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Integrated GIS and AHP for Marine Aquaculture Site Selection in Penghu Cove in Taiwan

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Abstract

Marine cage culture has been developed quickly in recent years from land-based operation transfer to marine cage culture by government policy in Taiwan. Therefore, the suitable site selection is an important premised and key factor for successful marine cage culture and sustainable development in the future. Especially, it's greatly influences economic viability by determining capital outlay and affecting running costs, production and mortality. Hence, the decision factors such as climate factors, geographic environmental factors, bio-environmental factors and social-economic factors are more important for site selection. This study use AHP (analytic hierarchy process) to evaluate the criteria weight for site selection. From AHP analysis, the weights of suitability of the four Geographic Information System (GIS) grid themes were 0.322, 0.410, 0.127 and 0.141, respectively. The result shows that the geographic environmental factors are the most important factors in selection suitable marine culture sits in Penghu cove in Taiwan. At the meanwhile, by using ArcMap, a GIS software package, a suitable map was made based on the selected grid themes. The suitable sites for marine cage culture development identified on the individual GIS grid themes, the GIS software and AHP method can be integrated to select objectively the optimal sites for marine cage culture development.

Keywords: Aquaculture; Site selection; GIS; AHP; Taiwan

Introduction

In recent years, there has been a dramatic proliferation of research concerned with fishery resources degradation in the world. As regard to solve the fisheries problem now is promoting to marine cage culture instead the land-based culture in recent decade in Taiwan. Therefore surge of research on marine cage culture has given us new opportunities and challenges. There are many criteria, guideline and essential factor for selection marine site for aquaculture in coastal zone. Such as reported that water flow, volume availability, water quality, access and location of utilities, topography of site, slope of land and legislation concerning water rights, study operate suitable site selection for oyster farm and further studies indicated that three site categories of cage site selection criteria there were physic-chemistry condition, site cage system, and profitability. Many studies have focused on the weighted liner combination method using the pairwise comparison. Weights indicate the relative importance of one variable with respect to the others and depend on expert knowledge, mostly. But it doesn't suitable for everywhere in the world. Even in a small number of countries, shows wide variations. While some of these criteria are obviously arbitrary or tentative, others are based on local environmental conditions and land use patterns. Other than the nature and composition of expected emissions or discharges from the farm, the pattern of water exchange and the bottom dynamic conditions in the area have to be considered. In the guidelines for site approvals, the environmental sensitivity has referred to as an important factor. Different areas may respond differently to the same nutrient dose [1].

With the rapid development of marine cage culture that creates a growing need for coastal zone environment analyses, a complex task need one useful tools for kinds of analysis is the GIS. GIS are information tools with the capacity to store, analyse and display special data. The general usefulness of the methodology of using GIS for aquaculture site selection has been explored and is now becoming established. For example, it was reported that applied the GIS with biophysical and social-economic characteristics for planning the aquaculture site spatial decision. Data also point out that the individual investor interested in aquaculture development requires spatial information particularly at the time of site selection from among a range of alternative locations with different biophysical and social-economic characteristics. It mentioned that the bathymetry, current, shelter and water quality variations were used to determine suitability site by PC-based GIS for coastal salmonid cage culture. Furthermore, although GIS uses in marine aquaculture planning began a decade ago, as more advanced GIS techniques were made available and motivated by the needs of environmental research and management, GIS marine applications included subjects as varied as sediment dynamics and bathymetry changes, artificial reefs site selection, or coastal hazards [2]. This article adopts the AHP method and using GIS, for a technological transfer project of marine cage culture site selection in Penghu cove, Taiwan.

On the other hand, the good water quality requirement of the site selection is also the first considerations for the proposed facility. With regard to the inflowing water, every aqua cultural endeavour is critically depending on a good water supply. During site selection this is the very first factor to be taken into account. Considering, the many physical, chemical and biological parameters that can influence water quality. Biophysical characteristics may include criteria pertinent to water quality (e.g. temperature, dissolved oxygen, alkalinity, salinity, turbidity, and pollutant concentrations), water quantity (e.g. volume and seasonal profiles of availability) and climate (e.g. rainfall distribution, air temperature, wind speed and relative humidity). Socio-economic characteristics that may be considered in aquaculture development

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include administrative regulations, competing resource uses, market conditions (e.g. demand for fishery products and accessibility to markets), infrastructure support, and availability of technical expertise [3]. The spatial information needs for decision-makers who evaluate such biophysical and socioeconomic characteristics as part of aquaculture planning efforts can be well served by geographical information systems.

Environmental impacts are now more frequently taken into account when aquaculture developments are undertaken. Aqua culturists must be environmentally aware to survive. The negative environmental impacts attributed to aquaculture have most often resulted from inappropriate site selection, pool planning, and lack of attention to environmental protection. Of all the wastes released by marine fish farms into the environment, particulate organic waste in the form of uneaten feed and faeces are usually the most significant fraction.

This generally settles on the seabed near to the cages, provides a net input of organic carbon and nitrogen to the sediments, thus, the accumulation of waste can cause major changes in the benthic community and may exceed the environment's capacity to bioprocess this material. Environmental deterioration due to high organic matter concentrations in the sediments may affect the health of farmed fishes and hence profitability. Therefore, floating cages should be located at sites where the water depth is sufficient to maximise water exchange and to keep cage bottoms well clear of substrate at low tide, and so, knowledge of the bathymetry is also an important factor [4-6].

GIS are powerful tools that can be used to organize and present spatial data in a way that allows effective environmental management planning, and hence answers these questions. GIS technology has been successfully applied in the analysis of the coastal zone to evaluate a number of environmental problems. GIS has several advantages for aquaculture development programmes, not only providing a visual inventory of the physical, biological and economical characteristics of the environment, but also allowing generation of suitability maps for different uses or activities without complex and time-consuming manipulations [7]. The general usefulness of the methodology of using GIS for aquaculture site selection has been explored and is now becoming established.

To ensure the sustainable development of Taiwan marine cage culture, it is essential to develop methods for site selection, that is, site selection method can be used to help marine cage culture development and to reduce risk for fish farmers. Marine cage culture in Penghu isolates over 90% located in the bay. Therefore, the site selection is crucial for the fish farmer and environment capacity [8]. Careful site selection can ensure minimum impact on sensitive areas, ecosystem. Indeed, there are several unfavourable factors hinder the development of marine cage culture in Taiwan, including potential environmental impacts, inappropriate laws and regulations, user conflicts, fish diseases and typhoons.

Materials and Methods

In selecting an appropriate site for aquaculture, it is essential to consider the criteria that define suitability and the factors that make up them. A factor is a variable that enhances, or detracts from, the suitability for a specific use under consideration. It is, therefore, measured on a continuous scale. A constraint, by contrast, serves to limit the region under consideration, disregarding localities such as navigation channels, fishing and anchoring grounds, and other specially protected areas, where, legally, the evaluated use cannot be allocated. The methodological scheme used comprised suitability criteria selection and their segregation in the significant factors embraced in them. Selected factors were weighted, and, on the other hand, cartography of the study area was produced, including a thematic map for each factor, with its levels scores according to the assigned weight. Methodical steps of site criteria and site selection as Figure 1. Therefore, we make use of this method for prioritizing the suitable criteria and then selecting the best site for marine aquaculture, based on prioritized criteria by questionnaire, AHP and GIS [9].

Study area and site characterization

The Penghu Islets, located in the middle of Taiwan Strait, are major fishing communities, and are known as the birthplace of cobia cage culture. Archipelagos have 276 km of rugged coastline, around 173.8 hectares of marine culture sites and a marine farm population of 1,416 people. The first marine cage culture operations were started in the Penghu Islands in the 1970s. This study was undertaken in the largest marine cage culture site, in the inner bay of Penghu (23°39′–23°45′N 119°18′–119°42′E) (Figure 2). The climate of Penghy archipelago is the subtropical zone therefore frequently affected by typhoons especially during summer season. Most of the cage culture are located in exposed sites or sea bay with poor shelter, The depth of the Chu-Wan culture area is average around 8–15 m and the salinity is about 28.0-32.4%. The average temperature is 25-27°C from spring to autumn, decreasing to 21-22°C in winter, with the lowest temperature below 16°C during the winter season. The Chu-Wan cove farm site was selected for this study because it produces more than 60% of marine net-cage aquaculture products in Taiwan.

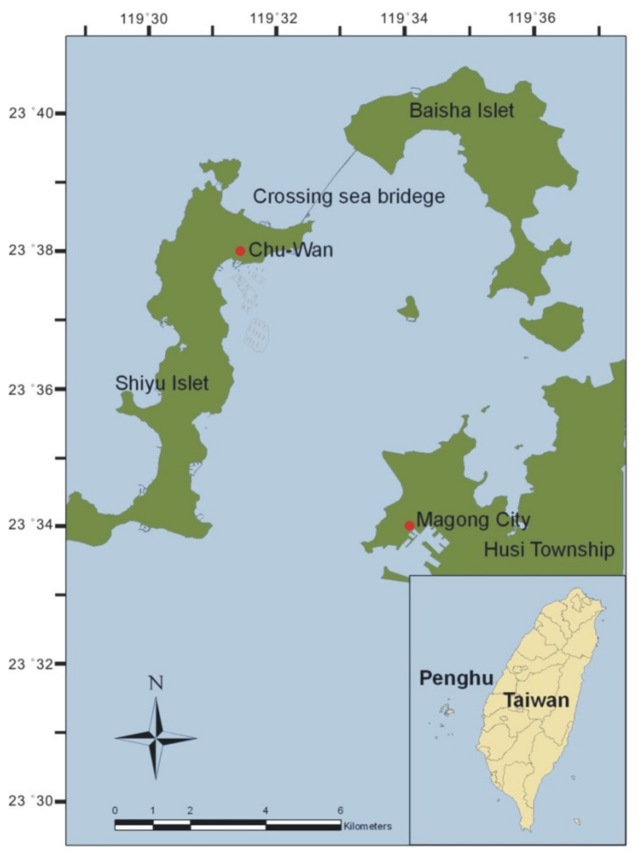

Figure 1: The study marine cage sites in the inner bay of Penghu.

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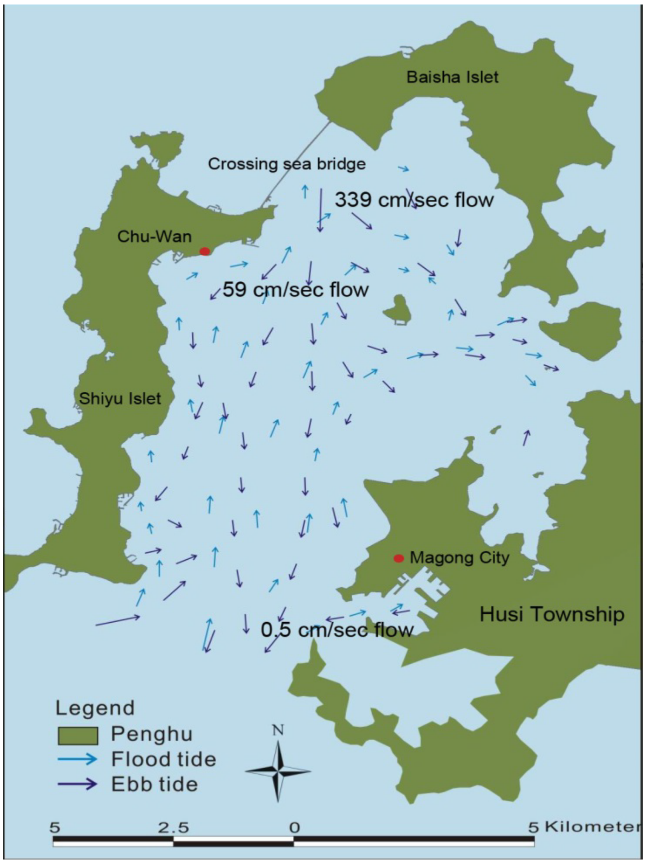

Figure 2: The current flow in the bay of Penghu.

The main culture species except cobia, there are red sea bream, great yellowtail, long dorsal fin pompano, orange spotted grouper, king grouper, three banded sweet lip grunt, pink snapper, spangled emperor, silver sea bream, mi-iuy croaker, black sea bream, etc., in Penghu Mari culture.

Owners of marine aquaculture farms in Chu-Wan can be classified as family-owned and company-owned farms. Family farms utilize traditional raft net cages which are built with Styrofoam to float cage in the water. Company farms employ HDPE which is Norwegian designed high density polyethylene, and traditional raft net cage.

Figure 3 displays the current flow. The Inner Islets have a current velocity in the range 15.4–339 cm/s. The highest current velocity is observed at the crossing-bridge which connects the Bei-Sha and Shi-Yu Islets. The lowest current velocity (0.5 cm/s) is observed at Ma-Gong Cove. Current flows from north to south. The tidal current can reach two thirds of the total length of the Inner Islets within 6 h. The turnover time of the water at Inner Islets is a week. These properties make the inner Islets attractive and suitable for net cage aquaculture [10].

Site selection criteria for aquaculture

In the present study, used ArcMap (Version 9.1, ESRI, USA, 2005), a GIS software package to evaluate suitable areas for marine aquaculture development in Penghu Islet, the western of Taiwan (Figure 2). In addition, the analytic hierarchy process (AHP) method was adapted as a decision support system through a multipate criteria analysis to evaluate objectively the important level (weight) of selected GIS grid themes.

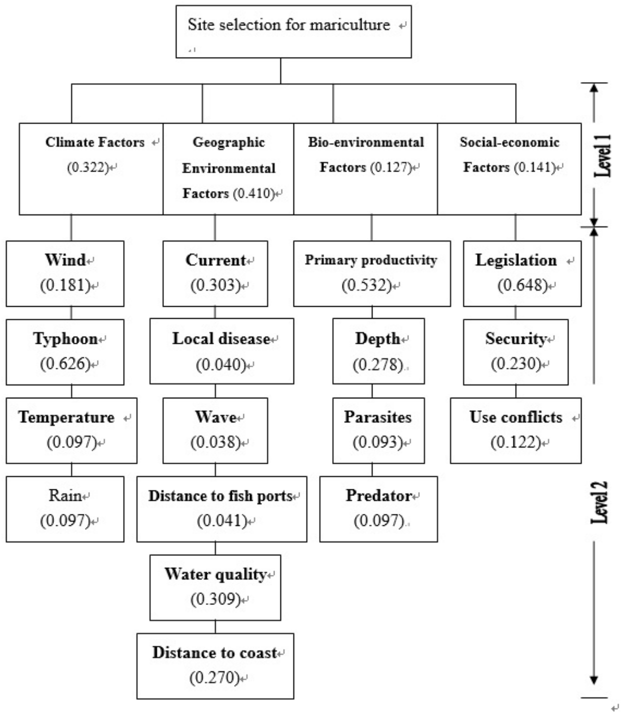

Figure 3: The magnified site selection criteria hierarchy chart and its weights obtained by the analytic hierarchy process (AHP) method.

Site selection criteria for marine aquaculture

The site selection for mariculture should take account for the following criteria:

(1) Topography: A flat and wide sea-floor.

(2) Water depth

(3) Bottom type

(4) Water quality: the basic requirement for marine aquaculture.

(5) Water quality should always be established before site selection.

(6) Ocean and tidal currents

(7) Distance to fishing ports

(8) Distance to the coast

The ideal site for semi closed system is determined by how the animals are to be grown. Every culture fish species require different types of sites. For example, a site for salmon cages must have unpolluted water at least 10m deep, a water temperature of 0-18′, current between 10-100 cm/s and protection from severe weather. For the site evaluation, data including water depth, bottom type, topography, distance to coast and distance to fishing ports, were first gathered and then digitized into GIS grid themes. In 1986, Wayne typhoon through Penghu reaching maximum sustained winds with 17 scale and 68 m/s wind speed caused 90% marine cage destroyed and damage [11]. At the meanwhile, Wayne also broke the record since the weather station established in 2000.

Analytic hierarchy process

The analytic hierarchy process (AHP) is a powerful and

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comprehensive methodology that provides groups and individuals with the ability to incorporate both qualitative and quantitative factors in the decision-making process. The AHP, developed, has been studied extensively and used in almost all the applications related with multiple criteria decision making in the last decades. There were many articles investigating the AHP combined with general applications. AHP was adopted in education, engineering, government, industry, management, manufacturing, personal, political, social and sports. The wide applicability is due to its simplicity, ease of use, and great flexibility. It can be integrated with other techniques, for instance, mathematical programming in order to consider not only both qualitative and quantitative factors, but also some real-world resource limitations. This approach, regarded as the integrated AHP, can definitely make a more realistic and promising decision than the stand-alone AHP. More focus, therefore, has been confined to the integrated AHPs recently. AHP used for agriculture, for tourism and environment. AHP falls into the broader category of pairwise comparison techniques in which attributes are ranked against each other to assess their relative importance. For instance, different weightings were assigned to factors important for pond aquaculture by different experts in continental-scale GIS studies [12-14].

Basically, the AHP process extracts a relative weight for each objective by computing an eigenvector for the objective. The eigenvector, which has the maximum eigenvalue, is computed from a square matrix that is populated with pair-wise comparisons of the relative importance of each objective to the overall goal. The estimated impacts of alternatives on every criterion, called criterion scores, are organized into a decision matrix M:

$$M=\begin{bmatrix} 1 & C_{12} & \dots & C_{1n} \\ C_{21} & 1 & \dots & C_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ C_{n1} & C_{n2} & \dots & 1 \end{bmatrix}$$

Where C_{JI} is the criterion score, J represent criteria, I=1 to n (numbers of criteria) represents alternatives. Moreover, the AHP also develops a consistency index (CI) to facilitate the decision-makers in evaluating the constituency among a pair of objectives.

$$CI=\lambda_{max} - n/(n-1)$$

If the CI is greater than 0.1, a re-evaluation of pair-wise assessment is desirable. Then, CI is divides by the random consistency index (RCI) to obtain the consistency ratio (CR) [12].

$$CR=CI/RCI$$

If the CR is smaller than 0.1, the pair-wise comparison results should be accepted. Finally, the eigenvector derived from the AHP method could be used as the weight of those criteria to be applied to a GIS system. Therefore, it is strictly required for AHP that decision-makers should be consistent in the pair-wise comparison process and judgment. ECP_{RO} software, AHP software designed by Expert Choice, Inc., has been used extensively by government and business organizations around the word. ECP_{RO} give the opportunity to change a given weight on the final result directly and take these changes back easily. In the present study, ECP_{RO} was applied to evaluate the criteria's weights of site selection for Mari culture [14-17].

Geographic information system application

A Geographic Information System (GIS) is one of commonly used tools for processing spatially referenced data and can be used to organize and present spatial data in a way that allows effective environmental management planning (Table 1). GIS also have developed rapidly in recent years and have begun to be used for aquaculture and fisheries development studies. GIS is considered potentially a powerful tool for assisting aquaculture decision-makers, and is already widely adopted for many applications, including aquaculture site selection [18]. Moreover, GIS technology has been successfully applied in the analysis of the coastal zone to assess several environmental problems.

Observations in coastal inlets used for finfish aquaculture have indicated that organic enrichment through enhanced sedimentation of particulate organic waste products from net-pen aquaculture is site-specific, spatially limited and highly dependent on physical factors such as water current speed, sediment composition and seasonal storm-related re-suspension. While physical variables are known to affect geotechnical and sedimentary properties, relationships between the rate of organic loading and resulting changes in sediment properties are not well known [19,20].

GIS can be applied to organize and present spatial data in a way that enables effective environmental management planning [11]. Many studies have addressed GIS applications for marine aquaculture on site selection or spatial decision support. For instance, GIS has been adopted in marine aquaculture planning, and in various marine applications including sediment dynamics and bathymetry changes, artificial reef site selection, and coastal hazards [21-24]. Hence, GIS mapping involves detailed information, which requires a good data set of environmental indicators to determine the impact distance and risk assessment guidelines.

This work presents a GIS application, based on ArcMap, for use in assessing the marine site selection.

The site suitable map

The criteria for site selection are climate factors, geographic environmental factors, bio-environmental factors, and social-economic factors [25,26].

Results and Discussion

Evaluation the weights of criteria by analytic hierarchy process method

The magnified criteria hierarchy chart for site selection of marine cage culture obtained by the AHP method and its weights are shown in Figure 3. The four main criteria were used in the first level pair-wise comparisons. To extract the eignvector, a decision was archived. The results of AHP analysis showed that geographic environmental factors were the most important criterion in selection sites for marine cage culture. Their weights accounted about 0.410 (total weight of first level=1). The other priority criteria were climate factors (0.322), social-economic factors (0.141) and bio-environmental factors (0.127). At the second level, the weights of sub criteria showed that water quality was the important factor and its weight is about 0.309 in geographic environmental factors sub criteria. About weather aspect, the typhoon factor archives the maximum weight, about 0.626, in the climate factors sub criteria. Furthermore, the primary productivity had larger weight. Bio-environmental primary productivity is important than local diseases archived the maximum weight of about 0.532 in these sub criteria. As regard to social-economic factors, the legislation is more critical than security and use conflicts in their sub criteria and weight is about 0.648 in the AHP analytic process [27-31]. However, their effects should still be account to derive the GIS suitable map of marine cage culture deployment.

Criterion	Optimum	Consideration	Weight
Climate factors			0.322
Wind			0.058
Typhoon			0.201
Temperature			0.031
Rain			0.031
Geographic environmental factors			0.410
Current	<1.5		0.124
Depth	>5 m		0.016
Wave			0.016
Distance to fish port			0.017
Water quality		Water quality should always be established before site selection.	0.127
Distance to coast			0.111
Bio-environmental factors			0.127
Primary productivity			0.068
Local disease			0.035
Parasites			0.012
Predator			0.012
Social-economic factors			0.141
Legislation			0.091
Security			0.032
Use conflicts			0.017

Table 1: Principle site selection criteria for marine cage culture deployment.

During the process of AHP analysis, the weight valuable of criteria could change due to the different criterion scores, which were usually altered subjectively by decision-makers when assigning the relative importance of alternatives on every criterion [32-34]. Therefore, assigning objectively the criteria scores would enhance the accuracy and reliability of AHP analysis [28]. Decision-makers using the AHP method must depend on the consistency index (CI) and the consistency ratio (CR) to evaluate the consistency among pairs of objectives. In the present study, both the first level's criteria and the second level's sub criteria in AHP analysis had consistency index and ratio less than 0.1, suggesting that the criteria's weights of pair-wise comparisons were acceptable [35].

Weight map of site selection criteria

A variety of weighting techniques exist fitness ratings for criteria have been established for different species and situations. Scaling and reclassifications, pairwise comparisons such as the Analytical Hierarchy Process and much other bias proof seeking techniques have been used [36,37].

A total of four grid themes (criteria), including climate factors, geographic environmental factors, bio-environmental factors, and social-economic factors, were adapted to evaluate the site for marine cage culture in Penghu island [38-40].

The weights of the different criteria or themes

The suitability map of a site for marine aquaculture has been objectively derived using the GIS software and AHP analysis. Another benefit of the GIS software and AHP method integration is that, when new or better data or information become available, the existing weights of criteria can be changed quickly to achieve a new suitability map. The database of the criteria can be easily expanded or updated. In this work, also found the useful of GIS depends on the complete fundamental data. However, data collection and digitizing the data collected into GIS themes were also the heaviest problems during the process of GIS system establishment [41].

Conclusion

This study combine the software, geographic information, nature resources data to select the suitable site with GIS and AHP methods to help the farmers and authorities to achieve the efficiency and immediately way to get the information, store, update, and analysis the marine cage culture related information. Furthermore, to support the fish farmers and authorities' agency to make the decision progressing for their suitable site plan. This approach can be a valuable tool in solving problems in a regional and continental forum. As more data become available, the usefulness and accuracy of this tool increases for optimum site selection.

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