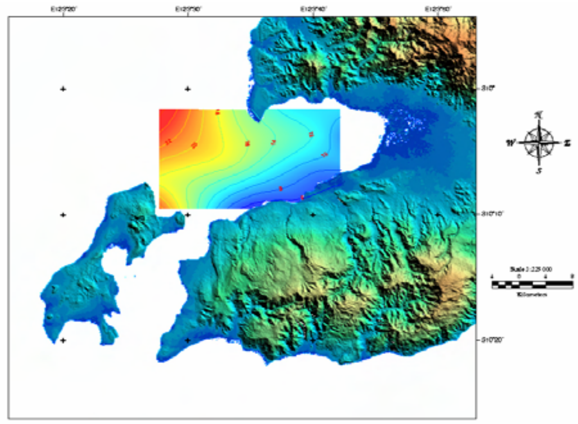

Figure 4. Results for Moderately-Suitable (S2 – yellow orange color) and Not-suitable (N – blue color) class of 'spatial-scoring analysis' for Oyster pearl culture sub-zone.

4. Summary

The sub-zone for seaweed culture was identified mainly almost at all area of the middle of the Kupang Bay with width of about 7,544 hectare. Class of 'most-suitable' sub-zone for grouper fish culture was found with width of 2,803 hectares wide and width of 1,336 hectares of moderately-suitable. Sub zone for pearl culture exists especially at the north part of Kupang Bay and some area nearby at the mouth of the Kupang Bay with width of about 4,383.8 hectare. By using significance difference of 'scoring-weight' on each specific and important ecosystem parameters (i.e. 50% nitrate and phosphate for sea weed culture sub zone; 40% dissolved oxygen for fish culture sub zone and 40% plankton abundance for oyster pearl culture sub zone). This study had resulted in a distinctive delineation for each culture spatial sub zone and minimize the possibility of spatial or sub zonal overlapping.

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