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Sustainability assessment based on the Aquaculture Intensity Index (AII) approach: a case study in Oita prefecture, Japan

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# ABSTRACT

The nutrient load generated by excessive coastal aquaculture farms leads to self-contamination, destroying aqua-environment and lead to a decline in aquaculture production. In order to assess the sustainability of coastal aquaculture and estimate the optimal aquaculture intensity in the future, a simplified Aquaculture Intensity Indicator (AII) is proposed, several variables such as annual fish production were utilized, of which the deep learning satellite image object detection technology is applied to estimate the number of fish cages. Case study of several aquaculture farms in Oita prefecture found that .... Results of the study provided a reference for the development of fishery environmental standards and aquaculture density decisions and ensure the sustainable development of marine aquaculture in Japan.

# KEYWORDS

Sustainability assessment; Aquaculture intensity index (AII); Fish production model; Satellite image object detection.

# INTRODUCTION

In recent years, coastal aquaculture production has increased rapidly with causing the contamination problem, the intensity of aquaculture in coastal areas has been a key variable of the red tides and anoxic water masses occurrence. As Club of Rome indicated [1], the increase in aquaculture intensity does not lead to a linear increase in fisheries, and even leads to a reduction in production. Determine the optimum aquaculture intensity is important for the sustainable development of aquaculture.

Many coupled numerical models of hydrodynamics and ecosystems in coastal waters have been developed to make estimations. For instance, a three-dimensional (3D) ocean model coupled with ecosystem and individual-based submodels, Marine Environmental Committee (MEC) [2-3], was developed to explore the aquaculture capacity, biochemical impact and ecological footprint. In these models, topography, tides, currents, surface forcing, and river boundaries need to be delicately configured, meanwhile, the application of an ecosystem submodel should consider regional specificity, and large-scale temporal and spatial dynamic prediction are not easy. In general, applying a sophisticated simulation is time consuming and tedious for data preparation, and it is still difficult to make a regional evaluation for collections of fisheries grounds based on limited data. On the other hand, current published statistical database on annual aquaculture production, the Marine Aquaculture Production Statistics (海面漁業生産統計調査) [4], have detailed statistics records over years but focuses on administrative division rather than fishery ground division. It surveyed the production of both fishery and aquaculture, from the category of inland, sea surface, coastal, offshore, and pelagic. However, the accuracy of such production data cannot be used to assess in fishery farm level, which leaves difficulties to estimate the farm intensity.

The construction and application of an appropriate index determines the feasibility of assessing the aquaculture sustainability. A Sealing Index of Bay [5] was proposed to evaluate the closure of the offshore bays of Japan, which had experienced frequent red tides and tides since the 1960s. This index evaluated the water exchange ability by non-dimensioning the surface area of the water, the width of the bay mouth, the average water depth of bay mouth and inner bay. However, the spread of waste materials from aquaculture farms cannot ignore the tides and flow. In 2006, the Ocean Policy Research Institute proposed a comprehensive approach [6] to the health assessment of 88 closed bays across the country from the perspective of ecosystem stability and material circulation fluency. Assessment in aquaculture farm scale has become the next step of the work.

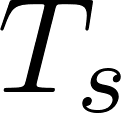
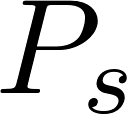
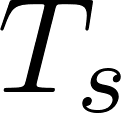
In this article, an index is established to assess the aquaculture intensity based on the annual aquaculture production and the fishery farm dimension information, and a case study is conducted in several bays of Oita prefecture.

# METHODS

## 1）Fish production model

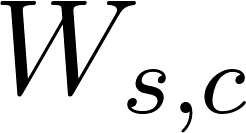
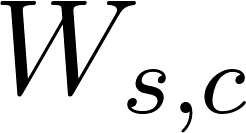
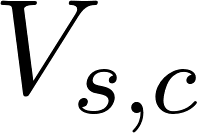
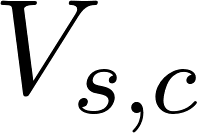
The formula of annual fish production of each farm is derived from Rebecca's study [7], in which the production per year was calculated by dividing the total farm output by the number of years between stocking and harvest. Considering the continuity of fishery farming, the annual fish production is defined as the ratio of total fishery production to stock cycle, as shown in Eq. 1:

|  |  |  |
| --- | --- | --- |
|  |  | (Eq. 1) |

where [](https://www.codecogs.com/eqnedit.php?latex=p%250) is the annual production of a fish farm. [](https://www.codecogs.com/eqnedit.php?latex=T_%7Bs%7D%250) is the period between stocking and harvest of a specific fish species, the subscript [](https://www.codecogs.com/eqnedit.php?latex=s%250) represents different species of fish, and [](https://www.codecogs.com/eqnedit.php?latex=P_%7Bs%7D%250) is the corresponding total output during [](https://www.codecogs.com/eqnedit.php?latex=T_%7Bs%7D%250). Considering that some farms stock more than one kind of fish species, annual production of a farm is the sum of annual production of each species.

To calculate the total production of each species, the formula shown in Eq. 2 is used:

|  |  |  |
| --- | --- | --- |
|  |  | (Eq. 2) |

where [](https://www.codecogs.com/eqnedit.php?latex=W_%7Bs%2Cc%7D%250) is the weight of seawater inside each fish cage, it is calculated by [](https://www.codecogs.com/eqnedit.php?latex=W_%7Bs%2Cc%7D%250) =[](https://www.codecogs.com/eqnedit.php?latex=%5Crho%250) [](https://www.codecogs.com/eqnedit.php?latex=V_%7Bs%2Cc%7D%250), and the subscript [](https://www.codecogs.com/eqnedit.php?latex=c%250) represents different number of fish cages. [](https://www.codecogs.com/eqnedit.php?latex=V_%7Bs%2Cc%7D%250) means the volume of fish cage and [](https://www.codecogs.com/eqnedit.php?latex=%5Crho%250) (1,025kg m-3) is the density of seawater. The area of fish cage is measured from satellite images and mean depth of cage is assumed 8.0 meters. [](https://www.codecogs.com/eqnedit.php?latex=R_%7Bs%7D%250) is the stock rate of species, which means weight ratio of stocked fish and seawater inside the cage when the fish are available for harvest. Table 1 shows the parameter value of each species, the values of which are based on interviews with local farmers.

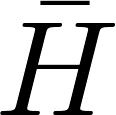
**Table 1 The stock rate and harvest period of two species fish.**

|  |  |  |
| --- | --- | --- |
| parameter | value | |
| yellow tail | tuna |
|  | 3.0% | 0.3% |
| (year) | 2.0 | 3.0 |

## 2）Culture intensity index

Kitazawa [8] proposed an indicator for evaluating the sustainability of farms and this paper simplifies this indicator: considering annual production, area and mean water depth of fish farms (see Eq. 3). The environmental impact of fish farm is not only related to stocking density (weight of fish stocked per cage volume), but also to the physical conditions of the farm. The greater the water depth, the more easily the excretion is spread, and the bottom pollution is less likely to occur. The larger the area of the farm, the smaller the stocking density and the smaller the local water quality pollution.

|  |  |  |
| --- | --- | --- |
|  |  | (Eq. 3) |

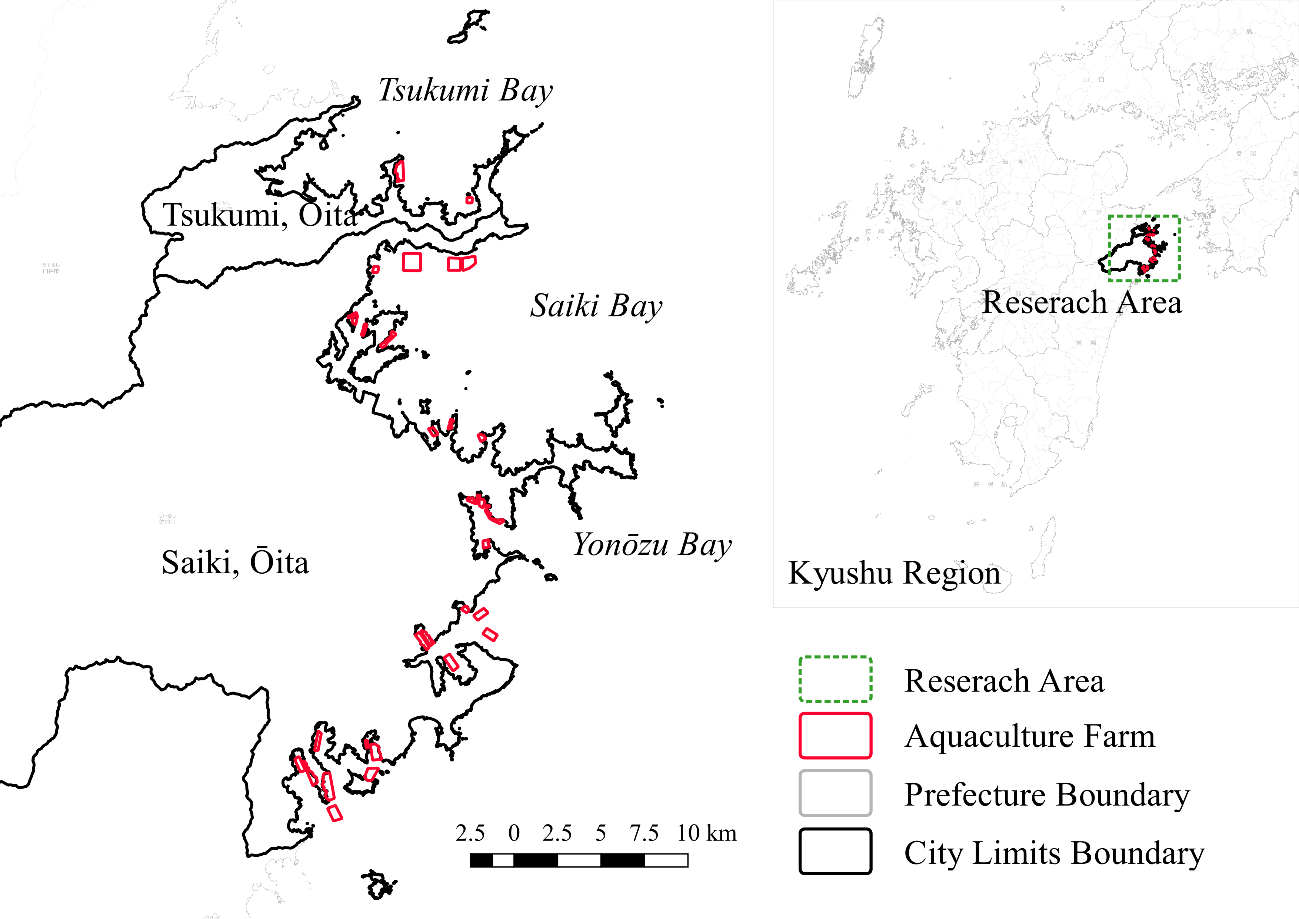
where [](https://www.codecogs.com/eqnedit.php?latex=I%250) (kg m-3) means the aquaculture intensity index. Smaller [](https://www.codecogs.com/eqnedit.php?latex=I%250) means lower culture intensity. [](https://www.codecogs.com/eqnedit.php?latex=p%250) (kg), [](https://www.codecogs.com/eqnedit.php?latex=A%250) (m2) and [](https://www.codecogs.com/eqnedit.php?latex=%5Cbar%7BH%7D%250) (m) is the annual production, surface area and mean depth of each farm.

# Materials

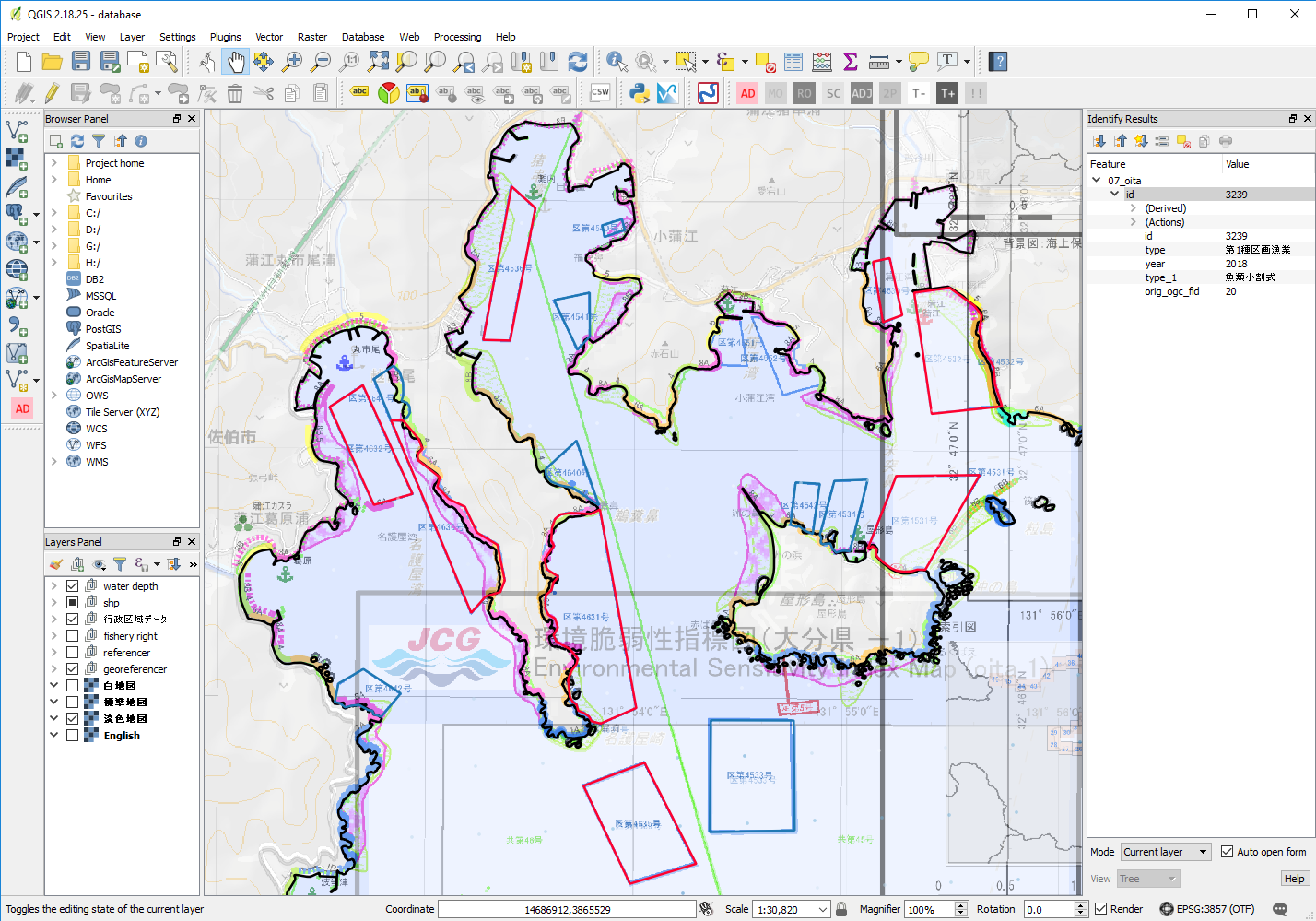
The Aquaculture Intensity Index (AII) approach is applied in the coastal area of Tsukumi city and Saiki city in Oita prefecture, Japan (see Fig. 1), where the yellow-tail and tuna account for about 91% of the aquaculture production of Oita prefecture in 2017.

## 1) Data source and preparation

In the research area, the aquaculture farm is marked out by red and light blue polygons (see Fig. 2) based on the Coastal Environmental Information Service (CeisNet) and Environmental Sensitivity Index (ESI) database (<https://www1.kaiho.mlit.go.jp/JODC/ceisnet/index.html>), the red polygons of which show the yellow-tail and tuna farms. The topography is integrated in a GIS based database from Japan Oceanographic Data Center (JODC, <https://www.jodc.go.jp/jodcweb/index_j.html>) with 500-meter resolution, which is used to estimate the AII. The satellite images are downloaded from Google Earth historical data server in the geographic Tagged Image File Format (geo-TIFF) tiles at 20th zoom level, which are spliced later to high resolution satellite images of interested aquaculture farms.



**Fig. 1 Research area and the aquaculture farms.**



**Fig. 2 An integrated GIS database of aquaculture farms.**

## 2) Aquaculture cage detection and counting

Detection and counting of aquaculture cages from a large number of satellite images is achieved by applying the Faster R-CNN framework based on the TensorFlow software library (TF-R-CNN) [9]. The object detection technology is a primary application of deep learning in the field of imagery, which has been widely used, for example, merchant ship detection from satellite images [10], and the Faster R-CNN is the state-of-the-art framework for target detection.

This application uses own training dataset with 150 satellite images be labeled manually in advance. The target detection mission focuses on aquaculture cages in satellite images, in which two subtasks are included, one of which is to generate the classes information of aquaculture cages, namely the classification task, which will locate the aquaculture cage and distinguish the classes name of the cage, such as “square” (cyan bounding box), “round” (green bounding box) and “ship” (white bounding box) (see Fig.3). The second is to output the geographic location information of the target, the positioning task, which will output the center latitude and longitude and scale of the bounding box. The area of the aquaculture cage will be estimated on the basis of the bounding box scale, and the number of aquaculture cages will be estimated based on the length of the bounding box latitude and longitude vector.



**Fig. 3 Diagram of fish cage detection and counting working flow.**

# RESULTS AND DISCUSSION

## Fish production

Compared with the Marine Aquaculture Production Statistics in 2017, the calculated value of yellow tail is 0.3% lower than the statistical value, and the calculated value of tuna is 3.68% higher than the statistical value. The possible causes of the deviation are the error in the calculation of the cage volume and the mean error in the stocking density.

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与2017年海水养殖生产统计相比，黄尾的计算值比统计值低0.3％，金枪鱼的计算值比统计值高3.68％。 偏差的可能原因是保持架容积的计算误差和放养密度的平均误差。

## 2) Aquaculture intensity index

养殖强度结果分析（分布图）

# CONCLUSIONS

The evaluation index of aquaculture intensity established here is the first step to assess the aquaculture intensity of fish farm. Water current and water quality information, such as total nitrogen and total phosphorus, will be combined in the future, which will be used to estimate the optimal stocking density within the environmental capacity of the cultured sea area.The result can provide reference for making environmental standards of fish farms and stock density decision and ensure sustainable development of marine aquaculture.

# ACKNOWLEDGEMENT

# BIOGRAPHY

Hongxia Gao is a Master course student at Department of Systems Innovation, Graduate School of Engineering, The University of Tokyo. Her main field of research area are making sustainability assessment of coastal and marine aquaculture in Japan, and the GIS-based database initialization and visualization.

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