REMOTE SENSING AND GIS APPROACHES TOWARD SUSTAINABLE MANAGEMENT OF MARINE AQUACULTURE IN INDONESIA

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ABSTRACT

The sustainable marine aquaculture (mariculture) has become increasingly important with the dramatic growth of the sector. To ensure long-term sustainability, planning is an important process that will stimulate and guide the evaluation of the sector. Many of the mariculture issues are entirely spatial in nature (e.g. siting, zoning), or have important spatial elements (potential mariculture areas, impact of mariculture, competition for space with other users). Satellite remote sensing integrated with geographic information systems (GIS) can play a major role in all geographic and spatial aspects of the development and management of mariculture. The potential capabilities of evolving GIS and remote sensing for the sustainability of mariculture provide a powerful tool for the efficient and cost effective management. These technologies are also useful for facilitating the decision making process in relation to mariculture. In this paper attempt to simply describe a number of ways in which GIS and remote sensing could be usefully employed as an aid to support sustainable mariculture development.

KEYWORDS: **mariculture, remote sensing, GIS, spatial planning, sustainable development**

INTRODUCTION

The sustainable aquaculture has become increasingly important with the dramatic growth of the sector. Global aquaculture output has increased significantly since 1985, and more than doubled in the last decade, reaching 52.5 million tonnes in 2008 (FAO Fisheries and Aquaculture Department, 2011). To ensure long-term sustainability, planning is an important process that will stimulate and guide the evaluation of the sector. The FAO code of conduct gives the direction for planning and management of aquaculture (FAO, 1995). FAO has produced practical framework mostly focusing on producing guidelines for policy-making, i.e. ecosystem approach to aquaculture (Soto *et al.*, 2008) and aquaculture planning: policy formulation and implementation for sustainable development (Brugère *et al.*, 2010). All efforts that make ecosystem approach more comprehensive and balanced in order to support sustainability of aquaculture.

Indonesia with 95,131 km coastline and 17,504 islands, has a potential for fisheries and aquaculture development. The potential needs to be managing in the proper way to ensure long term sustainability. To support the development of fisheries and aquaculture sectors, the Ministry of Marine Affairs and Fisheries (MMAF) of Indonesia has introduced some innovative programs such as minapolitan (Decree of the Minister of Marine Affairs and Fisheries No. KEP.39/MEN/2011) and industrialization of fisheries and aquaculture. These programs are essentially aimed at improving productivity and value added fisheries and aquaculture products, thus increasing competitiveness based on knowledge and technology. In implementing the programs, aquaculture is still play an importance role to enhance the production based on suitable potential areas. Minapolitan and industrialization programs should be implemented by taking into account the balance between economic

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growth and sustainability. Those balance is become current concern of MMAF through the blue economy program. Blue economy concept has five policy principles including integrated, cluster-based development, clean production system (zero waste), creative and innovative investment, and sustained (KKP, 2012).

The appropriate use of geographic information systems (GIS) and satellite remote sensing in close cooperation with sustainable aquaculture operation would be highly desirable. The potential capabilities of evolving GIS and remote sensing for the sustainability of aquaculture provide a powerful tool for the efficient and cost effective management. These technologies are also useful for facilitating the decision making process in relation to aquaculture. The main purpose of this paper is to simply describe the use of GIS and RS for improving the planning and management of mariculture in order to support sustainable development. The capabilities of evolving GIS and remote sensing provide a powerful tool for the efficient and cost effective management of sustainable marine aquaculture (mariculture). These technologies are also useful for facilitating the decision making process in relation to mariculture development.

MATERIAL AND METHODS

This paper was attempted to describe the capability of remote sensing and GIS; and its use, to date, in relation to problem solving for marine aquaculture. The ranges of different purposes are presented with some cases studies. The future use of remote sensing and GIS for the discipline is considered. Materials used in this paper were collected from various sources, including aquaculture statistic and some published publications. The paper was disscussed into folowing section: the importance and spasial aspect of mariculture, the used of remote sensing and GIS togather with selected case studies.

RESULTS AND DISCUSSION

The Importance of Mariculture

According MMAF (KKP, 2011), potential of mariculture area in Indonesia is very large, reaching 12.5 million ha, but the utilization of this area only 118 thousand ha (<1%). This shows that mariculture area is still available for further development, reaching 12.4 million ha. With the availability of those potential area, it needs strategic planning and management in a proper way to ensure sustainable and environmentally sound for development of mariculture in Indonesia.

Mariculture is an important component for aquaculture production in Indonesia (Figure 1). In addition as sources of aquatic food production, mariculture has great potential for alleviation of poverty and generation of wealth for the people living in coastal area. It has also contributed in reducing the pressure on marine natural resources. Many of the problems mariculture has faced as a result of its

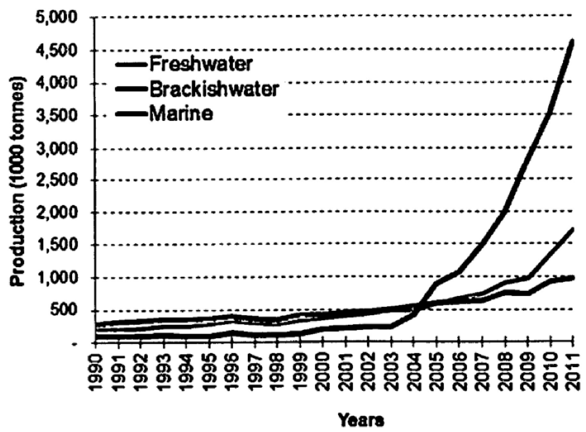

Figure 1. Production of aquaculture by different ecosystem in Indonesia from 1990-2011 (FAO, 2013)

own expansion and also because of increased activity by other sectors and stakeholders. This could effectively be resolved through a comprehensive mariculture planning, zoning and management information system that would facilitate the formulation of strategies and planning for mariculture development and sustain existing mariculture systems. Recently, mariculture development in Indonesia has been accelerated with MMAF national development plan, with emphazising on increasing mariculture production for export and domestic consumption as well as improving the income of coastal communities.

Mariculture comodity cultured in Indonesia are varied. It includes, finfish (seabass, groupers, and snappers), shellfishes, seaweeds, and others (sea cucumber). The cultured commodities are mainly based on high economically values (good price and widely accepted market). Seaweedis an important aquaculture commodity in Indonesia, recently, seaweeds is the main production mariculture in Indonesia followed by shellfishes and finfishes (seabass, groupers, and snappers). In 2010, seaweeds production accounted for 3.9 million tonnes (KKP, 2011). This production is expected to be increase through the MMAF nasional program such as identification of suitable sites for seaweeds cultivation (minapolitan).

Spatial Aspect of Mariculture

Considered by environment, aquaculture activity occupied three main ecosystems namely freshwater, brackish water, and mariculture (Figure 1). Nearly all of mariculture is located in sheltered areas in close proximity to the coastline. Therefore, it follows that coastal marine ecosystems, including bays, and the outer portions of estuaries, are much more influenced environmentally by mariculture than is the open ocean (Ross *et al.*, 2013).

Much of the information and data on mariculture have been collected, such as environmental, water quality, and socio economic; however, there are view studies which introduce a spatial element. Many of the mariculture issues are entirely spatial in nature (e.g. siting, zoning), or have important spatial elements (potential mariculture areas, impact of mariculture, competition for space with other users). To make the development sustainable, it is necessary to develop an analytical framework that can incorporate spatial (and temporal) dimensions of parameters that effect sustainability. Geographic information system (GIS) and remote sensing (RS) have an important role in all geographic and spatial aspects of the development and management of mariculture.

According to ecosystem approach to aquaculture (EAA), spatial scale for mariculture development could be classified into seven spatial scales: local, state or province, region within a country, national, region among countries, continental, and global (Anguilar-Manjarrez *et al.*, 2010). The local scale would correspond approximately to the farm and water body/watershed scale of the EAA. While the global scale that covers larger areas. The EAA scales are easily accommodated by GIS, remote sensing and mapping as applied to mariculture, this being because GIS is capable of being applied at any scale. Practically, many spatial applications in mariculture deal primarily with a natural or an artificial water body in its entirety or in part.

Remote Sensing and GIS in Mariculture

Satellite remote sensing integrated with GIS can play a major role in all geographic and spatial aspects of the development and management of mariculture. Remote sensing has been used to provide a large range of observation data to support mariculture management, and also provides a unique capability for regular, repeated observations of the entire globe or specific regions at different spatial scales. Remote sensing has become an important source of data used in GIS analysis. By using this technology, it can reduce the amount of field sampling and increase the spatial and temporal coverage of estimation.According to Grant *et al.* (2009), satellite remote sensing have been used in two different ways: as survey tools prior to field observation and as input data for GIS analyses. The extent of GIS and RS applications in mariculture has rapidly increased. The applications in aquaculture (mariculture) include different targeting species (such as aquatic plants, fishes and shellfishes) with different main issues, include suitability of the site and zoning (Buitrago *et al.*, 2005; Radiarta *et al.*, 2008), environmental impact of aquaculture (Corner *et al.*, 2006), planning for aquaculture among other uses of land and water (Longdill *et al.*, 2008), inventory and monitoring of aquaculture and the environment (Carswell *et al.*, 2006), and fisheries and other competing uses (Arnold *et al.*, 2000).

In the implementation of the GIS study, Nath *et al.* (2000) described that ideally the process will consist of seven phases (Figure 2): (1) identifying project requirements, (2) formulating specifications, (3) developing the analytical framework, (4) locating data sources, (5) organizing and manipulating data for input, (6) analyzing data and verifying outcomes, and (7) evaluating outputs. In the GIS analysis, data may be represented as several different layers where each layer holds data about a particular kind of feature. Satellite remote sensing integrated with GIS could be used to resolve some of the aquaculture issues: development aquaculture (identification of suitable site, zoning), aquaculture practice and management (impact of aquaculture at different scale and aquaculture inventory), and multi-sectoral development that include aquaculture (management of aquaculture together with fisheries and planning of aquaculture among other uses of land and water).

Regarding spatial information system, the Fisheries and Aquaculture Management Division at FAO is actively promoting the use of spatial analytical tools and geo-referenced information (GISFish; http://www.fao.org/fishery/gisfish/index.jsp) for the analysis of fisheries and aquaculture data, and in the development of fisheries and aquaculture management. Moreover, an ocean color community is also promoting the use of remote sensing for fisheries and aquaculture management through SAFARI (Societal Applications in Fisheries and Aquaculture using Remotely-Sensed Imagery; http://www.geosafari.org/index.html).

A large number of earth observation satellites has orbited, and is orbiting our planet to

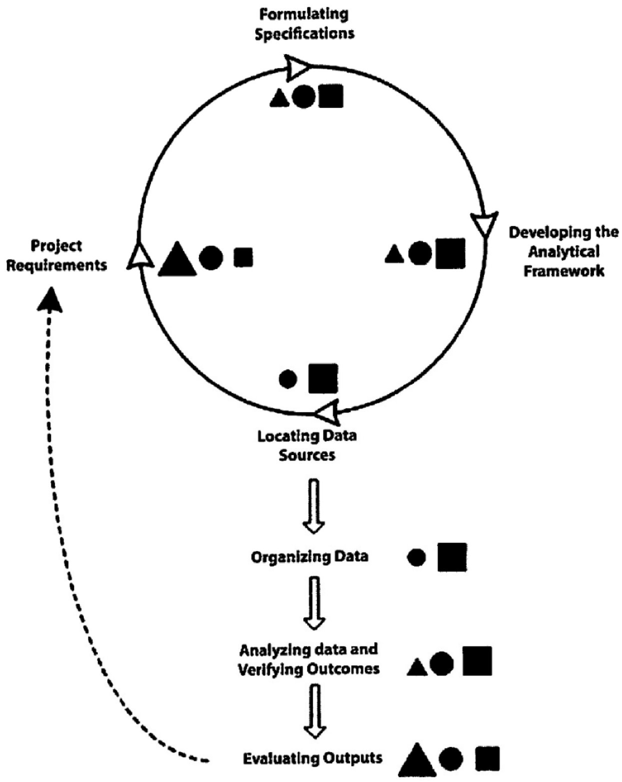

Figure 2. Schematic presentation of the phases in a GIS project. In practice, most of the iteration within the overall process is to be found within the first four phases. Involvement of end users (▲), subject matter specialists (●), and GIS analysts (■) within each of the phases is also indicated, with symbol sizes reflecting the importance of their respective roles (Nath *et al.*, 2000)

provide frequent imagery of its surface. From these satellites, many can potentially provide useful information for sustainable management of mariculture. The used of satellite data for mariculture depend on spatial scale and the purpose of the analysis. Typical satellite data used for mariculture study could be classified into three data scale: low resolution data (ocean color data: MODIS and NOAA), medium resolution (Landsat, ALOS, SPOT, IRS) and high/very high resolution (IKONOS, Quicbirds, and Worldview). Recently, some satellite data are available for downloading (i.e. Landsat). In Indonesia, LAPAN is the national agency that responsible for providing the satellite data from various sensors/ satellites.

Case Studies

Applications of GIS and remote sensing in aquaculture development, together with selected cases have been well documented (Kapetsky & Anguilar-Manjarrez, 2007; Mustafa *et al.*, 2011). In relation with EAA, the potential of spatial planning tools (GIS, remote sensing and mapping) have been reviewed (Anguilar-Manjarrez *et al.*, 2010). In this section selected case studies are presented from the perspective of their applications on sustainable management of mariculture.

Satellite remote sensing from different sensor coupled with decision support through GIS spatial analysis have been used by Radiarta *et al.* (2008) to analysed suitable site for scallop aquaculture in Funka Bay, Japan (Figure 3). Ocean color data of Sea Wifs and MODIS with 1 km resolution were used to extract some important water quality data (sea surface temperature, chlorophyll-*a* concentration, and turbidity). Those data were combined with logistical data (extracted from ALOS AVNIR), and made more quantitave by applying weighting scheme (multi-criteria evaluation). Results indicate that 80% of the bay area are suitable for scallop culture. This study provides more rigour in mariculture planning.

Work on seaweed site selection using GIS and remote sensing was carried out by Radiarta *et al.* (2012) in Bintan Regency Riau Island Province, Indonesia. In this study seven parameters were classified into two factors (water quality and socio-infrastructure) and constraints. Data were collected from the field measurement and remote sensing (ALOS AVNIR-2). They concluded that the application of GIS/remote sensing provides an effective methodology for identifying and quantifying areas of potential for seaweed aquaculture in order to support the development of seaweeds culture in the minapolitan areas of Bintan.

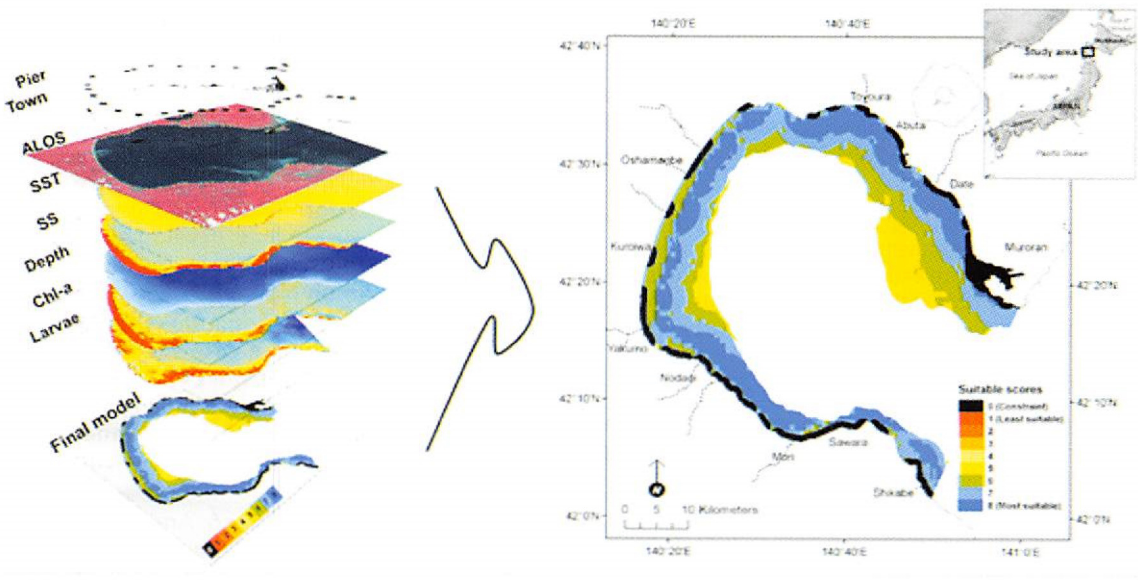

Figure 3. Data layers (left) used in GIS models for identifying suitable sites for Japanese scallop aquaculture potential in Funka Bay (right) (Radiarta *et al.*, 2008)

Combination of ICT (information and communication technology) and remote sensing data has been practicing in Pegametan Bay, Bali, Indonesia in order to monitor coastal environmental characteristic related with marine cage culture development (Wada *et al.*, 2013). Data on water quality (temperature and DO) were collected from real time buoy and logger (TidBid). Those data were overlaying with the occurrence of fish dead in the study area, in order to observe any relationship among them. To enhance the analysis, the authors also analyzed ocean color of MODIS sea surface temperature data. This combination application is veryuseful for monitoring of mariculture development.

Following the MMAF national plan for aquaculture development, remote sensing data could be useful also for mapping coastal ecosystem including mangrove, seagrass, coral reef, and intertidal area. Radiarta (2007) conducted a study on coastal sea bed habitat mapping and its implication for seaweed culture development in Mensanak, Lingga Regency Riau Islands Province, Indonesia. Data were used in this study comprise of satellite remote sensing of Landsat 7 data and field observation. In order to map sea bed habitat, Lyzenga algorithm was used. Based on ecological classification which was emphasis on dominance of type of each habitat and implication to seaweed culture, this study was able to classified sea bed habitat into four classes such as bare sand zone, substrate zone, seagrass zone, and life coral zone. From the total potential area for seaweed culture about 44 km^2, only about 8 km^2 (19%) is categorized into most suitable.

The case studies mentioned in this paper reveals the achievements possible by integrating GIS/remote sensing and information technology for coastal management with special emphasis on sustainable mariculture.

CONCLUSIONS

Increasing mariculture activity in Indonesia needs to be taking into account the planning and management of the sector in order to ensure sustainability of the development. Spatial planning has indicated play an important tool for enhancing planning and management of mariculture. From the simply describe of GIS/ remote sensing applications on mariculture, it can be conclude that:

- recent development of mariculture need to concern on its negative impact on the environment toward sustainable mariculture development.
- within the development of GIS and remote sensing can further enhance the development of generic framework that can be used by mariculture planner and policy maker to integrated mariculture based activities in a sustainable way.
- increasingly, remote sensing data are becoming available from a rich set of satellite sources that can be integrated into GIS to update and enhance the analyses.
- given information technology trends, that can be little doubt that future GIS tool will provide a range of functions embedded in various component that can be used for specific analyses.

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