Environmental characteristics and development prospective of sea cage aquaculture in Morotai Island Regency

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Abstract. Sea cage aquaculture, if well managed, is one of the most successful and profitable marine aquaculture systems and has demonstrated substantial economic benefits. A relatively suitable sea or coastal water quality, as well as availability waters areas, are the major supporting factors that enable successful sea cage culture. This study explores the environmental characteristics and the potential development of sea cage culture in Morotai Island Regency, North Maluku Province. This study employed a survey method by which environmental data were collected following a random stratified technique in geographical information systems (GIS). The results of water quality analysis generally indicated that the study areas are highly suitable for sea cage culture. The suitability of engineering design based on water depth and safety issues relating to extreme weather and highly exposed coastal areas was the only significant factor that directly limits the suitable areas. After the integration of water depth and safety factors variable into the final spatial analysis, only 398 ha of waters were found suitable for sea cage culture. However, previous studies have suggested that for the sake of sustainability, only a maximum 10% of suitable waters can be used for the sea cage culture. Therefore, this study has recommended no more than 15 units of cages per hectare with a dimension of 8 x 8 m² per cage or only the 597 units to be allocated for the whole identified suitable areas. A lack of marine aquaculture infrastructure and an inadequate as well unreliable supply of quality fish seed (fry) have been the major constraints for the sustainable production and operation of sea cage aquaculture in the study areas. With a better understanding of the existing suitable areas and its maximum production carrying capacity, aquaculture decision-makers can develop effective and efficient strategies to help improve the product for the sustainability sea cage culture activities in this region.

1. Introduction
Morotai Island District of North Maluku Province is one of 111 outlying islands of Indonesia [1]. The general characteristics of the society include poor, lower level of education, food insecurity, high prevalence of various diseases, isolated from the center of economic growth, and high unemployment. In the last 5 years, the government of Indonesia has made a great effort to accelerate and optimize the development of Morotai Island Regency by establishing what so-called “Special Economic Zone” (KEK). For the marine and fisheries sector, the Ministry of Marine Affairs and Fisheries of Indonesia (MMAF) has set up a MINAPOLITAN zone. The Minapolitan zone, in general is meant to implement equitable and sustainable economic development through rural development focusing on fisheries as a developing cluster point [2,3]. Considering the good quality of seawater as well as large available potential areas in Morotai Island, MMAF, in collaboration with the local governments, strive to develop
marine aquaculture (mariculture) as an alternative to the major activities of the local coastal community as fishermen within the study region. The idea is that natural resources in the outermost and remote islands could be utilized in the interest of the local people and the government.

Various studies and experiences have shown that sea cage aquaculture systems if practiced in an ecologically sustainable manner, will either sustain the production or have little impact on the environment [4,5]. On the contrary, failure to manage waste discharge from marine fish farms will potentially have negative environmental effects that could limit the growth of the marine sea cage farming industry [6,7]. Mariculture, including sea cage culture, is a new development that has only been carried out since the early 1980s in Indonesia. Despite the potential of its vast resources, some fish farmers have been culturing different species on a very small scale located mainly in protected coastal bays at several places in the country. Therefore, the production data and relating environmental and management problems have not been well documented. Major species raised in sea cages included tiger grouper (Epinephelus fuscoguttatus) and humpback grouper (Cromileptes altivelis), barramundi (Lates calcarifer) and mangrove red snapper (Lutjanus argentimaculatus) [8]. Past international studies showed that a combination of proper site selection, careful siting of farms, application of integrated of multitrophic aquaculture (IMTA), and improved feeds could potentially help maximize production while reducing environmental impacts [7,9,10].

Good knowledge of the environment characteristics is vitally important before selecting the site and also for the effectiveness and efficacy of aquaculture operation and management [11,12]. Water quality is the key environmental indicator for the suitability aquatic environment as a habitat for most aquatic species. Therefore, it is the essential factor to take into account coastal environmental management, including mariculture and, more specifically, sea cage aquaculture. Water quality and other biophysical environmental criteria must be satisfied for the targeted cultured species. This study presents the environmental characteristics of existing sea cage aquaculture in Morotai Island Regency, North Maluku Province and describes potential development challenges and opportunities.

2. Materials and Method

2.1. The study site

This study was conducted in the mariculture development zone in South Morotai District and South-West (SW) Morotai Sub-district from August to December 2016 (Figure 1). The study site was selected based on the results of a preliminary study in December 2015, by which a detailed review was done on existing government’s documents or report on sea and coastal spatial plans such as the Regional Spatial Plan (RTRW), Zonation Plan of Coastal Areas and Small Islands (RZWP-3-K) and Minapolitan zone. The preliminary study also included consultation and discussion with local aquaculture policymakers in Morotai Island regency. Most existing sea cage farms are located within the study site characterized by shallow water (8 to 10 m) and sheltered or protected environments.
2.2. Data Collection and Analysis

A total of 31 water samples was collected following a random stratified method. These seawater samples were transported to the water Laboratory of the Research Institute for Coastal Aquaculture and Fisheries extension (RICAFE), in Maros Regency of South Sulawesi Province, for further analysis. The baseline water quality variables that were measured covered: temperature, salinity, pH, NO$_2$, NO$_3$, NH$_3$, PO$_4$, and Fe. This suite of variables is effective as a set of indicators for the changes in water quality. Salinity and pH were measured in situ using a YSI Pro Plus. Nitrite (NO$_2$-N), Nitrate (NO$_3$-N), Ammonia (NH$_3$-N), and Phosphate (PO$_4$) were analyzed in the Water Laboratory of RICA following the procedure of [13]. Additionally, direct field observation and interview was also undertaken to get insight into the nature problems by means of cross-checking secondary data from government report and through a direct site visit to sea cage farms. The chlorophyll-a (Chl-a) was calculated following “nitrogen-based model”: Log$_{10}$Chl-a = -3.71 + 4.26 log$_{10}$DIN – 0.88(log$_{10}$DIN)$^2$ [14], which is generally applicable for estuary and sea environments. Trophic state was calculated based on “Tropical Index” (TRIX) = [log$_{10}$(Chl-a x aD%O x DIN x PO4)+ k]/m [15]. Where Chl-a is chlorophyll-a concentration; aD%O is oxygen as absolute [%] deviation from saturation; DIN is dissolved inorganic nitrogen as N-(NO3+NO2+NH3), and PO4 is calculated by means of dissolved inorganic phosphorus. The parameters k =1.5 and m =12/10 (1.2), are scale coefficients that are introduced to fix the lower limit value of the Index and the extension of the related trophic scale, from 0 to 10 TRIX units [16]. Trophic level categories of coastal water were then classified according to Table 1.

| TRIX Unit | Trophic level category |
|-----------|------------------------|
| 2 - 4     | Ultra-oligotrophic (high quality, low trophic level) |
| 4 - 5     | Oligotrophic (good quality, moderate trophic level) |
| 5 - 6     | Mesotrophic (moderate quality, high trophic level) |
| 6 - 8     | Eutrophic (degraded, very high trophic level) |
| > 8       | Dystrophic |

Modified from: [17]

Statistical analysis was performed by Microsoft Excel and SPSS software version 17. The descriptive statistics analysis (e.g., mean and standard deviation) was done to understand the distribution
values of water quality data. Spatial analysis that includes vectorization, spatial interpolation, and a combination of thematic maps was analyzed using ArcGIS 10.3, and SURFER 8.0 software.

3. Results and Discussion

3.1. Environmental Characteristics

Table 2 summarizes the results of the water quality analysis of samples collected from the study site. This analysis showed that most of the water quality variables under consideration were still within a suitable range for marine aquaculture. Dissolved oxygen (DO) was found to be the most influential variable on trophic level status of the study area due to its seasonal or daily fluctuation. [18] reported DO of seawater surface layer in Morotai Island Regency at specific season could reach 4.7 mg/L and decrease up to 2.5 mg/L at the depth layer of 300 m.

Dissolved oxygen is necessary for all organisms living within the water body for respiration; therefore, the concentration of dissolved oxygen in the waters becomes a major limiting factor in sustaining life and growth out [19]. In addition to seasonal variations, DO values can also fluctuate daily, during the day time the high biomass of photosynthetic algae will produce an aquatic environment that is saturated with dissolved oxygen (approximately 20 mg / L), whereas at night the algae will absorb oxygen for respiration causing a sharp decrease in dissolved oxygen (<3 mg / L). Therefore, whenever algae blooms occur, it will rapidly affect the DO level. However, a reduced DO in water can also occur if the dense bloom suddenly dies (algae die-off). Dead algae biomass will decompose and may result in DO depletion to zero, which in turn creates a dead zone [20].

High aD%O values were observed in open water areas with good current circulation and water changes. On the other hand, high DIN and PO4 values were found to concentrate at lower wave-exposed areas around small islands and the mainland with high anthropogenic activities. According to [21], the nutrients distribution will occur evenly in the surrounding area when the circulation or exchange water occurs throughout the year from various nutrient sources such as a bay, river mouth, or basin. [21] explained that the horizontal distribution of DO values in low energy waters such as bays is mainly influenced by currents. This is the reason why at the river mouth, TRIX values can be observed relatively lower at a specific period of time but higher at another time. Waters around river mouths with lower current energy and high turbidity, diminish light penetration and inhibit photosynthesis, therefore DO values are mainly due to phytoplankton activity. Such cases were found in the waters around Bobonga Island and Gomandandi Island. The mean values of calculated TRIX were 5.35, indicated that the study areas have a high trophic level.

Tabel 2. Descriptive statistics of water quality variables (N=31)

| Variables | Range (Mean) | *Suitable Value for Marine Aquaculture |
|-----------|-------------|---------------------------------------|
| DO (mg/L) | 5.9 – 7.77 (6.75) | > 5 (> 7 ) |
| NO2 (mg/L) | 0.0008-0.0093(0.0014) | < 1 |
| NO3 (mg/L) | 0.27 – 0.03(0.27) | 0.02 – 0.4 |
| NH4 (mg/L)** | 0.002 – 0.012(0.005) | <0.5 (0.2) |
| PO4 (µg/L) | 36.1 – 580.2 (131.75) | 200 – 500 |
| DIN (µg/L) | 37.50 – 608.80(272.11) | NA |
| Chl-a (µg/L) | 0.105 – 16.96 (2.79) | < 5 |
| aD%O | 0.90 - 24(8.91) | NA |
| TRIX | 4.18 – 7.08 (5.35) | > 3.0 - < 6.0 |

* [7,21,22,23]; **calculated from TAN value.

Further analysis discovered the tropical index was mainly controlled by Chl-a and aD%O variables (Figure 2). Base on figure 2, log (Chl-a*aD%O) factors are the direct expression of productivity. Chl-a variable was influenced by the DIN and PO4 variables. According to [15] the actual variation of TRIX is controlled 75% by the variables Chl-a and aD%O, while fluctuations in phytoplankton biomass (Chl-a) are influenced primarily by nutrient fluctuations (in this case N). Chl-a is a photosynthetic pigment.
algae (planktonic algae) so it is an indicator of phytoplankton in the waters. Increased chlorophyll concentration in waters was directly related to an increase in phytoplankton biomass. [24] found the addition of N compounds or elements causes an increase in N-containing photosynthetic pigments such as chlorophyll. The Chl-a concentration is inversely correlated to the Secchi disk depth but is positively correlated with POC (particulate organic carbon) [25,26]. [21] revealed that nutrient enrichment would stimulate the growth of phytoplankton only if there are certain nutrients that become growth limiting factors. Given this, additional nutrient inputs in the region, especially from compounds containing N elements has the potential to increase phytoplankton biomass. The low mean value of Chl-a concentration in marine aquaculture development zone in Morotai Island Regency is most likely related to low total dissolved N compared to dissolved P (low N / P ratio).

Figure 2. Relationship between TRIX and log (Chl-a*aD%O) values

Besides the water quality, the major environmental limiting factors identified were water depth and degree of exposure from the weather. Floating net sea cage requires a minimum distance 5 m from the bottom of the net to the sea bottom at low tide [11]. Additionally, areas with high waves and strong current must be avoided due to high basic setup and routine operational costs. The characteristics of the water depth in the study areas are presented in Figure 3A. If the water depth criteria ranging from 8 to 20 m used for delineating area suitable for sea cage aquaculture, an estimated total of 8,995 ha of the suitable water area was obtained. However, if the shelter from weather factor is integrated into the analysis, the total potential waters area based upon water depth will become 398 ha only (Figure 3B). Of this total area, it is also likely to coincide with the planned tourism development zone.

The existing mariculture practices in Morotai Island waters include fish growth out in floating net cages (sea cage aquaculture), seaweed cultivation, shrimp farming, pearl oyster farming. However, the main commodities developed are currently limited to seaweed and grouper. The analysis showed that some existing sea cage aquaculture activities are in areas with high trophic status. [27] revealed that the main impact of aquaculture waste on aquatic ecosystems originated from the enrichment of organic matter into the ecosystem and the direct effects of enrichment include an increase in oxygen consumption for heterotrophic organisms in sediments. [28] calculated an oxygen consumption rate of 45 - 55 mgO2 / m² / hour in sediments below the floating cage (freshwater) compared to only 16 mgO2 / m² / hour in undisturbed bottom sediments. Thus, there must be a clear preventive measure as well as mitigation strategies before setting up aquaculture at these sensitive locations so that it will not contribute to raising trophic levels to a severe eutrophic condition. For example, aquaculture activities must very carefully calculate the feed conversion ratio (FCR), stocking densities, and density of cage units that are safe for the aquatic environment. Stocking season regulation can also be undertaken by adjusting season conditions so that it can reduce the impact of the waste load on the environment and the potential failure of the sea cage aquaculture itself.
3.2. Sea Cage Aquaculture Development Challenges and Prospective

Of all identified suitable sea or coastal waters areas, it should be noted that a maximum usage must not be allocated solely for sea cage aquaculture activities, but spaces should also be provided for a buffer zone and other overlapped coastal industries with appropriate criteria. Since the sustainability of aquaculture activities does not merely depend on the simple biophysical or production requirements of cultured species, other non-technical aspects should also be taken into account. As an illustration, assuming the biophysical requirements for the cultured species is highly suitable, but there is likely potential of land-use conflicts with other coastal industries, this will seriously negatively impact on the aquaculture operation and even cause to fail or discontinue. Very often the suitable areas for aquaculture are also suitable for other designations that are likely to have a higher economic value such as the tourism industry and capture fishery.

The development of the aquaculture industry in suitable areas is also expected to continuously apply the principles of sustainability. For this reason, the existing suitable areas should not be fully utilized, areas which serve as a buffer zone and serves to support assimilation capacity must be provided to help reduce environmental degradation. This can be achieved, for example, by regulating maximum allowable cage units per area (suitable area). [29] suggested the ideal number of floating net cage units of no more than 10% of the suitable area. Thus, for an area of 1 ha, only 15 units of cages with a size of 8 x 8 meters per cage unit can be placed. If this principle is applied to the identified potential water area

![Figure 3](image-url)
(398 ha), only an approximate of 597 sea cage units can be allowed, and the layout must be adapted according to the topographic characteristics of each zone (region).

Based on the analysis, it is clear that the utilization rate of potential areas for sea cage aquaculture in the Morotai Island Regency is relatively low. [18] reported area utilization for mariculture in 2013 reached only 252.7 ha consisting of 250 ha for seaweed cultivation and 2.7 ha sea cage aquaculture. The results of field observations indicated that currently operating mariculture activities are less-attractive to the local community compared to that of the older main activities as fishermen (capture fishery). This because small-scale grouper aquaculture currently practiced is considered less promising as an alternative business. Factors contributing to low production as well as low activity in marine aquaculture included limited business capital, lack of skilled human resources as well as institutional support, and, more importantly, lack of information on aquaculture technologies (high-quality seeds, pest control, and post-harvest product processing). Other limiting factors included lack availability of supporting aquaculture infrastructure, particularly transportation systems, electric supply. Since 2014, the Bureau of Fisheries of Morotai Island Regency has been collaborating with the Ministry of Maritime Affairs and Fisheries (MMAF) to increase activities and production of sea cage aquaculture by providing cages and seeds to groups of farmers in Koloray, Galo Galo and Daruba islands. The grouper production is targeted to reach 2,912 tons/year through local community partnerships with private industries.

4. Conclusion
The present study has shown that the environmental characteristics of waters in the study site are generally suitable to support sea cage aquaculture practices. The existing environmental limiting factors can be easily managed through proper site selection, careful siting of farms and the implementation of sea cage culture best management practices. The availability of monitoring protocols for future development (density of sea cage units and stocking densities) for early impact detection is highly required. Other limiting factors, such as the availability of advanced aquaculture technologies, lack of processing and marketing infrastructure and skilled human resources, must also be of high priority. Since the operation of sea cage aquaculture, located in the sea or coastal areas, a resource always considered to be common property, relating social aspects such as public concerns at each stage of expansion must also carefully taken into account.

References

[1] Presidential Decree No 6 2017 Penetapan Pulau Pulau Kecil Terluar. Lampiran No. 6 Tahun 2017
[2] Mutamar M F F, Eriyatno, Machfud, and Soewardi K 2013 Agent-Based Simulation Model for the Sustainability of Minapolitan: A Case Study of Shrimp Agroindustry Journal of Economics and Sustainable Development 4(4) 1-8
[3] KKP 2010 Strategic Plan of the Ministry of Marine Affairs and Fisheries 2010-2014 Jakarta
[4] Cardia F and Lovatelli A 2007 A review of cage aquaculture: Mediterranean Sea. In M. Halwart, D. Soto and J.R. Arthur (eds) Cage aquaculture – Regional reviews and global overview pp 156–187 FAO Fisheries Technical Paper No 498 Rome FAO 2007 241 pp
[5] Masser M P and Bridger C J 2007 A review of cage aquaculture: North America In M Halwart, D. Soto and J.R. Arthur (eds) Cage aquaculture – Regional reviews and global overview. pp. 102–125 FAO Fisheries Technical Paper No 498 Rome FAO 2007 241 pp.
[6] Cardia F & Lovatelli, A. 2015. Aquaculture operations in floating HDPE cages: a field handbook. FAO Fisheries and Aquaculture Technical Paper No. 593. Rome, FAO. 152 pp
[7] Price C, Black KD, Hargrave B T, and Jr JAM 2015 Marine cage culture and the environment: effects on water quality and primary production. Aquaculture environment interactions 6 151-174
[8] De Silva, S S and Phillips M J 2007 A review of cage aquaculture: Asia (excluding China) In M. Malwart, D Soto and J R Arthur (eds) Cage Aquaculture—Regional reviews and global overview pp 18–48 FAO Fisheries Technical Paper 498 Rome FAO 2007 241 pp
[9] Grøttum J A, Beveridge M 2007 A review of cage aquaculture: northern Europe In: Halwart M, Soto D, Arthur JR (eds) Cage aquaculture: regional reviews and global overview FAO Fish Tech Pap 498 FAO Rome p 126–154 Available at www.fao.org/docrep/010/a1290e/

[10] Pittenger R, Anderson B, Benetti DD, Dayton P and others 2007 Sustainable marine aquaculture: fulfilling the promise; managing the risks Marine Aquaculture Task Force, Takoma Park, MD

[11] Lekang O-I 2007 Aquaculture Engineering Oxford UK: Blackwell Publishing 340pp

[12] Milne P H 1979 Fish and Shellfish Farming in Coastal Waters Surrey, England: Fishing News Books Ltd

[13] APHA 2005 Standard Methods for Examination of Water and Wastewater. 21st edition, Centennial edition, Washington, DC: APHA (American Public Health Association) -AWWA-WEF [14] Smith, 2006

[15] Vollenweider RA, Giovanardi F, Montanari G, and Rinaldi A 1998 Characterization of the trophic conditions of marine coastal waters with special reference to the NW Adriatic sea; proposal for a trophic scale, turbidity and generalized water quality index Environmetrics 9:329-357

[16] Giovanardi F and Vollenweider RA 2004 Trophic conditions of marine coastal waters: experience in applying the Trophic Index TRIX to two areas of the Adriatic and Tyrrhenian seas Journal of Limnology 63(2)199-218

[17] Pettine M, Casentini B, Fazi S, Giovanardi F, and Pagnotta R 2007 A revisitation of TRIX for trophic status assessment in the light of the European Water Framework Directive: Application to Italian coastal waters. Marine Pollution Bulletin 54 1413-1426.

[18] Bappeda-Kab.Morotai 2010 Penyusunan RTRW Kabupaten Morotai 2010-2030. Badan Perencanaan Pembangunan Daerah Kabupaten Pulau Morotai, Provinsi Maluku Utara Bekerjasama Dengan Pusat Pengkajian Perencanaan dan Pengembangan Wilayah, Lembaga Penelitian dan Pengabdian Kepada Masyarakat, Institut Pertanian Bogor Morotai

[19] Landau, M 1995 Introduction to Aquaculture John Wiley and Sons Inc. New York [20] (FAO 2015)

[21] Mrcelic G J and Sliskovic M 2010 The Impact of Fish Cages on Water Quality in One Fish Farm in Croatia International Journal of Biological, Biomolecular, Agricultural, Food and Biotecnological Engineering 4(8) 547-550

[22] Mayunard, Purba R dan Imanto P T 1995 Pemilihan lokasi untuk usaha budidaya ikan laut. Dalam: Sudradjat, A., Ismail, W., Priono, B., Murniyati dan Pratiwi, E. (eds.), Prosiding Tenu Usaha Pemasyarakatan Teknologi Keramba Jaring Apung bagi Budidaya Laut, Jakarta, 12-13 April 1995 p 179-189

[23] Effendi H 2003 Telaah Kualitas Air: Bagi Pengelolaan Sumberdaya dan Lingkungan Perairan. Bogor: Institut Pertanian Bogor

[24] Harrison P J, and Hurd CL 2001 Nutrient physiology of seaweeds: application of concepts to aquaculture Cah Biol Mar 42 71-82

[25] Min H 2011 Effects of nutrients from fish farms on culture of blue mussel (Mytilus edulis): Norwegian University of Science and Technology (NTNU) 57 p

[26] Kordi H, Hoseini SA, Sudagar M, and Alimohammadi AA 2012 Correlation of chlorophyll-a with secchi disk depth and water turbidity in aquaculture reservoirs: a case study on Mohammadabad Reservoirs, Gorgan, Iran World Journal of Fish and Marine Sciences 4(4) 340-343

[27] Islam M S 2005 Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: review and analysis towards model development Marine Pollution Bulletin 50: 48-61

[28] Ennell M and J Löf 1983 Environmental impact of aquaculture - sedimentation and nutrient loadings from fish cage culture farming [in Swedish] Vatten 39 364-75

[29] Radiartain, Saputra A, and Priono B 2004 Pemetaan kelayakan lahan untuk pengembangan usaha budidaya laut di Teluk Saleh, Nusa Tenggara Barat Jurnal Penelitian Perikanan Indonesia 10(5)19-32