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Full Length Research Paper

Site selection for grouper mariculture in Indonesia

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This research assesses a site selection approach for net-cage grouper mariculture off Kaledupa Island in Indonesia. Data collection focused on 15 biophysical site capability parameters, plus an additional 7 site suitability parameters assessed through interviews with villagers and local experts. Site capability analysis identified 4,511 ha capable of sustaining grouper mariculture within the 8,582 ha study area. Suitability analysis identified 2,667 suitable ha based on villager opinions and 4,083 suitable ha based on local expert opinions. Reliance on villager opinions and resolution of fragmentation issues reduced the final area deemed suitable to 2,423 ha.

Key words: Grouper, siting, mariculture, Kaledupa Island.

INTRODUCTION

Grouper has long been regarded as one of the most valuable market fishes in Southeast Asia where it is favoured by fish farmers because of strong market demand (Rimmer et al., 2004; Yamamoto, 2006). In large cities such as Hong Kong where groupers are traded as live fish, prices can range from $8/kg for gold spot grouper (*Ephinephelus coioides*) to $95 for mouse grouper (*Cromileptes altivelis*) or higher (Williams et al., 2006). Grouper farming is an interesting alternative to subsistence fishing in Indonesia because large marine areas could potentially support this form of mariculture. It is estimated that Indonesia has 812,000 ha of potential grouper mariculture sites of which only 8,000 ha are effectively used (Nurdjana, 2006). Given the significant potential of this form of mariculture and the need for sustainable development opportunities in many Indonesian coastal communities, planning tools are needed that can achieve both income generation and the protection of coastal resources (Pet-Suede, 2003, p. 138). Site suitability analysis is one such tool and this study investigates this approach in marine areas off Kaledupa Island in Wakatobi National Park which is one of Indonesia's largest marine conservation areas. The eastern coast of Kaledupa Island was selected as the study area is relatively protected from rough waves and strong currents by long fringing reefs. The study area also contains coastal villages where fishermen are in need of sustainable economic development opportunities that do not negatively affect fisheries or coral reef resources in the surrounding marine park.

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MATERIALS AND METHODS

Site selection is an important initial aspect of any coastal resource development activity and typically consists of two main elements: site capability and site suitability analyses. Approaches to site capability analysis are diverse and can be integrated with considerations of site suitability, but typically include all biophysical parameters and mitigating factors affecting a site's ability to support a proposed use (Cross and Kingzett, 1992). Biophysical characteristics such as water quality, water quantity, bathymetry, climate, predator and micro and macro fauna are commonly applied (Kapetsky and Manjarrez, 2007) and most capability classifications provide three classes: capable, moderately capable and not capable (Karthik et al., 2005; Perez et al., 2003; McLeod et al., 2002). However, examples exist that use more than three classes (Salam et al., 2005; Rajitha et al., 2007) or only two distinctive capability classifications (Nath et al., 2000). Site suitability is often used interchangeably with site capability (FAO, 1989) but it is important to differentiate between these terms. Site suitability focuses on extrinsic aspects of resource use such as potential conflicts, land use patterns, market conditions, infrastructure and technical support (Nath et al., 2000). These are in addition to the biophysical parameters that represent to focus of site capability analysis. Approaches that utilize geographic information systems (GIS) are common with a simple overlay process representing the most common technique. In this approach all areas deemed capable of supporting a proposed resource use are evaluated with suitability factors weighted equally within and across categories. Weighted overlay techniques can also be used and assume that each factor possesses a different degree of importance based on prior research or the subjective input of analysts or decision makers (Rajitha et al., 2007).

Data collection

Data collection within the Kaledupa Island study area was conducted during the month of August, 2007 with both biophysical and socioeconomic parameters collected during this period. The research area is relatively homogenous with respect to physical, chemical and geographic conditions as there are no large rivers or streams on Kaledupa Island. Biophysical measurements were taken between 10:00 AM and 2:00 PM at 31 sampling stations along the coastline of the study area where water depth ranged between 5 m and 100 m. This water depth is a strict requirement for net pen aquaculture and sites not meeting this requirement were excluded from sampling. The position of each station in areas possessing adequate water depth was selected using a grid superimposed on a base map of the study area. Sampling stations were centered within individual grid squares approximately, 1 km^2 in area and plotted using a field GARMIN GPS MAP Sounder 178. Nath et al. (2000) and others emphasize that biophysical parameters should be measured over time to obtain accurate data and reflect seasonal changes. Time and equipment restrictions limited this study to a single survey which was situated in the early rainy season and represents a worst case scenario with respect to environmental parameters such as sediment, salinity, nitrate, phosphate and pH due to high precipitation and sediment runoff (Caffrey et al., 2007; Interlandi and Crockett, 2003; Smith and Kreutzberger, 1987). Although time series data would be preferable, the selection of a single sampling period representing a worst case scenario can produce information that is useful in determining site capability. Cross and Kingzett (1992) support this approach where they state that “missing information will not affect a site capability evaluation if the variability of the environmental parameters is above the required standard to support mariculture operations”.

Biophysical parameters specific to grouper were based on studies by Kapetsky and Manjarrez (2007), Buitrago et al. (2005), Nath et al. (2000), Chou and Lee (1997), Ross et al. (1993), FAO (1989) and Caine et al. (1987). Grouper possess a range of biophysical preferences (water temperature, dissolved oxygen, salinity, ammonia-nitrogen concentration, nitrate concentration and turbidity) that have been documented by previous research (Table 1). Chou and Lee (1997) also suggest that water depth should be at least five meters so that floating net-cages possess at least three meters clearance from the bottom. A maximum water depth 50 m is recommended although 100 m is suggested by various researches. Wave height is suggested to be less than 1 m and tidal velocity is between 10 cm s^{-1} and 100 cm s^{-1} to avoid straining the net-cages and distorting cage shape (ibid).

With respect to socio-economic parameters, floating net-cage areas should be positioned away from local fishing grounds, shipping lanes, harbors, tourist sites and other existing coastal activities (Henderson and Davies, 2000; Papoutsoglou, 2000). The existence of conservation zones and unique habitats such as coral, seagrass, kelp and spawning ground for endangered marine species must also be considered (Walters, 2007; Vilalba, 2006; Kryvi, 1995). A rapid rural appraisal approach was used to conduct semi-structured interviews consisting of open-ended questions. Interviewees were asked about relevant socio-economic and the environmental conditions of the study area based on the approach adopted by Kapetsky and Manjarrez (2007), Perez et al. (2005) and Nath et al. (2000). Community members and local experts were asked to pinpoint physical features such as fishing or spawning grounds on a base map. A substantial amount of supplementary data was also gathered from local fishers on issues such as fishing patterns, target species, boat and gear types, price of fish marketed locally or exported and fishing seasons. Features identified by interviewees were cross-checked by field visits to insure the accuracy of this information. Three interviews were conducted in each of ten villages using a simple random sampling approach for a total of 30 surveys (25 men and 5 women). The youngest interviewee was 23 years old and the oldest was 71 years with an average of 40 years. Most interviewees worked as fishermen and seaweed farmers with only a small number employed as farmers and skilled labourers. Six experts from the Wakatobi National Park Authority and a local university were also interviewed based on their recent research into the environmental and socioeconomic condition in Wakatobi National Park or working knowledge of the study area.

Data analysis was performed using ArcGIS 9.1 on a 1999 Indonesian digital map to create the base map. Kriging interpolation which is a statistically-based estimator of spatial variables (Bolstad, 2005) was used to display the distribution of values for each parameter in the study area. The second component of Kriging interpolation was used because it can predict spatial correlations between two locations based on their distance and similar behavior. After the interpolation process, different layers generated from the capability and suitability variables were overlaid on the base map using Boolean operators used in the spatial selection of features (ibid). This approach produces only two categories in the classification, but creates a clear definition of suitability without any lack of clarity between these distinct categories (Nath et al., 2000). The use of GIS facilitates the manipulation of complex environmental data and is particularly valuable in marine site selection because it can show strong interactions among capability parameters in areas that are relatively homogenous and lacking obvious boundaries (Kapetsky and Manjarrez, 2007).

RESULTS AND DISCUSSION

Site capability analysis

Site capability analysis was performed using fifteen parameters identified in Table 1. The study area generally possesses a gravel-sand substrate that is well suited to grouper farming with bathymetry profiles dominated by a large number of lagoons with water depth ranging from 5 m to 53.9 m. Wave height is typically less than 1 m because of protection by islands and long barrier reefs, and surface water currents range from 3 - 56 cm/s with the average current speed of 26.38 cm/s. Water currents are acceptable, although slower than suggested optimal values in certain areas such as lagoons and near barrier reefs. Water temperature measurements were very uniform and within the optimal range for grouper ranging between 26.8 to 29°C. Water clarity was well above the minimum standards, but

Table 1. Capability and suitability parameters.

Parameters	Site capability Optimal capability	Method	Source
Bathymetry	>5 m - <100 m	Field survey	Chou and Lee (1997)
pH	7.0 - 8.5	Field survey	FAO (1989)
Temperature	26 - 31°C	Field survey	Chou and Lee (1997)
Dissolved Oxygen	>3 ppm	Field survey	Chou and Lee (1997)
Salinity	15 - 33 ppt	Field survey	Chou and Lee (1997)
Nitrate	< 4 mg/liter	Field survey and lab analysis	Chou and Lee (1997)
Phosphate	< 70 mg/liter	Field survey and lab analysis	Chou and Lee (1997)
Wave height	< 1 m	Field survey	Chou and Lee (1997)
Water current	>10 cm s^{-1} - <100 cm s^{-1}	Field survey	Chou and Lee (1997)
Sediment	Rock, sand or gravel	Field survey	Caine et al. (1987)
Water clarity	Secchi depth > 3 m	Field survey	Buitrago et al. (2005)
Red Tide	No red tide reported	Interviews and literature	Buitrago et al. (2005)
Parasites + Disease	No parasite reported	Interviews and literature	Buitrago et al. (2005)
Pollution	No pollution reported	Interviews and literature	Buitrago et al. (2005)
Tidal (Low tide)	> 2 m	Literature	Tookwinas (1989)
	Site suitability		
Parameters	**Optimal suitability**	**Method**	**Source**
Coastal activities	No overlap	Field survey and interviews	Kapetsky and Manjarrez (2007), Perez et al. (2005)
Transportation	No overlap	Field survey and interviews	Kapetsky and Manjarrez (2007), Perez et al. (2005)
Diving sites	Buffer	Field survey and interviews	Perez et al. (2005)
Fishing grounds	No overlap	Interviews	Perez et al. (2005)
Harbors	>500 m , < 8 km	Field survey and interviews	Perez et al. (2005)
Protected areas	>1000 m	Field survey and interviews	Kyrvi (1995)
Benthic species	No overlap	Field survey and interviews	Vilalba (2006)
Spawning ground	>1000 m	Interviews	Kyrvi (1995)

turbidity levels were sub - optimal because of unusually strong winds and currents during the sampling period. Previous research has identified relatively constant turbidity levels far below 10 nephelometric turbidity units (NTU) during both wet and dry seasons in the study area (BTNKW, 2003; COREMAP, 2001). Turbidity parameters were still included in the overall capability framework adopted by this study, but data from the single data collection period in August 2007 was excluded from the capability analysis since it does not appear to be representative of long-term conditions. Sampled pH values ranged from 6.49 - 7.68 with seven stations located in the southern part of the study area near traditional seaweed farms possessing values below suggested optimal values. Dissolved oxygen (DO) at all sampling stations was very good (ranging between 3.54 - 6.16 ppm) with an average level of 4.8 ppm. Nitrate concentrations in stations located away from the coastline are also optimal for grouper ranging from 1.6 mg/L - 3.9 mg/L. Three sampling stations near the coastline were above threshold concentrations and this could also be related to data collection during rainy season which can produce elevated nitrate concentration through nitrogen fixation. Phosphate levels were within the optimal range from 0.567 - 9. 353 mg/L. Red tide, parasites, fish diseases and pollution were not found in the study area based on interviews with villagers, local experts, fish farmers who have engaged in fish fattening in the area for a considerable period of time.

This biophysical capability data was analyzed and imported into the GIS with each parameter mapped in a single layer and interpolated to show distributions across the entire study area using Kriging interpolation. The interpolation process was then further assessed using a Boolean classification which produced a binary classification (Nath et al., 2000) with each layer possessing only two potential outcomes (capable or not capable). The final result of this stage was a composite capability map with a single thematic layer defining 4,511 ha of water area possessing the biophysical conditions to

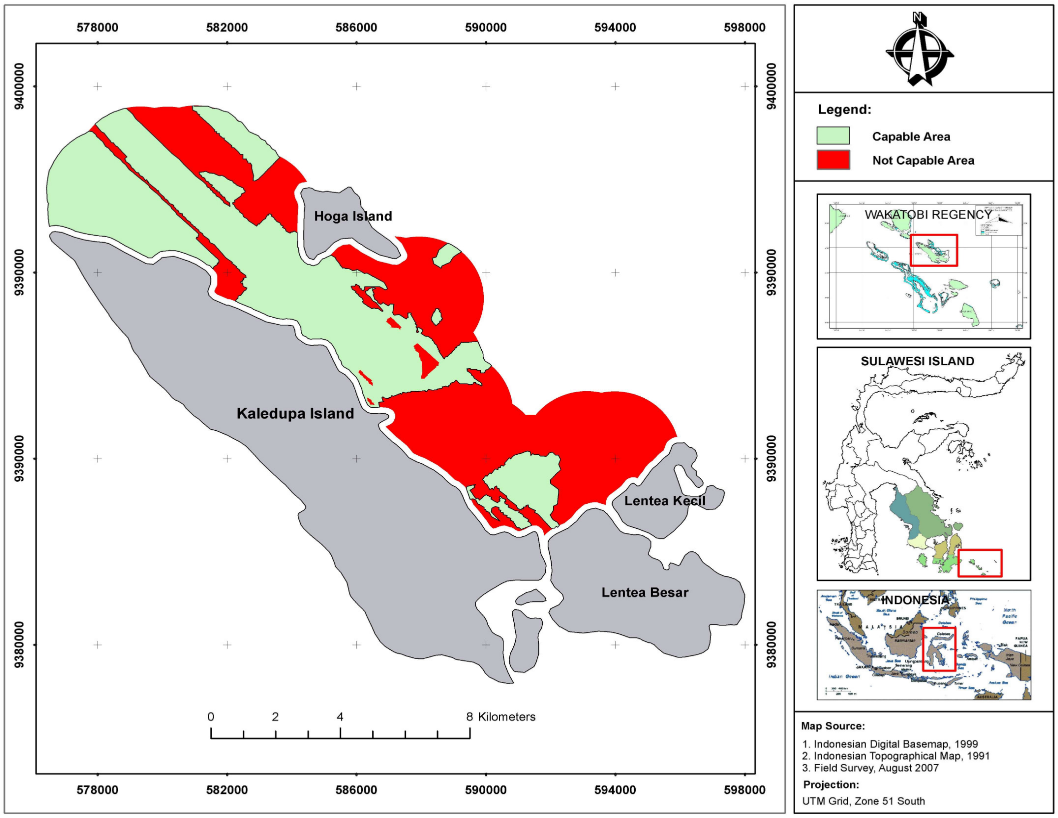

Figure 1. Capability map for grouper net-cage mariculture.

support grouper net-cage mariculture out of the entire 8,582 ha study area (Figure 1). A complex seabed profile was the primary reason for the discontinuous pattern displayed on this map, but shallow lagoons, sand bars and reef barriers also dominate the southern portion of the study area and reduce water flows to sub-optimal levels. Slow water currents cannot remove excess organic inputs (example, food and feces) and parameters such as oxygen or other physical or chemical water qualities can be affected by low or stagnant water flows. In contrast, northern portions of the study area possess fewer lagoons, sand bars or reef barriers that can affect water quality parameters and capability parameters are well within the recommended range for grouper production. A number of small isolated areas were excluded from subsequent suitability analysis to reduce fragmentation and concentrate farms into larger areas which facilitate future monitoring and impact assessment studies.

Site suitability analysis

Suitability analysis was performed using the eight parameters including: protected areas, fishing, spawning and seagrass areas, benthic species, transportations routes, harbors and dive sites and other coastal activities (Table 1). Both villagers and experts identified suitability parameters on a base map during interviews and the location of shipping lanes was crosschecked during field research and plotted with a handheld GPS. The resulting maps were then scanned and geo-referenced to fit the previously constructed digital base map. Locations of each suitability parameter were then digitized to determine spatial coordinates, import attribute information and produce eight separate suitability layers. Waters surrounding Hoga Island support some of the most significant coral and fish population in Wakatobi National Park and this area also provides spawning grounds for several grouper species and green turtle nesting habitat. Areas surrounding Hoga were, therefore, excluded from consideration as farm sites even though these areas are highly capable of supporting grouper production. Buffer analysis was performed on shipping lanes, protected areas, dive spots, tourist sites and harbor layers by applying a specific buffer distance to each parameter based on previous grouper suitability research (Kapetsky and Manjarrez, 2007; Perez et al., 2005). Seaweed farming and seagrass collection did not require buffer analysis because these activities only required that net-cages do not overlap existing locations. Results of the analysis were then overlaid to produce two separate site

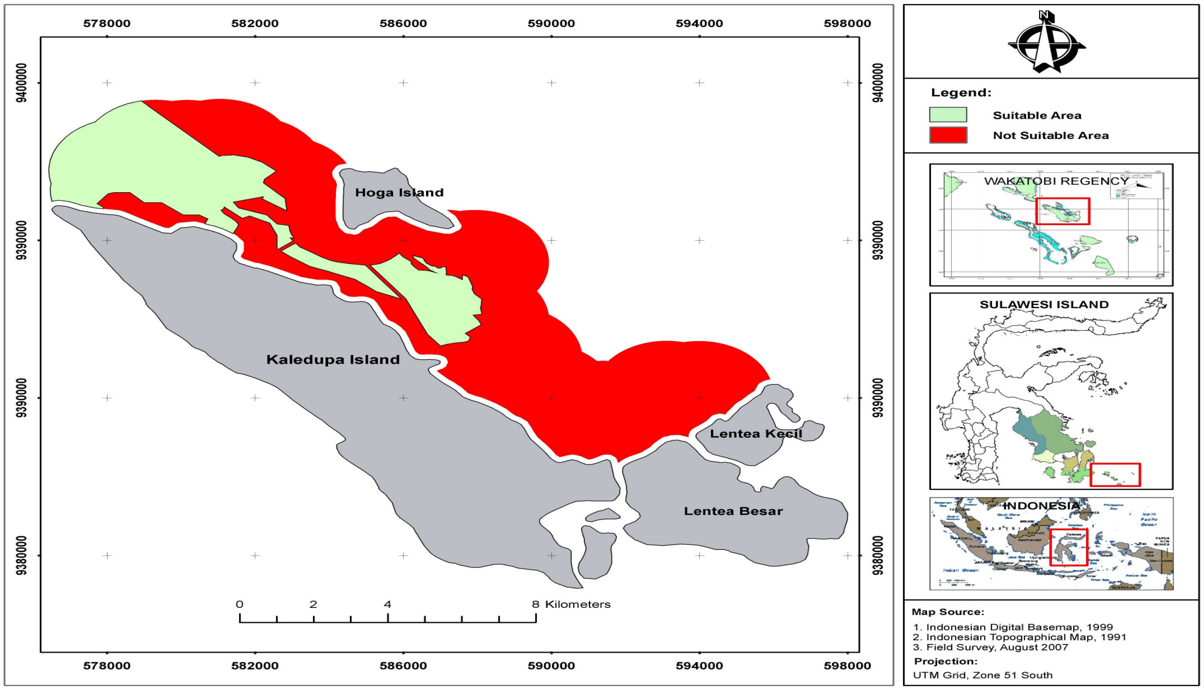

Figure 2. Suitability map for grouper net-cage mariculture.

suitability maps based on villager and expert knowledge of the study area. A villager's map identified a total of 2,667 ha as "suitable" for grouper farming from the 4,511 ha previously defined as "capable" of supporting this activity. Most of the suitable sites are located in the central and northern portions of the study area as villagers identified large areas containing seaweed farms and protected areas as unsuitable for grouper farming. Other parameters such as seagrass, dive spots and harbors excluded smaller areas and shipping lanes also contributed to a degree of fragmentation in the villager suitability map. Suitability analysis based on the expert interviews resulted in an area of 4,083 ha being classified as "suitable" for grouper farming from a total of 4,511 ha previously classified as "capable". This lack of distinction between capability and suitability by experts was surprising, but highlights their more limited knowledge of specific local resources such as seagrass and seaweed as compared to villagers who interact with these resources and activities on a daily basis.

On the basis of the capability analysis, field observations and detailed information provided both by local villagers and experts, a final suitability map was prepared using villager information as the primary input to the assessment of grouper mariculture suitability in the study area. Fragmentation was further reduced by removing several small isolated areas to concentrate mariculture operations and simplify future monitoring and evaluation of the mariculture activities. Several areas currently used for seaweed farming are also suitable for grouper and these areas could also be converted to grouper production if market prices for seaweed are low. This would require permission of the seaweed farmers but could potentially add an additional 705 ha to the overall area classified as suitable for grouper mariculture. After reducing fragmentation and adding areas capable of grouper production but currently allocated to seaweed farming, a final suitability map largely based on villager preferences identified approximately 2,423 ha of Kaledupa Island coastal waters as suitable for grouper net-cage mariculture (Figure 2).

Conclusion

GIS-assisted site suitability analysis represents a powerful tool for assessing the potential of grouper net-cage mariculture in areas such as Kaledupa Island and this study highlights several issues should be considered in future applications of this approach. First, single point data collection strategies conducted during sub-optimal periods such as the rainy season can be used to assess site capability, but these results should be confirmed by subsequent time series analysis to verify long-term environmental conditions or investigate a typical results produced by unusual weather conditions (such as the turbidity data obtained in this study). Second, data collection should be as extensive as possible so that the GIS interpolation analysis using kriging techniques can employed throughout the study area. Third, the use of both individual and group interviews may offer more detailed site suitability information because of the potential for group discussions and problem solving. Finally, information on local resources and resource use activities gleaned from expert groups such as government staff should be treated cautiously and supported by knowledge supplied by local residents who are often much more familiar with local conditions.

This study suggests that conservation areas such as Wakatobi National Park could potentially be used for both conservation and sustainable livelihood activities important to the local community if proper consideration is allocated to a wide range of biophysical and socio-economic factors. This important conservation area is under increasing pressure from illegal fishing and other unsustainable activities, but this stress could potentially be reduced by grouper farming that creates minimal impacts on the surrounding environment. It must be emphasized, however, that site capability and site suitability analysis is just the first step in developing sustainable forms of mariculture since this type of analysis only addresses questions related to the preferred location of facilities. It does not answer questions related to farm operations (examples, seed and feed sources) or address carrying capacity issues (example, appropriate number of farms located within areas deemed suitable for development or the number of fish contained within these farms). These questions require more detailed follow-up studies plus ongoing environmental monitoring and enforcement of environmental regulations to insure that negative impacts do not emerge as a result of mariculture development.

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