Sea rent aquaculture based on environmental carrying capacity approach and externality in Lampung Bay, Indonesia

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Abstract. The culture of grouper (*Epinephellus* spp.) in floating net cages is one of the economic activities utilized in the Lampung Bay area, Indonesia. This study aims to analyze the rents of aquaculture based on carrying capacity and externality approaches. The rent encompasses not just the economic rent, but also the environmental rent. The results of the study show that sea rent aquaculture is influenced by several factors, including the suitability of water, carrying capacity, the distance from aquaculture activities to marketing centre (fishing ports), and the externalities of aquaculture activities. Among these factors, the carrying capacity and distance play a significant role in influencing rents.

Key Words: aquaculture rent, floating cages, internal and external loading, Lampung.

Introduction. Rent can be defined as payment for the use of resources, such as land, labor, equipment, ideas, or even money (Alchian 1991). Economic rent is a surplus, the difference between the price obtained from using a resource and the cost per unit of input used to turn it into a commodity. Rent can also be defined as the value of productive inputs when used over the required costs (Fauzi 2010).

The rent concept is essential in resource management because it is related to public ownership; the determination of the economic rent of resources is made by the government acting on behalf of the public to increase social welfare. Rent must be obtained to avoid inefficient allocation of resource use. Another reason for rent being essential is an ethical reason, where the use of resources is not only for the current generation but also for future generations. Therefore, the absence of a mechanism for collecting rents will lead to misallocation and excessive extraction, resulting in damage or decline in the quality of resources (Scherzer & Sinner 2006). However, so far, economic rent of the region (Lampung Bay, Indonesia) is only based on land quality aspect (carrying capacity) to support production (Ricardian rent) and locational factors (locational rent) (Rustiadi et al 2011). Without paying attention to the value of environmental rents, they tend to be less concerned about aspects of environmental protection (Rustiadi et al 2011).

The concept of carrying capacity plays a vital role in ecosystem-based management. It helps set the upper limit of aquaculture production, considering environmental limits and social acceptance of aquaculture. This concept is applied to avoid unwanted changes to the condition of natural ecosystems and social functions and structures (FAO 2010). Environmental carrying capacity is related to aquaculture production that can be supported by an environment within specific criteria (Bunting 2013). Therefore, resource extraction with environmental carrying capacity limits is expected to maintain the sustainability of existing resources.

Growing aquaculture often generate high costs to the environment and may not be sustainable in long term. Many externalities associated with aquaculture, such as pollution, invasive species, and disease, are not included in production costs, but are passed on to local communities in the form of water pollution, degraded habitats, or introduced species (USAID 2013). Externalities themselves are costs and benefits arising from using resources experienced by people other than resource users and are not paid or accounted for; when paid, the externality becomes a business input cost (Scherzer & Sinner 2006).

One of the negative externalities that arise from aquaculture activities is organic waste (Hansen et al 1990; Cai & Sun 2007; Olsen & Olsen 2008; Junaidi et al 2019). Organic matter and nutrients derived from marine aquaculture activities will settle on the seabed and cause an increase in oxygen demand (Wu 1999). This organic matter and nutrients will decrease oxygen concentration around the cage (Price et al 2014). By the concept of sustainable development, the polluter must bear the cost of the pollution. This concept implies the application of the polluter pays principle (PPP) to aquaculture activities (Sunyowati 2008; FAO 2010). Based on this principle, negative externalities arising from aquaculture activities need to be paid for by resource users by internalizing negative externalities into resource extraction costs.

Lampung Bay has a good biodiversity and great potential for fisheries and marine resources to support economic activities, especially for people in coastal areas (Anggraini et al 2018). This area has been used for various economic and other activities, including diverse industries, coal extraction, power plants, tourism, commercial ports, fisheries, and settlements (Tugiyono et al 2015). The potential of this area for aquaculture activities in floating cages has been reported by Anggraini et al (2018) and Estigade et al (2019). However, to our knowledge, no study has calculated the Lampung Bay area's rent for aquaculture activities in floating net cages. Given the importance of determining the value of rents on resources, this study examines the value of rents from the use of marine space for mariculture activities in the Lampung Bay area. The value of this rent is based on aspects of land quality (Ricardian rent), environmental carrying capacity for sustainable aquaculture production, location rent, and internalization of negative externalities (environmental rent). The rent value obtained can illustrate the economic condition of Lampung Bay resources for fish culture activities in floating cages. This study can be used to reference the sustainable management of Lampung Bay area resources and the community's welfare.

Material and Method

Description of the study site. This research was conducted in the bay area of Lampung, Indonesia, especially in the waters of the city of Bandar Lampung and Pesawaran district as shown in Figure 1. The study was carried out from June 2020 to March 2021.

Data collection and research methods. This study used a survey method. The study used primary and secondary data. Primary data was generated from a questionnaire conducted on the grouper (*Epinephelus* spp.) farming activities using floating cages as culture facilities. Secondary data consisted of the thematic map of the Lampung Bay waters from the results of the Lampung Province RZWP3K report (Pemprov Lampung 2018). Earth's map data was taken from BIG data in 2013(BIG & Pushidrosal 2018), while the bathymetry map was taken from the Indonesian Navy's Hydro Oceanographic Center (PUSHIDROS) data in 2014 (BIG & Pushidrosal 2018). The distance of the area to settlements, rivers, and ports was primary data obtained from the results of field surveys.

Carrying capacity. Calculation of carrying capacity was based on the capacity of pollution load. The same method for calculation of carrying capacity for lobster has been conducted by Junaidi et al (2019).

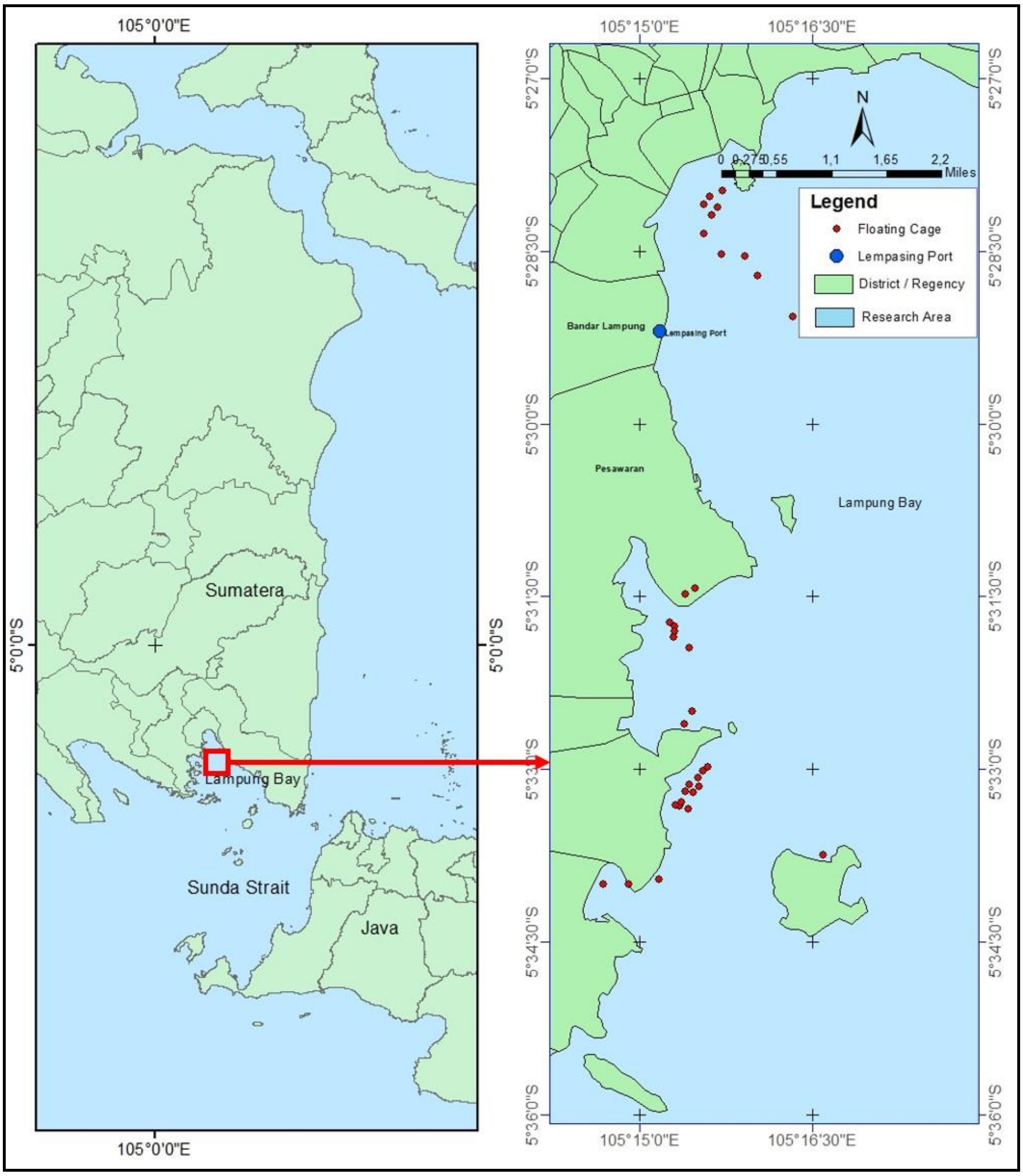

Figure 1. The location of floating cages at Lampung Bay.

Internal loading. In determining the total loading of organic matter from grouper culture in floating cages, the following formula was used (Iwama 1991):

$$O = TU + TFW$$

Where: O - total output of particulate organic matter; TU - total food uncaptured; TFW - total faecal waste.

TU was obtained with the formula:

$$TU = TF \, x \, UW$$

Where: TF - total feed; UW - percentage of uncaptured feed waste from total feed.

TFW was obtained with the formula:

$$TFW = F \times TE$$

Where: F - fecal waste production, which can be estimated from studies on the digestibility of main diet component; TE - total food eaten.

TE was obtianed with the following formula:

$$TE = TF - TU$$

Estimation of N and P waste was based on data on N and P content in fish feed and grouper carcasses (Beveridge 1984; Barg 1992).

External loading. Activities that can contribute to organic waste, N and P to the bay waters originating from land include settlements, livestock, hatcheries, and agriculture. Estimation of N and P waste loads originating from activities outside of marine aquaculture was based on secondary data calculated by referring to the LOICZ (Land Ocean Interaction in the Coastal Zone) method. The waste load from anthropogenic activities around the bay was calculated by multiplying the level obtained from secondary data by the waste discharge coefficient as shown in Table 1.

Table 1

Economic activities and discharge coefficient

Economic activities	*Discharge coefficient*	*% entered the bay*	*Reference*
	Household activities		
Solid waste	1.86 kg N/person/year 0.37 kg P/person/year	100	(SOGREAH 1974)
Domestic waste	2 kg N/person/year 5 kg P/person/year	25	(Padilla et al 1997)
	Livestock		
Cattle/Buffalo/Horse	43.8 kg/N/head/year 11.3 kg P/head/year	25	(Economopoulos & WHO 1993)
Goat/Sheep/Pig	4 kg N/head/year 21.5 kg P/head/year	25	(Economopoulos & WHO 1993)
Poultry	0.3 kg N/head/year 0.7 kg P/head/year	25	(Valiela et al 1997)

Estimating the environment's carrying capacity includes loading total nitrogen (TN) from the culture system and anthropogenic waste into the aquatic environment. The effluent from aquaculture activities will increase nutrient enrichment (TN) (hyper nitrification) in the bay. The degree of hyper nitrification is determined by the volume of water bodies, the flushing rate, and tidal fluctuations (Barg, 1992), providing the following estimation equation:

EC=Nx(F/V)

Where: Ec - equilibrium rise in concentration (level of hyper nitrification); N - daily output of soluble nitrogenous waste; F - flushing time of waterbody in days; V - volume of the water body. F is the time (number of days) needed by the waste to settle in a body of water to clean the water environment. Determination of F was done by using the formula:

F=1/D

D=(Vh – Vl)/(T x Vh)

Where: F - flushing time; D - dilution time; $(V_h - V_l)$ - volume exchanged every tide (m^3); V_h - high water volume of water body (m^3); V_l - low water volume of the waterbody (m^3); T - tide period (in days).

The calculation of water body volume is done at the Mean High Water Spring (MHWS) and the Mean Low Water Level Level (MLWL), using formula:

$V_h = A \times h_1$; $V_l = A \times h_0$

Where: A - surface area of water (m^2); h_1 and h_0 - depth in Mean High Water Spring (MHWS) and Mean Low Water Level (MLWL) (m), respectively; V_h - high water volume of the waterbody (m^3); V_l - low water volume of the waterbody.

Calculation of concentration (N_{lp}) from the enrichment of nutrients associated with the value of nitrogen ammonia (NH_3N) was based on the water quality standard for aquaculture (KEPMEN LH 51 2004). The optimal capacity for aquaculture production ($Prod_{opt}$) is the concentration value (N_{lp}) that comes from fish production waste (per unit of floating cages) and anthropogenic waste and does not exceed the water quality standard. The following equation can estimate the optimal production:

$$(Prod_{opt})\ (ton) = \frac{N_{bm}}{N_{lp}}$$

Where: N_{bm} - (N) water quality standard for aquaculture (0.3 ppm) ranger of required ammonia (NH_3H); N_{lp} - concentration (N) of fish production and anthropogenic waste from nutrient enrichment.

$Prod_{opt}$ is the amount of fish production obtained without exceeding the required water quality standards. The estimated value of optimal production is the ratio between the concentration (N) of the quality standard and the concentration (N) of the production waste. If the output of N waste produced in 1 unit of KJA, the optimum amount of fish production can be calculated.

Economic rent. The economic rents of this study area are based on Ricardian rents and location rents. The rent value equation used refers to the equation of Rustiadi et al (2011), namely:

$$ER=Y(m-c) - Y \times t \times d$$

Where: ER - economic rent; Y - output per unit based on carrying capacity of the area (ton ha^{-1}); m - price per unit output (USD ton^{-1}); c - cost per unit output (USD ton^{-1}); t - transportation cost per unit output (USD/ton/km); d - distance from the production unit to port (fisheries port) (km).

Environment rent. The environmental rent was determined based on the polluter pay principle. Waste from fish culture activities in floating cages is a negative externality of this activity. Organic matter derived from unconsumed feed and the metabolism of cultured fish is one of the contaminants resulting from aquaculture activities (Beveridge et al 1997; Wu 1999; Cai & Sun 2007). The organic waste then requires oxygen for decomposition processes, increasing oxygen demand in the waters (Wu 1999; Price et al 2014). Therefore, this study's assessment of environmental rent is based on the need for oxygen to decompose organic waste from aquaculture activities. The formula for determining the value of negative externalities is the following:

$$e = [(FCR-1) \times Y(1-WC)] \times OC \times DO \times C$$

Where: e - externality (USD ha^{-1}); FCR - food conversion ratio; Y - output per unit based on carrying capacity of the area (ton ha^{-1}); WC - water content of unconsumed feed (80%); OC - organic C level (40%); DO - O_2 requirement per kg c-organic (2.67) (Boyd 1989); C - the price of O_2 per kg (O_2 tube price assumption of 1.21 USD kg^{-1}).

Sea rent aquaculture. Sea rent aquaculture is formulated by the sum of ER and internalizing the negative externalities of the aquaculture activities impacts as environmental costs. The formula used is as follows:

$$SRAq = ER - e$$

Where: SRAq – Sea Rent Aquaculture; ER - economic rent; e - externality.

Results and Discussion

Existing condition. Lampung Bay is a strategic economic area with various activities, including aquaculture. The number of fish farmers using floating cages in 2019 was 647 people (KKP 2021), which came from Pesawaran Regency and Bandar Lampung City. Meanwhile, based on the survey results, the number of floating cages units operating in Lampung Bay are 7744 plots, consisting of 2158 plots in Bandar Lampung City and 5586 plots in Pesawaran Regency. Economic activities in Bandar Lampung City contribute to the waste of the waters of Teluk Lampung by domestic waste, livestock waste, and agricultural activities waste.

Spatial use of Lampung Bay. The Lampung Bay zone for grouper culture in floating cages results from a spatial analysis based on the suitability of 3 aspects and the Rencana Zonasi Wilayah Pesisir dan Pulau-pulau Kecil (RZWP3K)/ Coastal Zoning Lampung Province (Pemprov Lampung 2018). The area of Lampung Bay water that can be used for aquaculture activities using floating cages is presented in Figure 2. City Bandar Lampung has a high suitability area of 224.7 ha, moderate suitability area of approximately 23.71 ha, and a low suitability area around 61.69 ha. Meanwhile, in Pesawaran Regency, the waters with high suitability have an area of 1241.57 ha, and low suitability of 378.36 ha.

Carrying capacity of Lampung Bay for grouper (Epinephellus spp.) culture. A grouper culture carrying capacity analysis was carried out to determine how much production can be accommodated in the study area, as shown in Figure 3 and Table 2. The study area has a total carrying capacity of 9196.21 tons, Bandar Lampung City with 337.89 tons, and Pesawaran Regency with 8858.33 tons. The S4PSW09 segment has the highest carrying capacity in the study area of 2798.29 tons, and the S4BL04 segment has the lowest carrying capacity of 1.02 tons. The S4BL03 segment has the highest carrying capacity for the Bandar Lampung City (87.07 tons), while S4BL04 segment has the lowest capacity (1.02 tons). In Pesawaran Regency, the S4PSW09 segment has the highest carrying capacity (2798.29 tons), the S2PSW03 segment the lowest (62.89 tons). The results show that the surface area of the segment does not influence the carrying capacity. However, the activities in the area will determine the carrying capacity, floating cages activities (internal loading), and the resulting load from anthropogenic activities (external loading) where the bay area is located. Lampung bay is divided into six sections based on the characteristics of the waters.

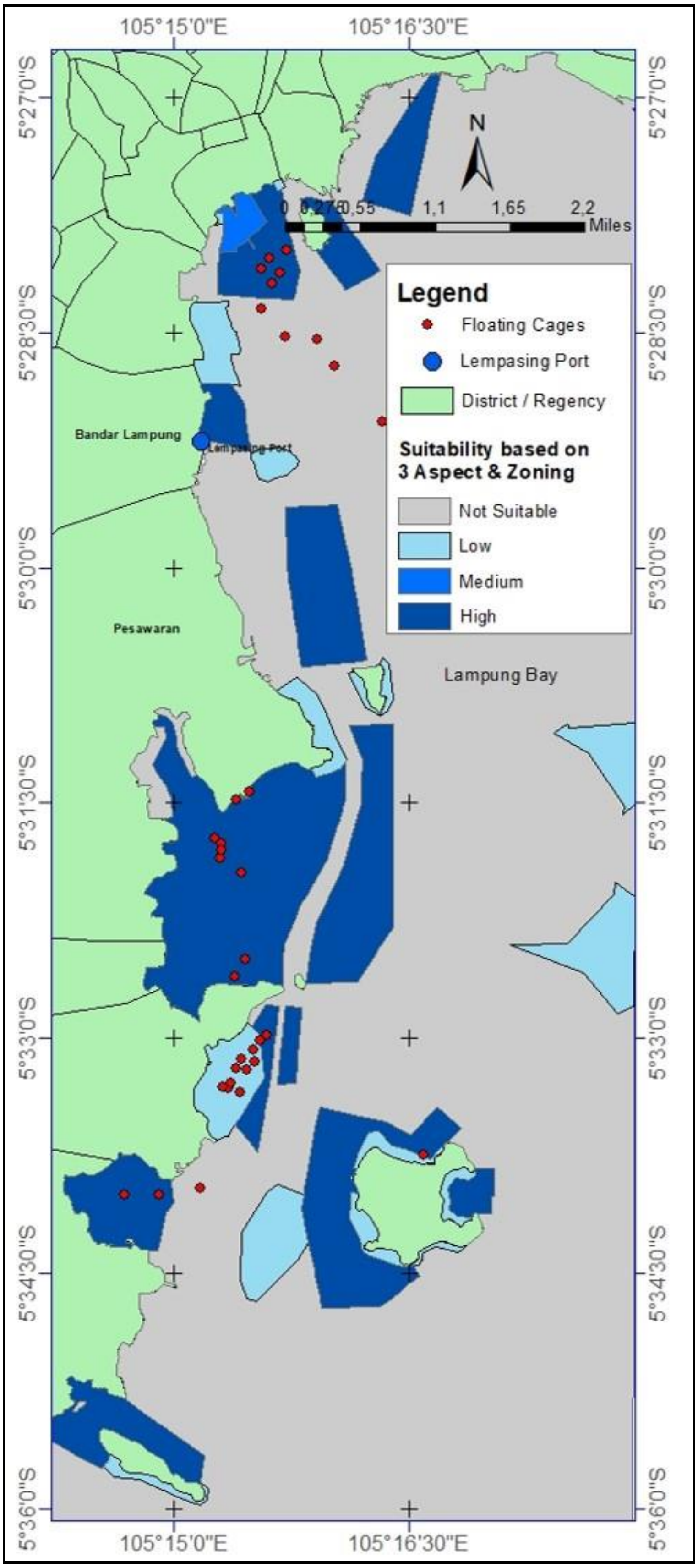

Figure 2. Suitability of three aspects (physic, chemical, and social-economic) and zoning plan (RZWP3K).

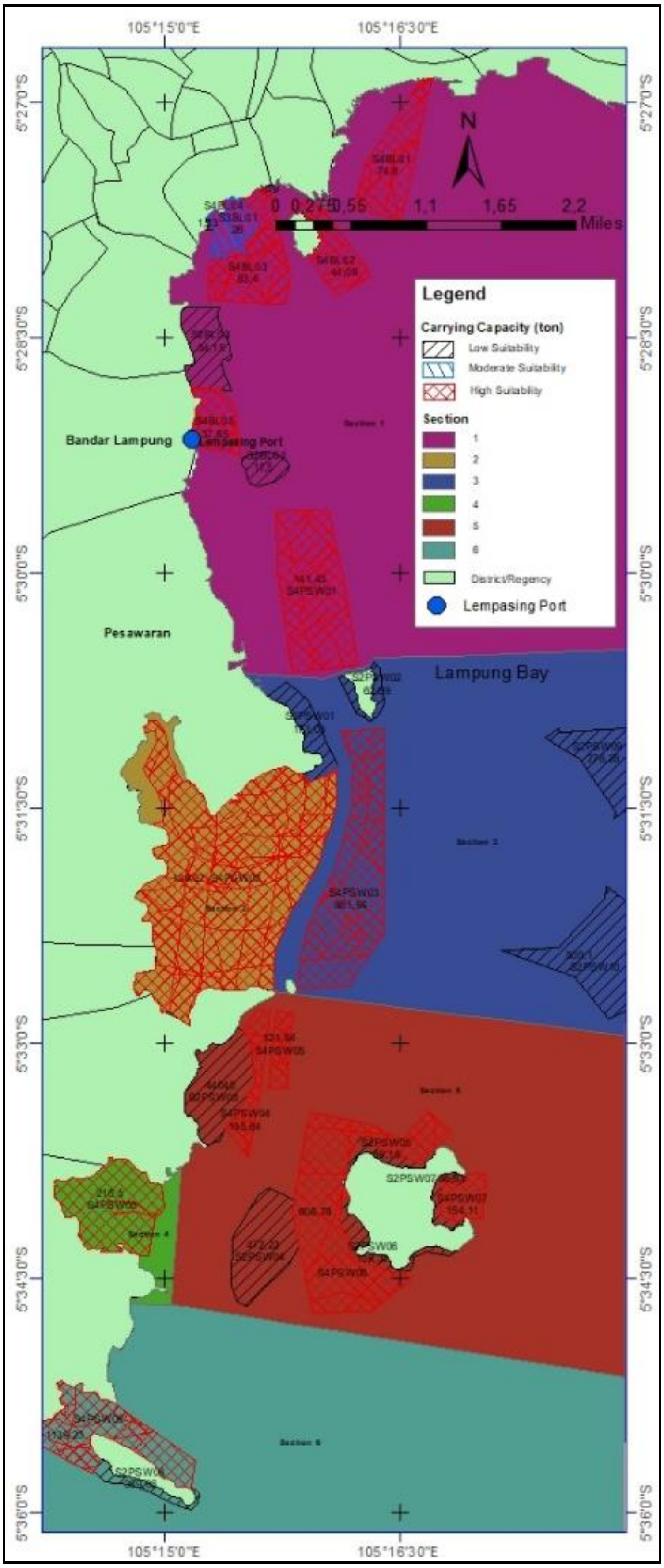

Figure 3. Carrying capacity and distance to port.

Table 2

Area, carrying capacity and distance to port

Segment	*Area (ha)*	*Carrying capacity (ton)*	*Distance (km)*
Bandar Lampung	310	338	
S4BL01	69	75	4.7
S4BL02	40	44	2.9
S4BL03	80	87	2.5
S4BL04	1	1	2.8
S4BL05	35	38	0.4
S3BL01	23.71	26	2.7
S2BL01	1.18	1	3.4
S2BL02	1.13	1	2.61
S2BL03	43.13	47	1.25
S2BL04	16.25	18	0.92
Pesawaran	1620	8858	
S4PSW01	138.89	151	2.47
S4PSW02	463.96	393	7.2
S4PSW03	178.38	1.025	5.3
S4PSW04	30.62	196	8.1
S4PSW05	19.07	122	7.9
S4PSW06	189.63	1212	8.6
S4PSW07	24.12	154	9.7
S4PSW08	99.68	217	11.3
S4PSW09	97.22	2798	12.7
S2PSW01	29.78	171	3.6
S2PSW02	10.95	63	3.85
S2PSW03	70.37	450	8.2
S2PSW04	73.91	472	9.9
S2PSW05	13.96	89	9.1
S2PSW06	20.56	131	10.5
S2PSW07	10.46	67	9.96
S2PSW08	12.85	370	13.1
S2PSW09	48.45	278	6.29
S2PSW010	87.07	500	8.05

Economic rent. The cost component in producing grouper consists of operational costs, including preparation, biological material, feed, electricity/fuel, permits and labor, and equipment depreciation costs, including floating cages and generators. The average operational cost for Bandar Lampung City is 4 USD kg^{-1}, and the average depreciation cost is 0.55 USD kg^{-1}, while for Pesawaran Regency, the average operational costs are 3.8 USD kg^{-1}, and the average depreciation is 0.52 USD. The grouper price per kg for the two locations is the same, namely 8.71 USD kg^{-1}. The total economic rent value of the study area is 37362534 USD, with an area suitable for grouper cultivation activities in floating cages covering an area of 1930 ha.

The S4BL03 segment has the highest economic rent in Bandar Lampung USD 355,528, but the economic rent per ha is higher in S4BL05, namely 4529 USD ha^{-1}. For Pesawaran Regency, the S4PSW09 segment has the highest rent (11050756 USD), and economic rent per ha (113668 USD ha^{-1}) shown in table 3. Economic rent is influenced by carrying capacity, area, prices of fish, production costs, and distance to fishing ports.

Segments with a high carrying capacity, but different operational and depreciation costs, and the distance to the port affect economic rent. Segments located near the port have high economic rent, this also being observed by Zaucha (2019) in Poland.

Table 3

Economic rent and externality of Lampung Bay

Segment	*Economic rent (USD)*	*Economic rent (USD ha^{-1})*	*Externality (USD)*	*Externality (USD ha^{-1})*
Kota Bandar Lampung	1378874		425931	
S4BL01	299695	4366	94293	1374
S4BL02	179396	4434	55573	1374
S4BL03	355528	4449	109759	1374
S4BL04	4171	4438	1291	1374
S4BL05	157333	4529	47716	1374
S3BL01	105308	4442	32566	1374
S2BL01	5210	4415	1621	1374
S2BL02	5023	4445	1552	1374
S2BL03	193937	4497	59240	1374
S2BL04	73273	4509	22320	1374
Pesawaran	35983660		11166532	
S4PSW01	651605	4692	190769	1374
S4PSW02	1627756	3508	495530	1068
S4PSW03	4310344	24164	1291521	7240
S4PSW04	803953	26256	246612	8054
S4PSW05	501548	26300	153589	8054
S4PSW06	4957778	26144	1527271	8054
S4PSW07	624696	25900	194261	8054
S4PSW08	865549	8683	272914	2738
S4PSW09	11050756	113668	3527437	36283
S2PSW01	729734	24504	215616	7240
S2PSW02	267773	24454	79281	7240
S2PSW03	1846056	26234	566757	8054
S2PSW04	1910941	25855	595268	8054
S2PSW05	363423	26033	112433	8054
S2PSW06	528831	25721	165589	8054
S2PSW07	270303	25842	84244	8054
S2PSW08	1455471	113266	466237	36283
S2PSW09	1161135	23966	350792	7240
S2PSW010	2056008	23613	630411	7240

Floating cages externality. The externality analysis from grouper culture in floating cages showed a total externality of the study area of 11592463 USD. For Bandar Lampung City it was 425931 USD, and for Pesawaran Regency it was 11166532 USD (Table 3).

Sea Rent Aquaculture. The total sea rent of aquaculture in the study area was 25770071 USD, for the city of Bandar Lampung being 952943 USD and for Pesawaran Regency 24817128 USD. The average sea rent of aquaculture per ha for the study area was 15281 USD, the average sea rent aquaculture in Bandar Lampung being lower, namely 3079 USD ha^{-1}. For Pesawaran, the average value of sea rent aquaculture was higher than the average, with a rent of 21704 USD ha^{-1}.

The S4BL05 segment with a high level of suitability has the highest sea rent aquaculture per ha, which is 3155 USD (Table 4). This rent is the highest among the segment for aquaculture activities in Bandar Lampung. Distance from the floating cage location to the port is the most important factor that affects the rent, being only 0.4 km from the port. Meanwhile, for Pesawaran, the S4PSW09 segment has the highest rent per ha, 77384 USD.

Table 4

Sea rent aquaculture

Segment	*Sea Rent Aquaculture (USD)*	*Sea Rent Aquaculture (USD ha^{-1})*
Kota Bandar Lampung	952.943	
S4BL01	205.402	2.992
S4BL02	123.823	3.060
S4BL03	245.769	3.076
S4BL04	2.880	3.064
S4BL05	109.616	3.155
S3BL01	72.742	3.068
S2BL01	3.589	3.041
S2BL02	3.471	3.071
S2BL03	134.697	3.123
S2BL04	50.953	3.136
Pesawaran	24.817.128	
S4PSW01	460.835	3.318
S4PSW02	1.132.226	2.440
S4PSW03	3.018.822	16.924
S4PSW04	557.341	18.202
S4PSW05	347.959	18.246
S4PSW06	3.430.507	18.091
S4PSW07	430.435	17.846
S4PSW08	592.636	5.945
S4PSW09	7.523.319	77.384
S2PSW01	514.118	17.264
S2PSW02	188.491	17.214
S2PSW03	1.279.299	18.180
S2PSW04	1.315.674	17.801
S2PSW05	250.989	17.979
S2PSW06	363.242	17.667
S2PSW07	186.059	17.788
S2PSW08	989.234	76.983
S2PSW09	810.343	16.725
S2PSW010	1.425.597	16.373

The study results show that the variation of sea rent aquaculture for each segment in the study location depends on the carrying capacity, segment area, production costs, and distance. The location in Pesawaran Regency can be developed with a high sea rent aquaculture per ha, but the port location is still quite far away. The sea rent aquaculture in Pesawaran Regency can be increased by supplying port infrastructure to shorten distances and reduce transportation costs. The segment with high sea rent aquaculture can be considered to develop alternative commodities that are more promising compared to grouper, including lobster (*Panulirus* spp.) culture. Policies on restrictions and improvements of infrastructure for the segments with low rent value are restrictions according to carrying capacity, while for the segment with low rents because of distance, the implementation of the policy should concentrate on port development.

Zoning the inland area also needs regulation to reduce external loading (anthropogenic waste) into the Lampung Bay, increasing the carrying capacity of Lampung Bay waters.

Conclusions. Sea rent aquaculture is influenced by several factors, including the suitability of water, carrying capacity, the distance from aquaculture activities to market centers (fishing ports), and the externalities of aquaculture activities. Among these factors, the carrying capacity and distance play an important role in influencing the rents. By knowing the value of sea rent aquaculture, planners or policymakers can determine the feasibility of grouper aquaculture locations in floating cages. The development of grouper culture in floating cages in Lampung Bay, Pesawaran can be improved and increased more than in Bandar Lampung with infrastructure improvements (shorter distance).

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Conflict of Interest. The authors declare that there is no conflict of interest.

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