JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 4 No 1 2020

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

GIS Application for Water Quality Suitability Mapping to Optimize Floating Net Cages Cultivation in Lampung Bay

Arief Wicaksono[1,2*], Ariani Puji Astuti[1], Wirastuti Widyatmanti[1]

[1]Department of Geographic Information Science, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia.

[2]The Master Program in Planning and Management of Coastal and Watershed, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia.

*Corresponding author e-mail: wicaksono.arief08@gmail.com

Received: November 20, 2019
Accepted: May 6, 2020
Published: May 9, 2020

Abstract

Lampung bay is one of potential aquaculture for floating net cages. Site selection for cultivation is influential on the floating net cages cultivation production, while currently selected sites have not considered water quality suitability criteria. The study goals are to identify the optimal site for cage cultivation based on the water quality suitability and to examine the main affecting factor for the suitability of cage cultivation in Lampung Bay. The water quality suitability parameters including water depth, water clarity, current speed, sea surface temperature, salinity, pH, and dissolved oxygen. Field survey was conducted on the southern part of Lampung Bay which is close to the coastal urban area. The tools used consisted of GPS navigation, pH meter, secchi disk, refractometer, bathimeter, digital thermometer, current meter, DO meter, and sample bottles. There are 32 sampling points which are distributed systematically. Inverse Distance Weighted is used to obtain the spatial distribution of parameters. The water environment suitability is carried out using two models from the weighting result using GIS, i.e. binary model and weighted model. Based on these model, the optimal area for cage cultivation are 17.41% (200.97 ha) and 65.95% (761.29 ha) using binary and weighted model respectively. The most influential parameter in order to promote sustainable cage cultivation are the water depth parameter with the consideration of the pattern similarity with the final model. Physical waters suitability map produced from this study provides valuable information for farmers and decision makers in Lampung Province so the cages cultivation in Lampung Bay can continue and obtain the optimal results.

Keywords: water quality suitability, IDW, binary and weighted model, Lampung Bay

1. Introduction

Maritime aquaculture production can help to support food security (FAO, 2014). Based on data from Directorate General of Capture Fisheries (or in bahasa means Direktorat Jenderal Perikanan Tangkap) on 2016 (BPS, 2020), the marine aquaculture production in Lampung has always increased from 2004 to 2014 and has decreased in the last few years. Aquaculture in the coastal waters of Pesawaran Regency is one of the aquaculture sub-sectors that has a considerable opportunity to increase production volume, both in commodities and producing regions. Waters suitability evaluation needs to be carried out because it will determine the success rate of the successful sustainable farming business in the coastal area. Incompatibility in determining the location for the development of floating net cages can cause these activities to not last long (Perez et al., 2003). Therefore, the characteristics of biophysical, chemical, and air quality conditions in a location must be compatible with the technology used and the type of commodity that is cultivated.

FAO and World Bank (2015) mentioned that the first step taken in the process of selecting cultivation sites was to identify priority locations on a national scale, afterwards plan in detail at a regional scale, but this research focused on the Lampung Bay to evaluate the existing cage cultivation activities. The use of water, land and resources for various purposes is one of the challenges in sustainable

aquaculture development. Therefore, this activity needs to be spatially planned, including zoning, selecting suitable sites and designing management area. Currently, most fishermen make aquaculture based solely on feelings that are suitable for aquaculture without considering biophysical, chemical and air quality environmental factors. In addition, the consideration of location selection for fishermen in floating net cages, especially in Pasaran Island, Lampung Bay, is close to settlements and not in accordance with the shipping lane. In sustainable development, including the fisheries sector, not only the economic aspects need to be developed, but also the social and ecological aspects so that their activities can be sustainable.

The potential profitability of cultivation with floating net cages is very large, but if there is pollution problem, it can affect the productivity of floating net cages. The suitability of physical, chemical and biological conditions needs to be taken into consideration in the selection of floating net cages locations to ensure the continuity of cultivation. The Lampung Bay area is more widely used for shipping, tourism and industrial activities. It also requires planning regarding the location of the appropriate floating net cages placement so that there is no conflict of interest. Therefore, information about the potential of the coastal and marine areas is very much needed for the development of the coastal and marine areas. This information can be obtained using remote sensing and geographic information systems (GIS) (Estigade et al., 2018). Several similar studies that show the powerful of GIS in helping to map the site suitability for cultivation including Assefa and Abebe (2018), Estigade et al., (2018), Gimpel et al., (2018), Estigade et al., (2019), Fransisco et al., (2019), and Yunis et al., (2020).

This study aim to find out the optimal location for cultivation using floating net cages and to understand the main factor that affect the suitability of floating net cages. The optimal location in this study considers physical variables, i.e. water depth, water clarity, current speed, sea surface temperature (SST), salinity, pH, and dissolved oxygen (DO). Thus determining the main factor that influence the suitability of the floating net cages are in accordance with the seven appropriate physical variables. The main parameter that influence are determined by the pattern of similarities between the final map and the suitability parameters map. This research is part of maritime spatial planning (MSP), which aims to integrate the interaction between social, economic, ecological factors and human activities so it can reduce the potential for conflict and the allocation of sea space for upcoming activities (Gimpel et al., 2018). However, this research only looks at the ecological aspect, i.e. water quality.

Explanation for each water quality suitability parameters is as follows. Depth variables are limiting variables in determining the suitability of floating net cages because they play a role in determining the design of cage construction, both floating net cages and fixed net cages (Ghani et al., 2015). SST is one of the parameters that affects the metabolism and development of marine organisms, so that it can be used to determine the location of marine cultivation. Fish tend to avoid high-temperature waters and move to lower temperatures (Laevast and Haye, 1981). According to Hutabarat and Evans (1986), salinity is stable in the open ocean even though in some places it shows fluctuations in change. Seasonal salinity changes in the estuary usually result from seasonal evaporation or seasonal changes in freshwater flow (Nybakken, 1988). Hartoko (2012) suggests that salinity is the main factor that determines migration and distribution, the existence and availability of fish. The higher the salinity, the smaller the maximum oxygen capacity.

Water clarity is one indicator used to determine the location for fish enlargement. The waters with very high clarity levels and even translucent waters are fairly clear indicators of the waters and these waters are very good for enlargement locations. Conversely, waters with very low clarity indicate the level of dissolved organic matter is very high (Jumadi, 2011). pH is the concentration of hydrogen ion levels in water. pH levels can be expressed by the equation pH = - log [H +]. The lower the pH value, the more acidic the water will be. Conversely, the higher the pH the more alkaline. Neutral water has a pH value of 7. Most aquatic biota can live optimally under conditions of pH 7-8.5. Current plays a role in the circulation of water, the carrier of dissolved and suspended materials, the solubility of oxygen and can reduce the attaching organism. The design and construction of marine aquaculture activities must be adjusted to the current speed and the condition of the bottom waters substrate because it will affect the facilities and infrastructure of these aquaculture activities. The location selection for grouper cultivation at floating net cages with optimal current speed is around 0.15 - 0.35 m/sec. Tidal variation is preferably 100-200 cm (Effendi, 2003). DO measurement aims to see the extent to which water bodies are able to accommodate aquatic biota such as fish and microorganisms. In addition, the ability of water to clean pollution is also determined by the amount of oxygen in the water.

2. Methods

This research was conducted in part of Lampung Bay around Pulau Pasaran, Bandar Lampung City, with an area of 1,154.43 ha. The selection of study locations is based on variations in land cover on land, and the existence of floating net cages. The tools used in the study consisted of GPS navigation, pH meter, secchi disk, refractometer, bathimeter, digital thermometer, current meter, DO meter, and sample bottles. Secondary data in the form of satellite imagery obtained from Google Earth is used to observe the distribution of existing floating net cages and land use around the study site on October 5, 2017. The field data collection was carried out on April 29, 2017 to take water samples and May 1, 2017 to interview the farmers on the Pasaran Island.

The sampling of 32 points was carried out by a systematic method. The advantage of this sampling method is to reduce the potential for bias caused by human error factors so that samples are taken representative of the population studied. The interpolation method used in the distribution analysis of each water quality parameter is Inverse Distance Weighted (IDW) method because Pramono et al. (2005) and Radiarta et al. (2006) stated that the IDW method is more appropriate for interpolating physical data in coastal areas because it does not produce

values exceeding the sampled data. This method assumes that each input point has a local effect, thus giving a large weight to the pixel closest to the point compared to the pixel that is far from the point.

Interviews were conducted to explore information about the types of fish cultivated, management of cultivation, and income from cultivation. The data from the interview results are expected to be used as reinforcement of arguments against the results of the maps obtained. Qualitative data analysis is carried out on interview data by selecting and grouping data. Data selection is done if not all questionnaire questions are able to be filled out by the respondents, while data grouping is done to facilitate the conclusion. Quantitative data analysis was carried out on field data from laboratory tests, where data were compared against the suitability parameters obtained from literature studies. With GIS assistance, the area per suitability class can be calculated, the distribution of the existing floating net cages can be observed and can be compared with the results of the suitability map so that the interpreter can read the pattern and conclude the current conditions of floating net cages around Pasaran Island.

The most important part that must be completed before developing the weighted model is the determination of the approved parameters that are relevant for the model (Sutrisno, 2017). The weights for the weighted model of each floating net cages suitability parameter are shown in Table 1, while for binary models, the classifications of classes are done from Table 1 where very suitable and sufficiently suitable classes are classified into suitable classes and the weight is 1, whereas conditionally suitable and not suitable classes are classified into not suitable classes and the weight is 0. The research flow chart is presented in Figure 1.

Table 1. Suitability of water parameters for marine fish cultivation in floating net cages.

Para-meters	Very Suitable	Sufficient Suitable	Conditionally Suitable	Not Suitable
Depth (m)	10-20	20 – 25	25 – 30	<10 &> 30
Clarity (m)	> 3	2 – 3	1 – 2	<1
Current Speed (cm/s)	5-15	15 – 25	25 – 35	<5 &> 35
SST (ºC)	28 – 32	25 – 28	20 – 25	<20 &> 32
Salinity (ppt)	31 – 35	28 – 31	25 – 28	<25 &> 35
pH	> 7	6 – 7	4 – 6	<4
DO (mg/L)	> 7	5 - 7	3 - 5	<3

Source: Affan (2011)

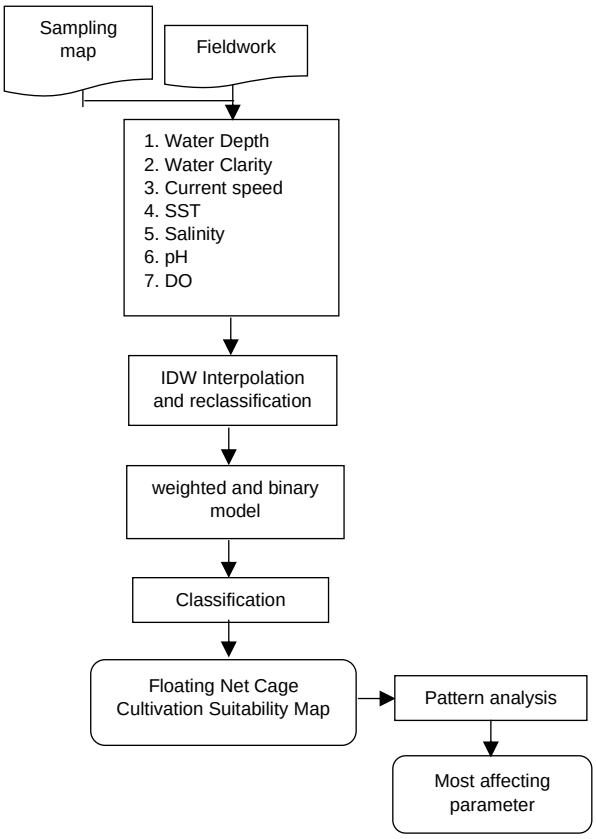

Figure 1. Research flow chart

3. Result and Discussion

The built-up land use around Lampung Bay consisted of settlements and industrial zones dominating the coastal area. The strategic location and proximity to the port in Bandar Lampung encourages the land use development in the area to be more intensively constructed than other areas on the Lampung coast. Around Lampung Bay there are two quite large river estuaries. The first river estuary is on the north side of Pasaran Island, while the second river estuary is on the west side of the study area. Land cover type and the existence of river estuaries (Figure 2) make the study area have dynamics in terms of water quality, specifically the content of suspended solid particles and other types of waste. The floating net cages distribution map is obtained from the results of Google Earth plotting. By understanding the spatial distribution of floating net cages in the study area as shown in Figure 3, conclusions can be obtained regarding the suitability class of existing floating net cages based on the floating net cages suitability map. Based on the results of identification on Google Earth imagery acquired on October 5, 2017 (after fieldwork), 11 groups and 22 single floating net cages were obtained, where the single symbol showed one cage, while the group symbol showed a collection of more than 5 cages.

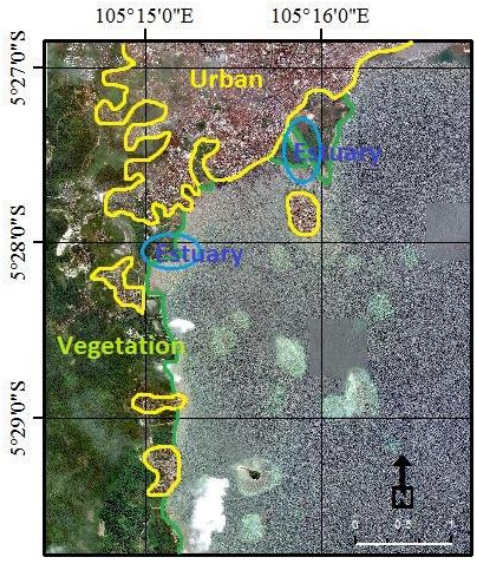

Figure 2. Land cover type and river estuaries around the study area taken from Google Earth data

Figure 3. The spatial distribution of floating net cages in part of Lampung Bay taken from Google Earth data

3.1 Water Depth Parameter

Judging from the depth parameters in Figure 4, part of the existing floating net cages is in not suitable class. The floating net cages location is in the base part of Lampung Bay, so it has a shallow depth so most classes are not suitable due to the relatively shallow sea (less than 10 meters). The reason of local people prefer to put floating net cages on the edge is because it is closer to their residence so that it is easy to monitor and not on the shipping lane without regard to physical parameters, like as water depth. In fact, when viewed from the depth suitability parameters, the location of the existing floating net cages is considered not suitable. Depth that is too shallow (<5 meters) can affect water quality due to accumulation of leftover food and residual decay of fish feces, while depths of more than 15 meter require anchor lines that are too long and this makes installation of the binding system more complicated (Estigade et al, 2019).

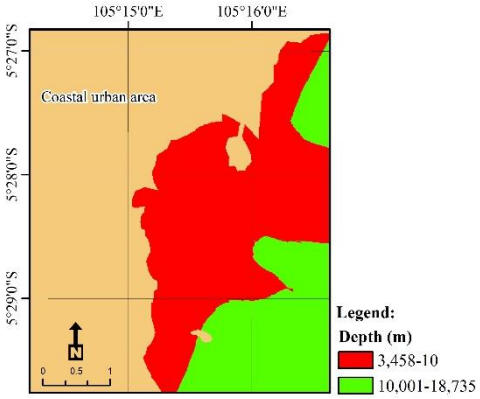

Figure 4. Water depth map

3.2 Water Clarity Parameters

Good water conditions for aquaculture marine like floating net cage cultivation have a clarity of more than 5 meters (Junaidi et al, 2018). Water clarity measurements were carried out at each sample point using secchi disk. The measurement results show that the clarity value of the waters around Lampung Bay has a clarity value of 0.3-6.93 meters. The results of visualization of water clarity data in Figure 5 show that the distribution of clarity values around Lampung Bay is dominated by clarity values ranging from 3 meters to 6.93 meters. The gradual distribution of clarity changes brighter towards deeper waters. Different with depth parameters, most floating net cages locations in the study area are in the very suitable class.

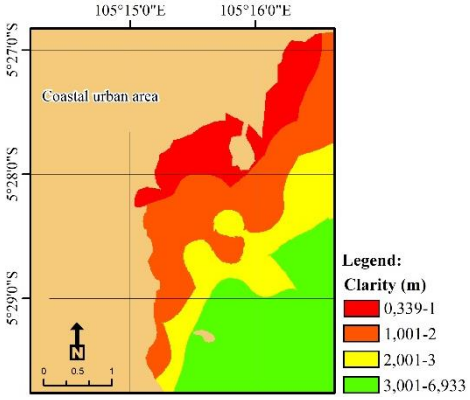

Figure 5. Water clarity map

3.3 Current Speed Parameters

One of the conditions for selecting water locations for the development of floating net cages cultivation is that waters must be protected from waves and strong winds. This is because large waves can damage cages and cultivated marine biota. The location of the waters in the study area faces the open sea so it is needed the media to break the waves so that the cultivation of floating net cages is protected from physical damage. Besides being protected from waves and strong winds, the current speed for good floating net cages cultivation generally ranges from 0.05 m - 0.15 m/sec. Yusrudin (2011) states that the current is a determining factor for marine aquaculture because it has an important role in supporting the cultivation process with the main function of being a carrier of nutrients and dissolved gases needed by aquaculture organisms. The results of the field measurements presented in

the map as shown in Figure 6 show that the locations around Lampung Bay generally have a current speed ranging from 0.12 m - 0.16 m/sec. Based on the results of these measurements, the study location is classified as sufficient suitable class for floating net cages cultivation activities. Besides that, the wave height at the study location has a dynamic throughout the day with a height ranging from 5-30 cm with wind direction coming from the northeast or from west to north.

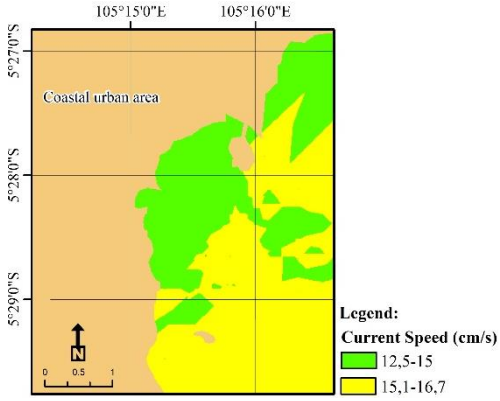

Figure 6. Current speed map

3.4 Sea Surface Temperature Parameters

SST is one of the important parameters in determining the location of marine cultivation. SST affects the metabolism and development of marine organisms. The SST also gives an influence on the biological activity in it, so that the temperature has an influence on the density of fish populations in a waters. SST can influence directly on growth, feeding rates, swimming speed, and spawning (Klemas, 2013). So it can be influential on productivity's rate of floating net cages. From the results of field measurements using a digital thermometer, temperature values ranged from 30.1 to 31.7 ºC at the time of the morning measurement until noon. Temperature changes from morning to afternoon reach 2ºC. Based on the SST suitability parameters in Figure 7, the entire study area included in the class is very suitable for floating net cages cultivation. It means the entire study area have good sea surface temperature for productivity's rate of floating net cages.

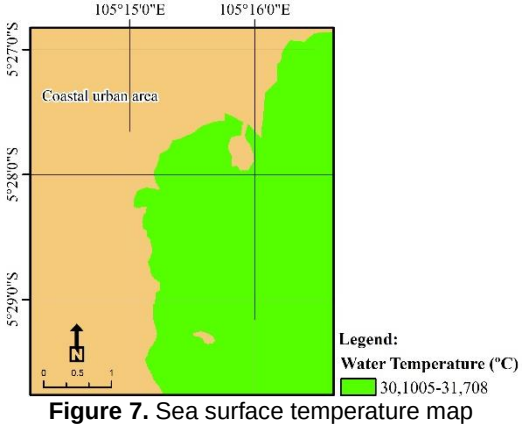

Figure 7. Sea surface temperature map

3.5 Salinity Parameters

Salinity is related to the level of salt in the sea. Salinity between shoreline to the deep sea has different values. The near shoreline has a lower salinity level than offshore and inshore marine. This is caused by the supply of fresh water on the beach more than the others. This fresh water supply is obtained from river and rainwater. Unlike fresh water, fish in the sea can only live well if the salinity is appropriate. Based on Affan's classification (2011), there are 4 classifications, which are very suitable, sufficient suitable, conditionally suitable, and not suitable. The range of salinity that is very suitable for fish is 31-35, sufficient suitable is 28-31, conditionally suitable is 25-28 and not suitable is < 20 or > 32. In Figure 8, it is known that the results of salinity classification are dominated by very suitable and sufficient suitable salinity values, while based on the map of the existing floating net cages, in this area most of the floating net cages are in areas that have the sufficient suitable salinity class.

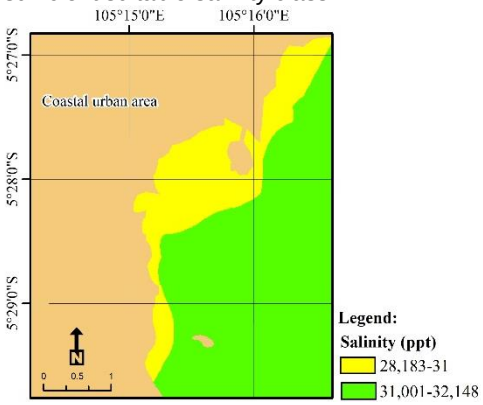

Figure 8. Salinity map

3.6 pH Parameters

pH is one of the important parameters in determining the location of aquaculture. pH has an effect on aquatic communities. Each range of pH values has a general influence on the biological community in the waters. The acquisition of pH data at the study location was carried out by direct measurement in the field using a pH meter tool. Based on the waters suitability criteria for pH parameters which refer to Affan's study (2011), the waters with pH > 7 are very suitable for floating net cages cultivation, while waters with pH <4 are not suitable for floating net cages cultivation. The results of measuring data in the field indicate that at the study location the lowest pH value is 4.14 while the highest value is 8.25 (Figure 9). In the study area the pH value is dominated by a pH value ranging from 8-8.1. There are differences in pH values which are very significant when compared with the average pH value at other points or can be called outliers. The point of the sample that has a pH value of outliers is the sample point number 32 with the lowest pH value of 4.14. Obtaining these outliers can be caused by several factors, one of which is the error in performing field data collection procedures. The distribution of pH around Lampung Bay as a result of interpolation is around 5.01 to 8.17. Based on the results of measurements in the field, it is known that most of the study sites are very suitable to be used as floating net cages cultivation locations.

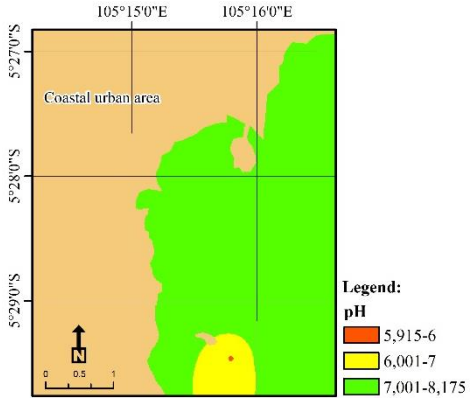

Figure 9. pH map

3.7 Dissolved Oxygen Parameters

The value of DO that is suitable for floating net cages cultivation is more than 5 mg/l. If the DO is not balanced, it will cause stress to the fish because the brain does not get enough oxygen, and death due to lack of oxygen (anoxia) caused by fish tissue cannot bind oxygen dissolved in the blood. During the day, oxygen is produced through photosynthesis, while at night, the oxygen formed will be reused by algae for metabolic processes when there is no light. The maximum oxygen level occurs in the afternoon and minimum before the morning. The value of DO in the study area is mostly in the sufficient suitable class, and only a small portion in the area is entering the conditionally suitable class (Figure 10).

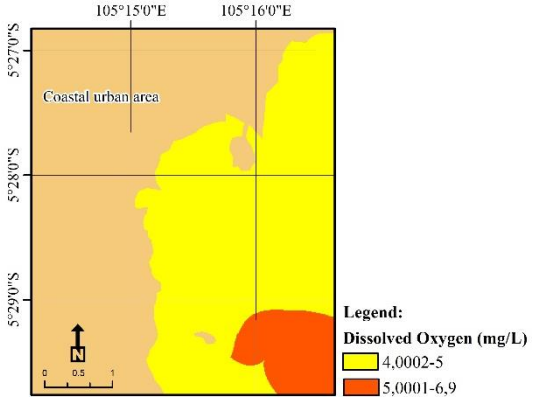

Figure 10. Dissolved Oxygen map

3.8 Floating Net Cages Cultivation Suitability Map

The suitability map of floating net cages cultivation is made into two models, namely weighted models and binary models (Figure 11). The weighted model requires more tenuous parameters so the result is very suitable and sufficient suitable classes, while the binary model requires more stringent parameters, so that there are only two classes, namely very suitable and sufficient suitable classes grouped into suitable class and conditionally suitable and not suitable classes are grouped into not suitable class.

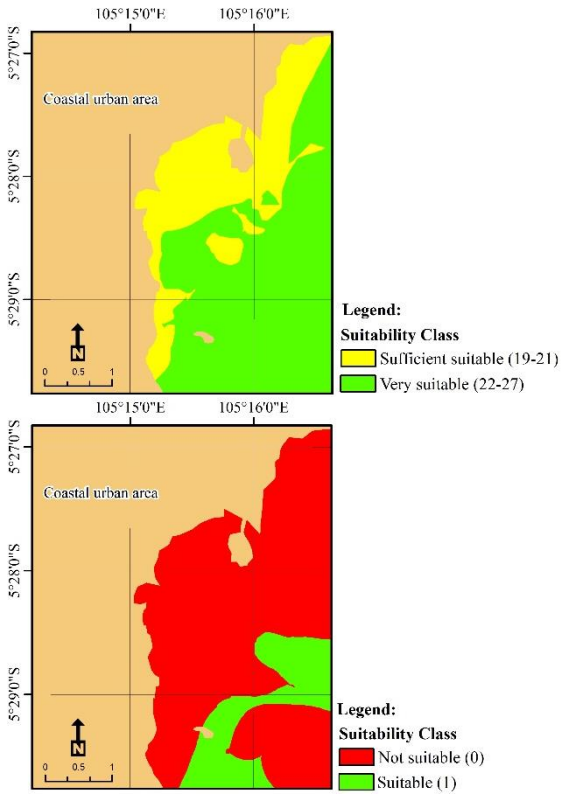

Figure 11. Floating Net Cages Cultivation Suitability Map of the weighted model (up) and binary model (down)

A summary of the suitability classes of each model can be seen in Table 2. From the Floating Net Cages Cultivation Suitability Map of the weighted model, it is known that the existing floating net cages locations are mostly included in the sufficient suitable class, while the Floating Net Cages Cultivation Suitability Map of the binary model shows that most existing floating net cages includes in not suitable class. The results of overlaying between existing floating net cage and the suitability model show the following results. Based on the binary model, there are only 3 single floating net cages that fall into the suitable category, the remaining 30 cages (11 groups and 19 single) are not suitable. Meanwhile, based on the weighted model, all groups and 10 single floating net cages fall into the sufficient suitable category, while for the very suitable category there are 12 single floating net cages. The different ways of expressing the class in making suitability models greatly influence the final results. To examine which model is more suitable for explaining the floating net cages suitability class, interviews with local peoples are conducted regarding the productivity of floating net cages at the study area.

Table 2. Area of suitability of binary and weighted models.

Class (Score)	Area (ha)	Percentage
Binary		
Not Suitable (0)	953.46	82.59%
Suitable (1)	200.97	17.41%
Weighted		
Very Suitable (22-27)	761.29	65.95%
Sufficient Suitable (19-21)	393.14	34.05%

In contrast to this study, research by Porporato et al., (2020) uses time series data sources from remote sensing to obtain SST and Significant Wave Height (SWH) parameters, but its scope is broad in area. Other studies by Assefa and Abebe (2018), Fransisco et al., (2019), and Yunis et al., (2020) use Analytical Hierarchy Process (AHP) and Multi-criteria Evaluation (MCE) for weighting the parameters because of its superiority. AHP is used because this method considers the effect of each criterion and has a scale for determining criteria priority (Fransisco et al., 2019). In addition, they use several modeling scenarios (for example: Blue Growth, Economic, Environment) to obtain different results. The limitations of this study include the absence of final model validation and statistical significance tests in determining the most influential parameters. These models are built only on the basis of data collection at one time so that the conclusions cannot be generalized at all seasons. Therefore, further testing of the model with different seasons or additional parameters is needed.

3.9 Analysis of Main Affecting Factor for The Suitability of Cage Cultivation

The main affecting parameter for floating net cages in the study location can be understand by conducting a comparative visual analysis between the floating net cages suitability distribution pattern with each parameter composing the suitability model according to Affan (2011). Based on the Floating Net Cages Cultivation Suitability Map of the weighted model, the most affecting parameter is salinity, while based on the Floating Net Cages Cultivation Suitability Map of the binary model, the most affecting parameter is depth. The facts found on the field are that the cage cultivation farmers choose the floating net cages cultivation location not based on water quality, but rather the distance to the residence and the results of interviews with the four cultivators who have the most floating net cages on Pasaran Island show that from year to year the floating net cages productivity decreases, so based on the statement the depth factor is the most influential parameter for the suitability of floating net cages in the study location because seen from the distribution of the existing floating net cages, mostly in waters that do not match depth resulting in low floating net cages productivity. Nevertheless, the public complained that there were other factors outside the model parameters that caused the decrease in floating net cages productivity, namely the problems of industrial and port waste so that in the next study it was necessary to consider these two parameters to make a better floating net cages suitability model.

4. Conclusion

Based on the Floating Net Cages Cultivation Suitability Map of the weighted model, it is known that there are two floating net cages suitability classes in Lampung Bay, that is sufficient suitable class with the area of 393.14 ha and very suitable class with an area of 761.29 ha, whereas based on the Floating Net Cages Cultivation Suitability Map of the binary model, it is known that there are also two floating net cages suitability classes in Lampung Bay, that is not suitable class with the area of 953.46 ha and suitable class with the area of 200.97 ha. The distribution of floating net cages suitability locations tends to stay away from the coast. The main affecting parameter for the suitability of floating net cages in Lampung Bay is the water depth. This is supported by interviews with cage cultivation farmers that from year to year, floating net cages productivity is decreasing because based on the Floating Net Cages Cultivation Suitability Map of the binary model that the distribution of existing floating net cages is mostly in waters that are not suitable depth resulting in low floating net cages productivity.

5. Acknowledgement

The author would like to thank the Faculty of Geography, Universitas Gadjah Mada for all the facilities and assistance that support this research activity. Also thank you to Muawanah, S.P., M.Sc. as the Head of the Water Quality Laboratory of Balai Besar Perikanan Budidaya Laut (BBPBL) Lampung and Wahyu Widiatmoko and BBPBL Lampung water quality team, Wawan and Masran, for their assistance during the field survey.

6. References

Affan, J. M. 2011. Seleksi Lokasi Pengembangan Budidaya dalam Keramba Jaring Apung Berdasarkan Faktor Lingkungan dan Kualitas Air di Perairan Pantai Timur Kabupaten Bangka Tengah. *Jurnal Sains MIPA*, 17(3), 99-106.

Assefa, W.W., & Abebe, W.B. 2018. GIS Modeling of Potentially Suitable Sites for Aquaculture Development in the Lake Tana Basin, Northwest Ethiopia. *Agriculture & Food Security*, 7(72), 1-15.

Badan Pusat Statistik. January, 14 2020. Produksi Perikanan Budidaya Menurut Provinsi dan Jenis Budidaya (ton), 2000-2017. URL https://www.bps.go.id/statictable/2009/10/05/1706/produksi-perikanan-budidaya-menurut-provinsi-dan-jenis-budidaya-2000-2017.html (accessed 03.12.20).

Effendi, H. 2003. *Telaah Kualitas Air: Bagi Pengelolaan Sumber Daya dan Lingkungan Perairan*. Kanisius.

Estigade, A. P., Astuti, A. P., Wicaksono, A., Maitela, T., Nadia, D., Aziz., M. H., & Widyatmanti, W. 2018. Physical Waters Suitability for Floating Net Cages Cultivation Mapping Using Landsat 9 OLI and Worldview-2 Imageries in Part of Hurun Bay, Lampung Province, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 169, 1-10.

Estigade, A. P., Astuti, A. P., Wicaksono, A., Maitela, T., & Widyatmanti, W. 2019. Remote Sensing and GIS Application for Water Environment Suitability Evaluation in Lampung and Hurun Bay. *IOP Conference Series: Earth and Environmental Science*, 256, 1-10.

Estigade, A. P., Astuti, A. P., Wicaksono, A., Maitela, T., & Widyatmanti, W. 2019. Aplikasi Web Map dalam Pemetaan Kesesuaian Fisik Perairan untuk Budidaya Keramba Jaring Apung di Teluk Lampung. *Majalah Globe Indonesia*, 21(1), 9-16.

FAO. 2014. Food and Agriculture Organization of the United Nations. *The State of World Fisheries and Aquaculture*. FAO.

FAO and World Bank. 2015. *Aquaculture Zoning, Site Selection and Area Management Under the Ecosystem Approach to Aquaculture*. World Bank.

Fransisco, H.R., Correia, A.F., & Feiden, A. 2019. Classification of Areas Suitable for Fish Farming Using Geotechnology and Multi-Criteria Analysis. *ISPRS International Journal of Geo-Information*, 8(394), 1-19.

Ghani, A., Hartoko, A., & Wisnu, Restiana. 2015. Analisa Kesesuaian Lahan Perairan Pulau Pari Kepulauan Seribu sebagai Lahan Budidaya Ikan Kerapu (*Epinephelus sp*.) pada Keramba Jaring Apung dengan Menggunakan Aplikasi SIG. *Journal of Aquaculture Management and Technology*, 4(1), 54-61.

Gimpel, A., Stelzenmuller, V., Topsch, S., Galparsoro, I., Gubbins, M., Miller, D., Murillas, A., Murray, A.G., Pinarbasi, K., Roca, G., & Watret, R. 2018. A GIS-based Tool for an Integrated Assessment of Spatial Planning Tradeoffs with Aquaculture, *Science of the Total Environment*, 677, 1644-1655.

Hartoko, A., & Alexander, K. 2009. Spatial Modeling for Marine Culture Site Selection Based on Ecosystem Parameters at Kupang Bay. East Nusa Tenggara. *International Journal of Remote Sensing and Earth Science*, 6(3), 57-64.

Hutabarat, S., & Evans, S. M. 1986. *Pengantar Oseanografi Cetakan ke-3*. UII Press.

Jumadi, W. 2011. Penentuan Kesesuaian Lahan Keramba Jaring Apung Kerapu Macan (*Epinephelus Fuscogutattus*) Menggunakan Sistem Informasi Geografis Di Pulau Panggang Kepulauan Seribu. (thesis).

Junaidi, M., Lestary, D.P., & Scabra, A. R. 2018. Mariculture Site Selection Based on Environmental Parameters in Tanjung and Gangga Sub-District, North Lombok. *The 1st International Conference and Workshop on Bioscience and Biotechnology for Human Health and Prosperity*, 233-251.

Klemas, V. 2013. Advance in Fisheries Applications of Remote Sensing. *Fisheries Research*, 148, 124-136.

Laevast, T. & Haye, L. 1981. *Fisheries Oceanography and Ecology*. Fishing News Books Ltd.

Nybakken, J.W. 1992. *Biologi Laut: Suite Pendekatan Ekologis*. Gramedia Pustaka Utama.

Perez, O. M., Telfer, T. C., & Ross, L. G. 2003. Use of GIS-Based Models for Integrating and Developing Marine Fish Cages within The Tourism Industry in Tenerife, Canary Islands. *Coastal Management*, 31, 355-366.

Porporato, E.M.D., Pastres, R., & Brigolin, D. 2020. Site Suitability for Finfish Marine Aquaculture in the Central Mediterranean Sea. *Frontiers in Marine Science*, 6(772), 1-12.

Pramono, G. H., Suryanto, H., & Ambarwulan, W. 2005. *Prosedur dan Spesifikasi Teknis Analisis Kesesuaian Budidaya Kerapu dalam Keramba Jaring Apung.* Pusat Survei Sumberdaya Alam Laut, Bakosurtanal.

Radiarta, I. N., Prihadi, T. H., Saputra, A., Haryadi, J., & Johan, O. 2006. Penentuan Lokasi Budidaya Ikan KJA Menggunakan Analisis Multikriteria dengan SIG di Teluk Kapontori, Sulawesi Tenggara, *Jurnal Riset Akukultur*, 1(3),303 -318.

Sutrisno, D. 2017. The Development of Marine Spatial Planning and Its Application for Floating Fish Net Culture. *Geoplanning: Journal of Geomatics and Planning, 4*(1), 41-52.

Yunis, C.R.C., Lopez, R.S., Cruz, S.M.O., Castillo, E.B., Lopez, J.O.S., Trigoso, D.I., & Briceno, N.B.R. 2020. Land Suitability for Sustainable Aquaculture of Rainbow Trout (*Oncorhynchus mykiss*) in Molinopampa (Peru) Based on RS, GIS, and AHP. *ISPRS International Journal of Geo-Information*, 9(28), 1-18.

Yusrudin, S. 2011. Analisis Kualitas Perairan Untuk Karamba Jaring Apung Ikan Kerapu di Kabupaten Situbondo. Neptunus. *Jurnal Kelautan*, 17(1), 17-26.