Eco. Env. & Cons. 26 (February Suppl. Issue) : 2020; pp. (S8-S17)

ISSN 0971–765X

Site selection of aquaculture location in Indonesia Sea

Muhammad Zikra[1], Haryo Dwito Armono[1] and Billy Mahaputra[2]

[1]Ocean Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2]Ocean Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

(Received 1 October, 2019; accepted 8 December, 2019)

ABSTRACT

Aquaculture is one of the methods of fish farming that can be developed at rivers, lakes or seas. To determine a proper location for aquaculture site, there are some requirements that need to be fulfill to maintain sustainibility of floating cages. Those requirements are bathymetry, meteorology or climate, water quality parameters, and quality of environmental and biological information as well as the legal framework. This paper will discuss the site selection of aquaculture activities using geographical information system based on environmental factors and water quality. The study take place on Prigi Bay, Trenggalek, East Java, Indonesia. The result show that the Prigi bay generally suitable for aquaculture activities. The result of weighted overlay analysis show that 23.13% of the water area (about 8.33 km^2) considered as "very suitable" and the rest area of 76.87% of water area considered as " suitable".

***Key words :** Selection of aquaculture, Sea location*

Introduction

In the future, mariculture activity is likely to be further offshore in more exposed waters. One of the reasons the future of mariculture is likely to be further offshore is a variety pressures on environments impacts and pollution (Fearn, 1990; Beveridge, 1996). Also, with continually rising world demand for food, and declining stocks of fish make the move offshore inevitable. Added, it has been reported that profits are slightly higher in offshore cages than inshore or sheltered waters (Myrseth, 1991).

Recent technological advances in offshore cage systems allow for the development of aquaculture operations in the open ocean. The technology is in place, as over the past decade a variety of modern submersible, semisubmersible, and locating cages have been designed and built to "conform" with waves and strong currents associated with the high-energy environment generally associated to offshore areas.

Before the establishment of any fish farming operation nearshore or offshore using floating or submerged cage systems, a site assessment must be conducted to carefully evaluate parameters related to infrastructure, topography, bathymetry, meteorology, annual ranges of water quality parameters, and environmental and biological information as well as the legal framework. Because a suitable site selection for an aquaculture location determines the ultimate success of the resulting aquaculture activitiy beside investment and running cost (Lawson, 1995).

This study will discuss the site selection of aquaculture activities using geographical information system based on environmental factors and water quality parameters. By utilizing Geographic Information Systems (GIS) and remote sensing technology and overlaying the processed images containing those factors and parameters, an information about the spatial and temporal information for the suitable site of aquaculture location can be presented in form of thematic map. Recenly, Geographical information systems (GIS) have become widely used in environmental planning and assessment. Extensive literature is available on the use of GIS, remote sensing/mapping in site surveying, environmental planning, development and management of open ocean aquaculture (Ervik *et al.,* 1997; Hansen *et al.,* 2001; Kapetsky and Aguilar-Majarrez, 2007; Kiefer *et al.,* 2008; Pérez *et al.,* 2002; Rensel *et al.,* 2006; Stigebrandt *et al.,* 2004, Ross *et al.* (1993). (Aguilar-Manjarrez and Ross, 1995); Nath *et al.* (2000) and Welcome (2001).

Materials and Methods

Area of Study

Prigi Bay is located on the southern coast in the edge of the Indonesian Ocean. Administratively, the Prigi Bay included in the area territory of Tasimadu Village, Watulimo District, Trenggalek Regency, East Java, Indonesia. Prigi Bay located at coordinates 8°19’39" S and 111° 43’43" E as shown in Figure 1. This area has a lot of potential, especially the potential of fisheries and tourism. Beside as beautiful natural tourism object in Trenggalek regency, Prigi Bay has been established as one of the center of the fishing industry in East Java which equiped with the Prigi Nusantara Fishery Port.

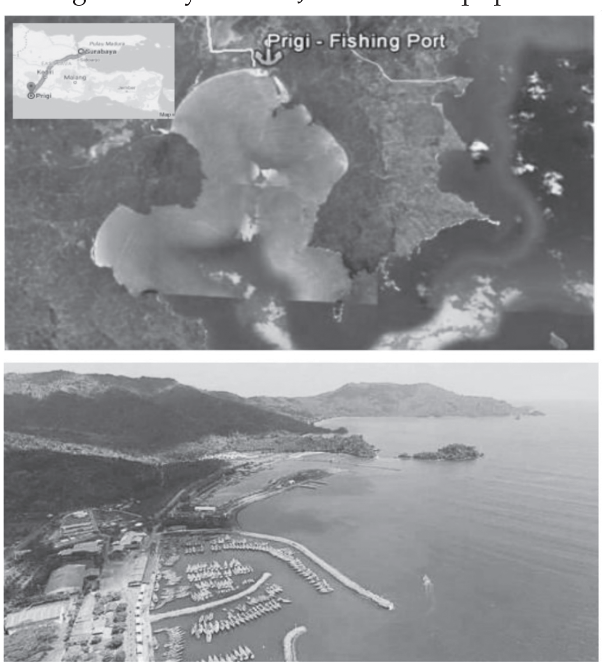


Fig. 1. Location of Prigi Bay and Fishing Port

Data

The data in this study is collected from various sources. The image data processed in this study was the MODIS level 1b obtained from NASA Ocean Color Web on area of 8°19’39" S - 111°43’43" E. Wind data obtained from the Agency of Meteorology, Climate and Geophysics (BMKG). Oceanographic data such as depth of the sea, the sea brightness, current speed, salinity, dissolved oxygen and acidity collected from Prigi Fishing Port and the Oceanographical Research Center – Indonesian Institute of Science (LIPI).

Method

The evaluated parameters used for classification of aquaculture suitability in this study were based on environmental factors such as turbidity, depth, current speed, and wave as presented in Table 2, and water quality such as temperature, salinity, pH, and dissolved oxygen as presented in Table 3. The weight values for environmental and water quality factors were presented in Table 4.

Furthermore, scoring method is used in determination of the criteria and the division suitability class (3 for very suitable, 2 for suitable, and 1 for not suitable) for floating cage aquaculture activities using physical and chemical parameters by reducing some parameters such as sheltering location, substrate condition and distance from pollution. The weighting is performed by Pair Wise Comparison analysis as presented in matrix form as presented in Table 5 (Adipu *et al.,* 2013). Parameters that have strong influence to the aquaculture activities have higher weighting factors than those with less influence.

Determination of Class Classification

The total score of each class is defined by multiplying the suitability level score with the parameter weight as presented in Table 5 using the following expression (FAO, 1976).

$$Y = \Sigma (a_i \times X_n) \quad .. (4)$$

where:
Y = Total Score
a_i = Weighting factors
X_n = Suitability level score

Furthermore, the interval calss for suitability

Table 2. Weight values based on Environment Factors

Environment	Turbidity	Depth	Current	Wave	Weight
Turbidity	1	2	4	7	0.53
Depth	1/2	1	2	3	0.26
Current	1/4	1/2	1	2	0.14
Wave	1/7	1/3	1/2	1	0.07

Consistency ratio 0.0029

Table 3. Weight values based on Water Quality

Water quality	Temperature	Salinity	pH	Oxygen	Weight
Temperature	1	2	7	4	0.52
Salinity	1/2	1	4	2	0.27
pH	1/7	1/4	1	1/2	0.07
Oxygen	1/4	1/2	2	1	0.14

Consistency ratio 0.0008

Table 4. Weight values based on Environment Factors and Water Quality

Kriteria Kelayakan Lahan	Environment	Water quality	Bobot
Environment	1	3/2	0.6
Water Quality	2/3	1	0.4
Consistency ratio	0.0000		

Table 5. Parameter Suitability for Floating Cage Aquaculture

No	Parameters	Weight (%)	Unit	Very Suitable (Score 3)	Suitable (Score 2)	Not Suitable (Score 3)
1	Turbidity	31,8	NTU	<11	11–40	40>
2	Temperature	20,8	°C	27–29	26–27 and 29–32	<26 and >32
3	Depth	15,6	m	15–25	5–15 and 25–40	<5 and >40
4	Salinity	10,8	‰	30–35	20–30	<20 and >35
5	Current Speed	8,4	cm/s	15–35	10–15 and 35–100	<10 and >100
6	Dissolved Oxygen	5,6	mg/L	>6	4–6	<4
7	Wave	4,2	cm	<20	20-40	>40
8	pH	2,8	-	7,0–8,5	4–7 and 8,5–9	<4 and >9

level were estimated using Equal Interval method (Ariyanti *et al.*, 2007) to divide the range of attribute values into sub-range with the same size. Mathematically it can be expressed as follows:

$$I = (\Sigma (a_i \times X_n)max - \Sigma(a_i \times X_n)_{min})/k \quad ..(5)$$

Where:

I = Interval of suitability classes

k = Number of the desired suitability classes

As presented in Table 5 above, there are three suitability classes: “very suitable”, “suitable” and “not suitable”. Based on equation 5, if the value of N_{max} is 3 and the N_{min} is 1, and the desired suitability classes is 3, it is found that the class interval was 0.667, and the score of suitability were:

2.333 to 3 = Very Suitable (S1)

1.668 to 2.332 = Suitable (S2)

1 to 1.667 = Not Suitable (S3)

The level of suitability is defined as [13]:

Very Suitable (S1)

This grade indicates that the reviewed location is potentially suitable for aquaculture activities. At this location there are minor to no limiting factor and will not affect the productivity of aquaculture significantly.

? Suitable (S2)

This grade indicates that the aquaculture activities can be implemented in this location, but less suitable because it has a considerable limiting factor that affecting the productivity. Therefore, it required additional treatment and modification for aquaculture activities.

Not Suitable (S3)

This grade indicates that the location is unsuitable for aquaculture due to limiting factors that affect the productivity of aquaculture activities.

Sampling Data Interpolation

The interpolation method called Inverse Distance Weighted (IDW) was employed to considers the spatial distance as "weights". The distance meant in this study here is the distance of the sample points to a block of data to be estimated. So, the closer the distance between sample points and a block to be estimated, the greater the "weight", and vice versa. The IDW method assumes that the estimated value at the point which is not recorded is a function of the distance and the average value point located nearby. The interpolation depends on how strong a data point affects the area around it. It is also the number of points in the vicinity which are used to calculate the average value, and the pixel size / raster desired. IDW interpolation method provides more accurate results than Kriging method (Pramono, 2004). This is because the value of data generated in IDW, are close to the minimum and maximum value of the sample data. While the method of interpolation Kriging sometimes results in a low range and have less influence on the sampling variation.

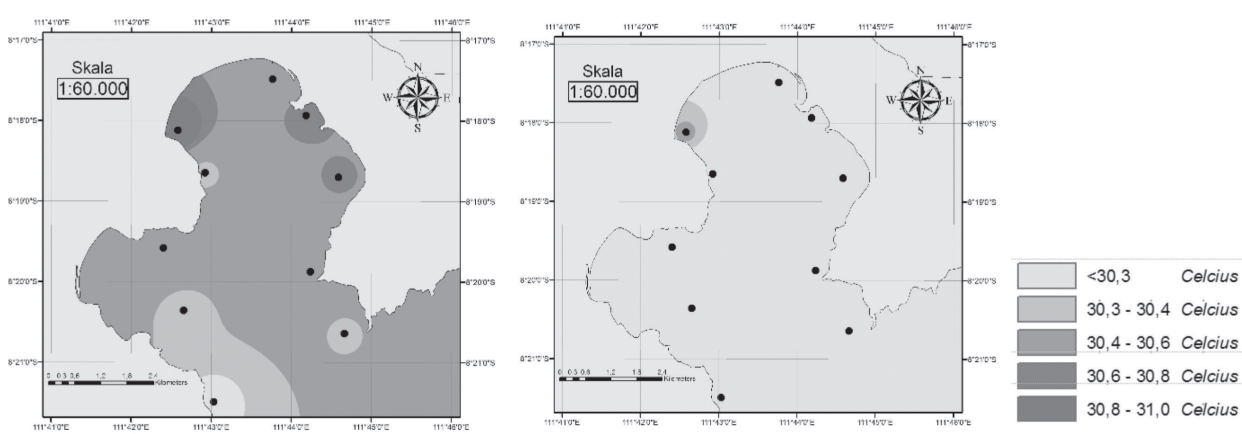
Results

Sea Surface Temperature

The sea surface temperature distributions are shown in Figure 2 below. The sea-surface temperatures in March and October 2016 did not have a significant differences, although in the month of October, the sea surface temperatures tend to be lower compared to March. Sea surface temperature in March has the lowest temperature and the highest temperature of 30.25 °C and 30.96 °C, while the average temperature was 30.54 °C. Meanwhile on October the sea surface temperatur has 29.47 °C as lowest temperature and 30.43 °C as highest temperature with average value of 30.1 °C. The sea surface temperatures are very feasible for aquaculture in the range of temperature 28-32 °C . Therefore, based on spatial analysis shown in Figure 2, the sea surface temperatures in the Prigi bay are very suitable for aquaculture activities.

Turbidity

Turbidity is one of the main environmental factors that influence the determination of the location of floating net cage cultivation because it affects the amount of light entering the waters needed by plants or phytoplankton to photosynthesize. The results of spatial analysis with IDW interpolation method showed turbidity characteristics in the waters of the Prigi Bay in March and October 2016 tended to be low. Even so, turbidity in October tended to be higher than in March with an average turbidity level of 0.89 NTU with a value of a maximum of 3.25 NTU. Meanwhile in March the average



(a) (b)

Fig. 2. Map Distribution of Sea Surface Temperature (a) March (b) October 2016

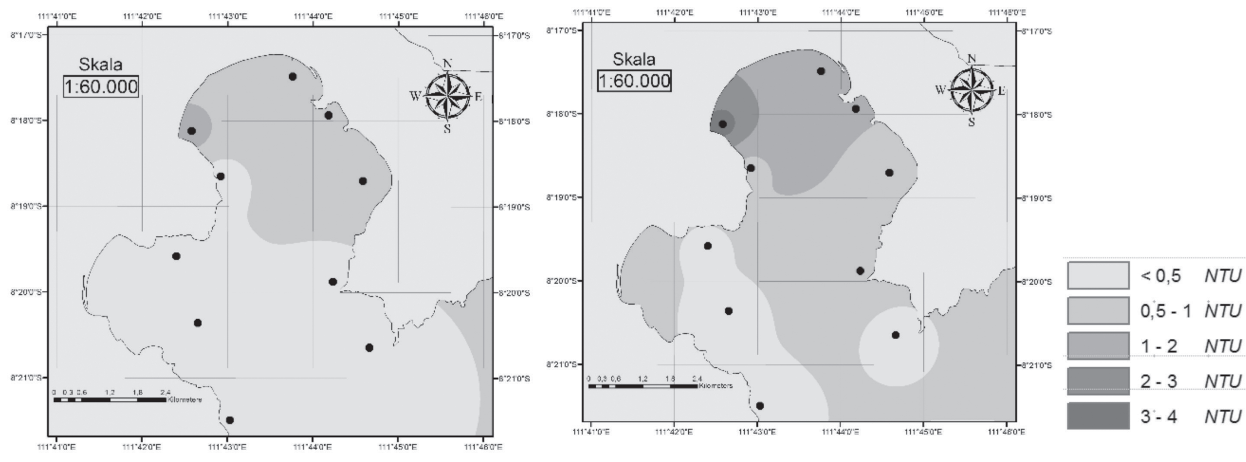


Fig. 3. Map Distribution of Turbidity (a) March (b) October 2016

turbidity level was 0.56 NTU with a maximum value of only 1.17 NTU.

This indirectly indicates that the content of suspension or pollution content in Prigi Bay waters tends to be low because according to Adipu *et al.* (2013) the turbidity level that is very suitable for aquaculture of floating net cages is less than 11 NTU. If the turbidity level of the waters reaches more than 40 NTU, then the waters are not suitable for aquaculture.

Bathymerty

The depth contour map is obtained from field survey. The results of the bathymetry map can be seen in the Figure 4. The depth that is very suitable for aquaculture with floating net cages is around 10-20 m (Radiarta *et al.*, 2006) while the depth of 20-30 meters is still quite feasible for the development of aquaculture. Depth that is too shallow can cause

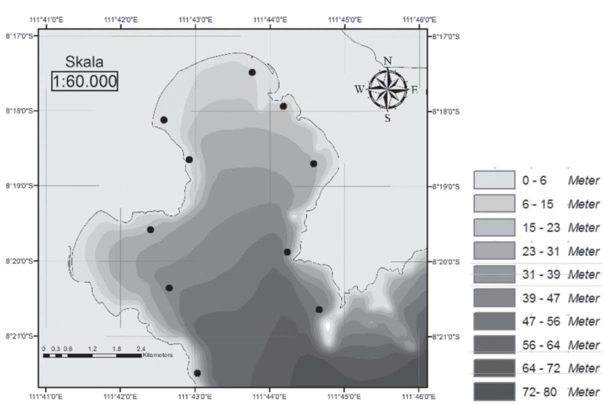


Fig. 4. Bathymerty Map in Prigi Bay

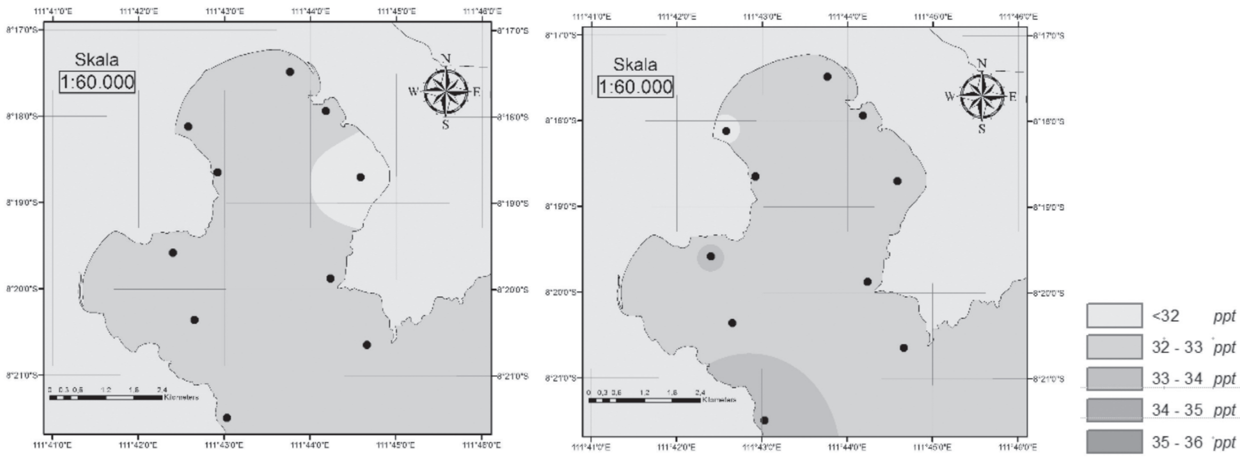
accumulation of feces from the metabolism of fish that will be cultivated and can cause turbidity that causes a lack of dissolved oxygen supply, while for depths that are more than 30 meters less efficient to do floating net cages and will require more levels and operational costs high.

Salinity

The level of salinity in the waters of Prigi Bay in March and October 2016 is not much different. But in October, it has a slightly higher distribution of salinity. For the average salinity level from March and October, the difference is very thin, which is only around 0.15 ppt with an average of 32.6 ppt in March and 32.75 ppt in October. The ideal salinity level for floating net cage cultivation is around 30-35 ppt (Adipu *et al.*, 2013). In this case the spatial analysis of data by interpolation of data in the site shows that the waters in Prigi Bay have a level of salinity that is suitable for the development of floating net cage cultivation.

Current Speed

The current speed of the Prigi Bay in March and October 2016 has an uncertain direction and tends to be weak, this is due to the two periods season including the transitional season (Nontji, 2006). The results of spatial analysis by interpolation of data in the site from the sample point show that the current speed in October is stronger compared to March, especially at depths of 40 meters and above. But at some points, the current speed is lower in the west coast of the Prigi Bay. In general, the current speed



(a) (b)

Fig. 5. Map Distribution of Salinity (a) March (b) October 2016

in March has an average speed of 13.38 cm/s, while in October the average speed reached 20.38 cm/s. The difference between the two is quite significant but based on the classification of the two periods in general it is still suitable for the development of floating net cages that range from 15-35 cm/s (Sari, 2011). This is indicated by the map of the results of the following reclassification method as shown in Figure 6.

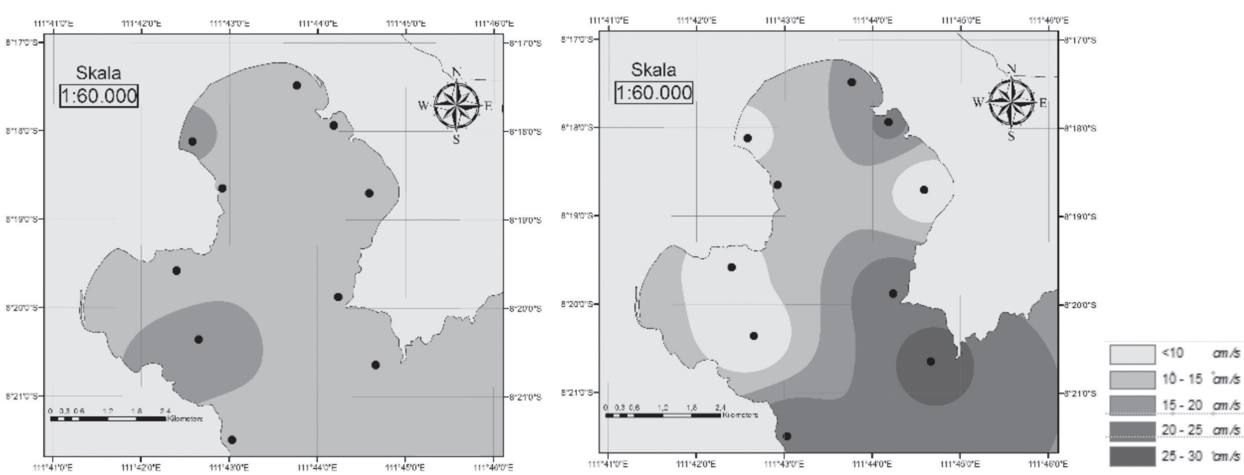
Dissolved Oxygen

Dissolved oxygen is an indicator of water quality. Dissolved oxygen levels in sea waters are generally 8 mg/L (Sari, 2011). Spatial analysis results with in situ data interpolation showed no significant difference between oxygen levels in March and October 2016. Both had levels in the range of 6 mg/L but dissolved oxygen levels in October were slightly higher at around 6.6 mg/L compared to March which had dissolved oxygen levels of 6.1 mg/L.

The level of dissolved oxygen that is very suitable for the development of floating net cage culture is more than 6 mg/L, therefore both periods according to the dissolved oxygen parameters are suitable for floating net cage cultivation. The results of spatial analysis of dissolved oxygen levels can be seen in the Figure 7.

Waves

Waves as one indicator of the aquatic environment



(a) (b)

Fig. 6. Map Distribution of Current Speed (a) March (b) October 2016

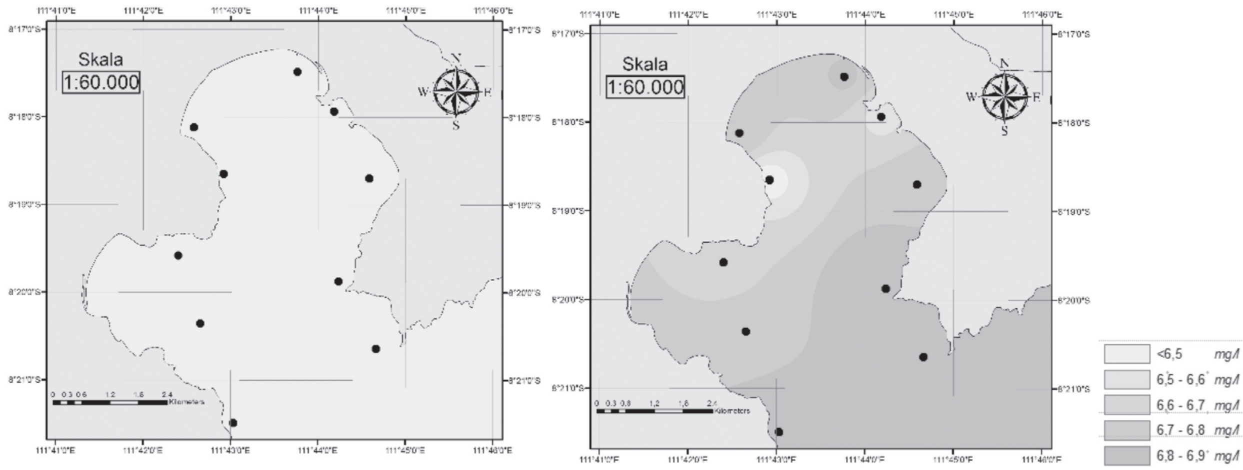


Fig. 7. Map Distribution of Disoved Oxcigen (a) March (b) October 2016

has an influence on the process of air exchange and the resistance of fish to be cultivated against waves. The results of spatial analysis of 10 sample points processed by the IDW interpolation method show a significant difference in wave height in the period March and October 2016. In March, the wave height was only around 0.38 to 0.44 meters while in October the wave height reaching 1.28 to 1.33 meters.

Wave height which is very suitable for conducting aquaculture is less than 0.2 meters, but can still be tolerated if the height is below 0.4 meters (Radiarta, 2006). Therefore, wave height in October is not suitable for floating net cage cultivation because it can endanger the survival of fish to be cultivated, but wave height does not have a significant effect based on Table 3.4 which is 4.2% of the development of net cage cultivation floating. The results of spatial analysis of wave height can be seen in the following Figure 8 below.

The degree of acidity

The degree of acidity or pH in sea waters usually ranges from 7.7 to 8.4 (Sari, 2011). The results of spatial analysis show that the average of acidity degree in Prigi Bay is 10.25 in March and 10.65 in October. In March 2016 the degree of acidity tended to be homogeneous with a range of 10.25 to 10.45. But in October, the distribution of acidity degree was quite heterogeneous. The waters area in Prigi Bay in terms of the acidity level parameter are not suitable for conducting aquaculture, but this parameter has a very small effect based on Table 3 and 4 which is

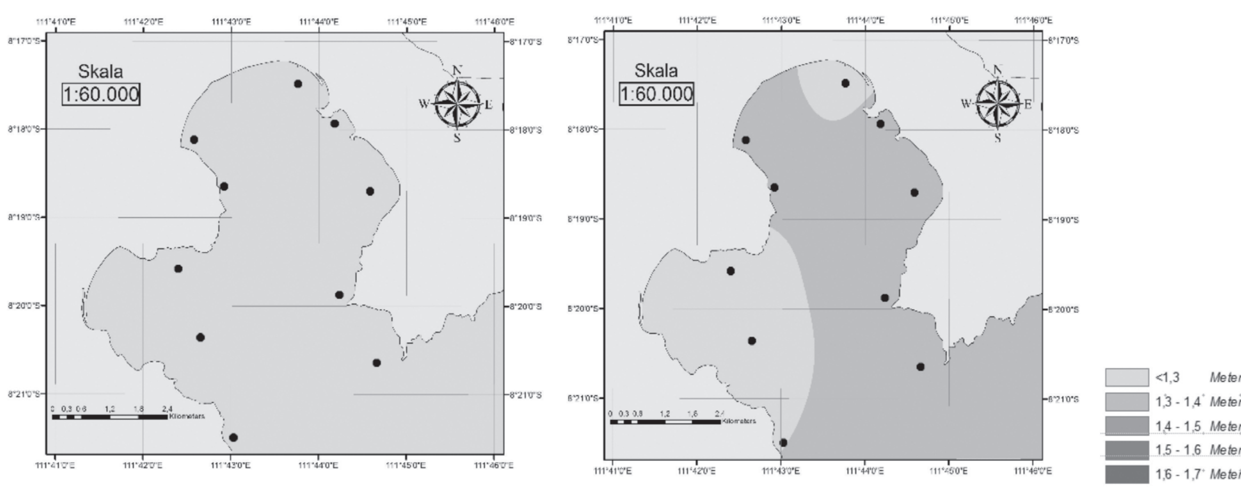


Fig. 8. Map Distribution of Wave Height (a) March (b) October 2016

only around 2.8%. The appropriate level of acidity for the development of floating net cage cultivation is 7 to 8.5. Distributuion maps of Ph produced from spatial analysis can be seen in the Figure 9.

Suitability Location using Weighted Overlay Method

The spatial analysis using various parameters presented in Table 5 above can be reclassified based on three interval suitability classes as discussed previously; i. Very Suitable (S1), ii.Suitable (S2) and iii. Not Suitable (S3). A suitability score can be evaluated using equation 4, and the result of aquaculture suitability location is shown in Figure 10.

The green color in Figure 10 represents the very suitable location and yellow colors indicate suitable location for floating cages aquaculture. In general, the waters of the Prigi Bay quite suitable for floating cage aquaculture activities. By weighted overlay

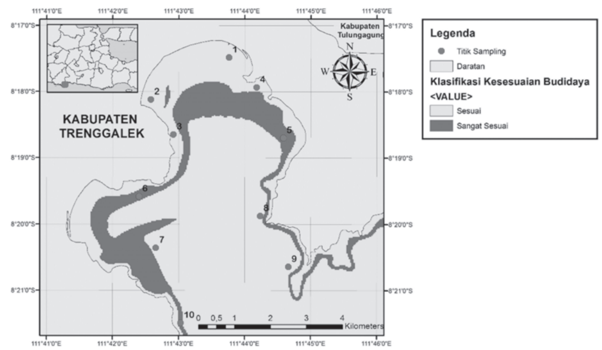
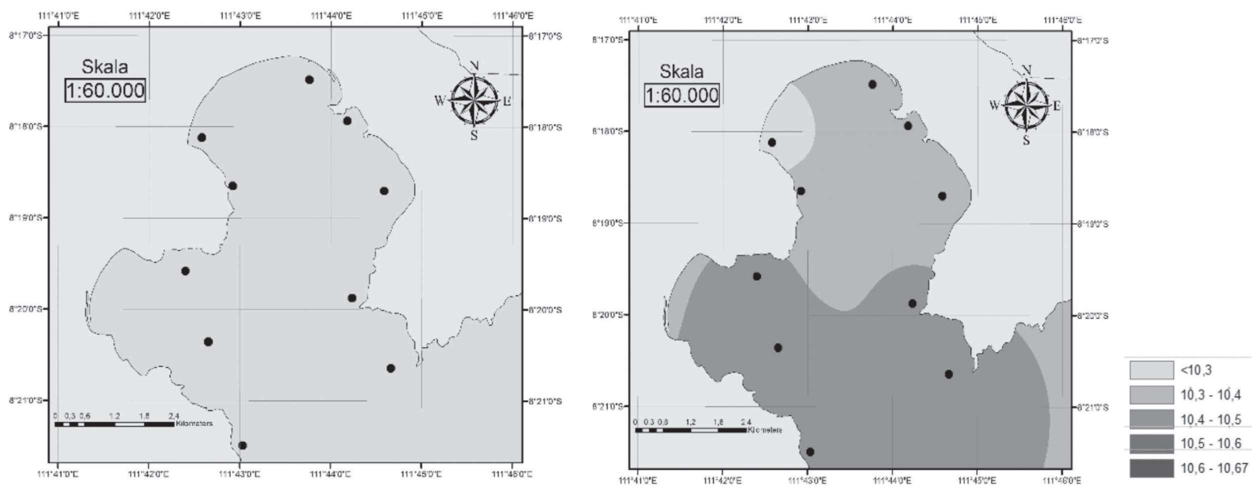
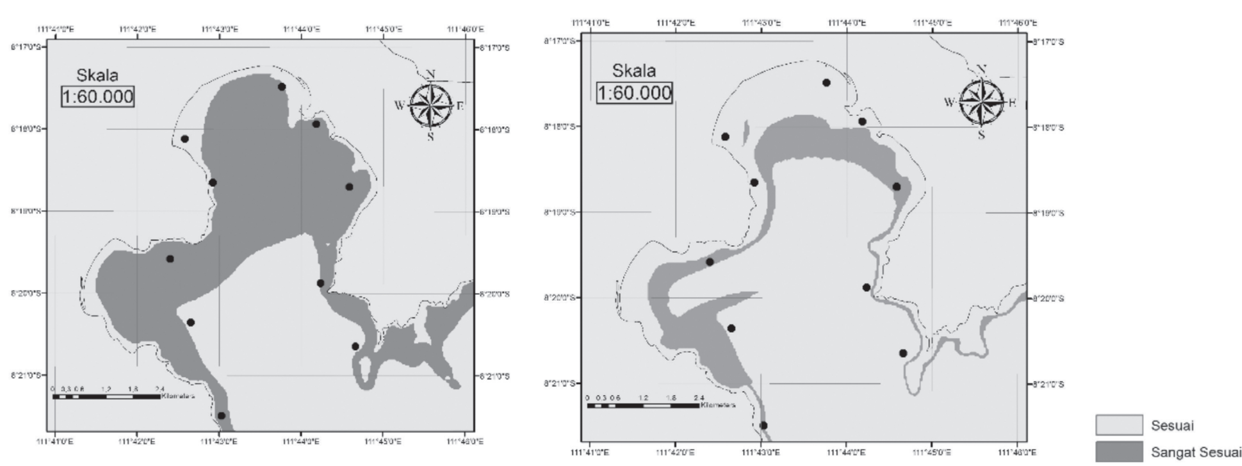


Fig. 11. Map of Suitability for Aquaculture Location in Prigi bay



(a) (b)

Fig . 9. Map Distribution of Ph (a) March (b) October 2016



(a) (b)

Fig. 10. Map of Suitability for Aquaculture Location in Prigi bay. (a) March and (b) October 2016

methods and combining March and October 2016 analysis results, the average suitablity score was 2.18 of 3 and categorized as "suitable". Further analysis shows that "very suitable"area in Prigi Bay was 8.33 km^2 (23.13% of the water area) while "suitable" area was 27.67 km^2 (76.87% of the total water). The most suitable location for Aquacuture activities are stations 5, 6 and 10 in Figure 11.

Conclusion

This study presents a simple methodology for fish cage site selection based on environmental factors and water quality using geographical information system. The study case take place in Prigi Bay, Trenggalek, East Java, Indonesia. Based on spatial analysis results, the Prigi bay generally suitable for aquaculture activities. The result of weighted overlay analysis show that 23.13% of the water area (about 8.33 km^2) considered as "very suitable" and the rest area of 76.87% of water area considered as " suitable".

References

Adipu, Y., Lumenta, C., Kaligis, E. and Sinjal, H.J. 2013. *Kesesuaian Lahan Budidaya Laut Di Perairan Bolaang Mongondow Selatan, Sulawesi Utara*. Universitas Sam Ratulangi, Manado, Sulawesi Utara.

Aguilar-Manjarrez, J.A. and Ross, L.G. 1995. Geographical information system (GIS) environmental models for aquaculture development in Sinaloa State, Mexico. *Aquacult*. *Int*. 3, 103-115.

Ariyati, R. Wisnu, Lachmuddin Sya'rani, Endang Arini. 2007. *Analisis Kesesuaian Perairan Pulau Karimunjawa dan Pulau Kemujan sebagai Lahan Budidaya Rumput Laut Menggunakan Sistem Informasi Geografis*. Universitas Diponegoro, Semarang

Beveridge, M. 1996. *Cage Aquaculture*. Fishing News Book, Great Britain, p. 346Fearn, P.T., 1990. The development of an offshore fish cage. In: Osborn, H.D., Eadie, H.S., Funnell, C., Kuo, C., Linfoot, B.T. (Eds.), *Engineering for Offshore Fish*. Thomas Telford, Great Britain, pp. 107-117.

Ervik, A., Kupka Hansen, P., Aure, J., Stigebrandt, A., Johannensen, P. and Jahnsen, T. 1997. Regulating the local environmental impact of intensive marine fish farming: I. The concept of the MOM system (Modelling On growing fish farms-Monitoring). *Aquaculture*. 158 : 85-94.

Fearn, P.T. 1990. The development of an offshore fish cage. In: Osborn, H.D., Eadie, H.S., Funnell, C., Kuo, C., Linfoot, B.T. (Eds.), *Engineering for Offshore Fish*. Thomas Telford, Great Britain, pp. 107_117.

Food and Agriculture Organization. 1976. A Framework for Land Evaluation. *FAO Soils Bulletin*. (32): 51-54

Hansen, K.P., Ervik, A., Schaaning, M., Johannensen, P., Aure, J., Jahnsen, T. and Stigebrandt, A. 2001. Regulating the local environmental impact of intensive, marine fish farming: II. The monitoring programme of the MOM system (Modelling On growing fish farms-Monitoring). *Aquaculture*. 194 : 75-92.

Kapetsky, J.M. and Aguilar-Manjarrez, J. 2007. Geographic Information Systems, remote sensing and mapping for the development and management of marine aquaculture. *FAO Fisheries Technical Paper,* No. 458, Rome: FAO. 125 pp.

Kiefer, D.A., Rensel, J.E. and O'Brien, F. 2008. *Aqua Model Simulation of Water and Sediment Effects of Fish Mariculture at the Proposed Hubbs-Sea World Research Institute Offshore Aquaculture Demonstration Project*. Report to Hubbs-Sea World Research Institute, San Diego, California by Systems Science Applications, Inc., Irvine, CA and Rensel Associates Aquatic Sciences, Arlington, WA. 70 pp.

Lawson, T.B. 1995. *Fundamentals of Aquacultural Engineering*. Chapman and Hall, New York

Myrseth, B. 1991. Looking at the cage realities. *Fish Farming,* July/August, 58.

Nath, S.S., Bolte, J.P., Ross, L.G. and Aguilar-Manjarrez, J., 2000. Applications of geographical information systems (GIS) for spatial decision support in aquaculture. *Aquaculture Eng*. 23 : 233_/278.

Nontji, A. 1993. *Laut Nusantara*. Jakarta: Penerbit Sjambatan.

Pérez, O.M., Telfer, T.C., Beveridge, M.C.M. and Ross, L.G. 2002. Geographical information systems (GIS) as a simple tool to aid modeling of particulate waste distribution at marine fish cage sites. *Estuary Coast Shelf Sci*. 54 : 761-768.

Pramono, G.H. 2008. Akurasi Metode IDW and Kriging untuk Interpolasi Sebaran Sedimen Tersuspensi. *Forum Geografi*, Vol. 22, No. 1 Bakosurtanal

Rensel, J.E., Kiefer, D.A. O'Brien, F. 2006. *Modelling Water Column and Benthic Effects of Fish Mariculture of Cobia (Rachycentrum canadum) in Puerto Rico: Cobia AquaModel*. Report to NOAA by System Science Applications, Inc., Pacific palisades, California. 64 pp.

Ross, L.G., Mendoza, Q.M.E.A. and Beveridge, M.C.M. 1993. The application of geographical information systems to site selection for coastal aquaculture: an example base on salmonid cage culture. *Aquaculture.* 112 : 165-178.

Radiarta, I.N., Saputra, A.J. and Prihadi, T.H. 2006. Pemetaan Kelayakan Lahan Budi Daya Ikan Laut Di Kecataman Moro, Kepulauan Riau: Dengan Pendekatan Sistem Informasi Geografis. *Jurnal Riset Akuakultur*. Volume 1 Nomor 2

Stigebrandt, A., Aure, J.J., Ervik, A., Kupka Hansen, P.

2004. Regulating the local environmental impact of intensive marine fish farming: III. A model for estimation of the holding capacity in the Modelling-On growing fish farm-Monitoring system. *Aquaculture*. 234 : 239-261.

Sari, K.Y. 2011. *Analisis Spasial Citra Satelit Landsat Untuk Penentuan Lokasi Budi Daya Keramba Jaring Apung Ikan Kerapu di Perairan Pulau Semujur Kabupaten Bangka Tengah*. Institut Pertanian Bogor, Bogor

Welcome, R.L. 2001. *Inland fisheries ecology and management*. In: Malden, M.A. (Ed.), Food and Agriculture Organization of the United Nations. Blackwell Science/ Fishing News Books, Oxford, p. 358.