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Surveying shrimp aquaculture pond activity using multitemporal VHSR satellite images - case study from the Perancak estuary, Bali, Indonesia

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ABSTRACT

From the 1980's, Indonesian shrimp production has continuously increased through a large expansion of cultured areas and an intensification of the production. As consequences of diseases and environmental degradations linked to this development, there are currently 250,000 ha of abandoned ponds in Indonesia. To implement effective procedure to undertake appropriate aquaculture ecosystem assessment and monitoring, an integrated indicator based on four criteria using very high spatial optical satellite images, has been developed to discriminate active from abandoned ponds. These criteria were: presence of water, aerator, feeding bridge and vegetation. This indicator has then been applied to the Perancak estuary, a production area in decline, to highlight the abandonment dynamic between 2001 and 2015. Two risk factors that could contribute to explain dynamics of abandonment were identified: climate conditions and pond locations within the estuary, suggesting that a spatial approach should be integrated in planning processes to operationalize pond rehabilitation.

1. Introduction

From 1980's, Indonesian shrimp production has continuously increased through a large conversion of mangrove areas as well as an intensification of production (Ilman et al., 2016). Total national shrimp production raised from 24,000 t in 1980 to 585,000 t in 2014, representing an approximate increase rate of 65%·year^{-1} (FAO, 2016). Land use for brackish water tambak (pond) was estimated to 667,083 ha in 2014 (Ministry of Marine Affairs and Fisheries, 2015). At the same time, 613,194 farmers were working in shrimp industry, making shrimp the most important species in the fisheries sector with around a Free On Board value of 1,706,784.4 thousands USD (Ministry of Marine Affairs and Fisheries, 2015; Badan Pusat Statistik, 2016). Shrimp farming has become one of the primary sources of income for coastal communities. It supports rural economic development and contributes to national food security, employment and foreign exchange earnings. This sector has thus become strategic for economy of this country (Ministry of Marine Affairs and Fisheries, 2014).

Rapid growth in shrimp production, use of unsustainable production technologies and laxity in environmental regulation have generated negative ecological impacts on the environment as well as socio-economic issues on communities depending on coastal resources (Bhatta and Bhat, 1998). Impacts of shrimp farming include destruction of mangrove forests, salinization of coastal and agricultural lands, loss of genetic diversity in shrimp populations, conflicts over land rights and access to natural resources, and water pollution caused by discharge of pond waters (effluents) (Páez-Osuna, 2001). Effluents typically contain high concentrations of suspended particulate matter (mineral and organic), dissolved organic compounds, and nutrients (Briggs and Funge-Smith, 1994; Robertson and Phillips, 1995; Thomas et al., 2010). With emitted chemical and biological pollutants, which are redistributed among high-density farms through hydraulic vectors, problems of self-pollution and transmission of diseases were likely to occur in the ecosystem (Salama and Murray, 2011). Alteration of environmental suitability leads to stressful environmental conditions experienced by animals, which can increase disease incidence, and results in mass mortality and harvesting failure (Chanratchakool et al., 1995). Disease incidence that mostly hindered shrimp production in Indonesia was White Spot Disease

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(WSD). It was reported for the first time on Java island in 1994 and has become pandemic in Indonesia since then (Sunarto et al., 2004). As consequences of diseases and environmental degradations, there are currently 253,739 ha of abandoned shrimp ponds in Indonesia (37% of the total surface of tambak) including 39,862 ha in Java (19% of the total surface of tambak in this area), 100,461 ha (45%) in Sumatra, 5124 ha (3%) in Sulawesi, 102,377 ha (33%) in Kalimantan, and 5965 ha (40%) in Maluku, Lesser-Sunda (Ministry of Forestry, 2013), although an accurate estimation of the number of abandoned ponds is hard to obtain since land tenure records are often unreliable and out of date (Dahuri, 2012).

Indonesian government continues to encourage shrimp industry growth to ensure food security. For the Indonesian government, the target was to double shrimp production in the next decade from 0.3–0.4 t to 0.6–1,0 million tons by 2030, quoting that there were 0.9–1.2 million ha potential area for tambak development (Ministry of Marine Affairs and Fisheries, 2014; Ilman et al., 2016). To reach this goal, a strong development policy has been implemented by building farms in Sulawesi, Kalimantan and Papua, especially in mangrove areas. Rehabilitation of abandoned areas is the second implemented policy to reach this objective (Ilman et al., 2016). Three options are generally considered for pond restoration or rehabilitation (Bosire et al., 2008; Lewis et al., 2003; Lewis, 2005; Stevenson, 1997; Stevenson et al., 1999; Di Nitto et al., 2013): (1) rehabilitation of pond sites into sustainable shrimp production, (2) rehabilitation into alternative and sustainable rearing practices, and (3) restoration of environmental conditions within the pond and its surrounding area to rehabilitate the wetland ecosystem and its services (Duncan et al., 2016). However, rehabilitation of abandoned aquaculture area with the objective of maintaining an aquaculture activity was not considered at landscape or ecosystem scales, despite the fact that ponds are connected to each other and to open sea, and that rehabilitation of a pond should impact other ponds (Kautsky et al., 2000; Salama and Murray, 2011; Tendencia et al., 2011). In its code of conduct, FAO (1995) encouraged "to implement effective procedures to undertake appropriate environmental assessment and monitoring (...) and strategies and plans to ensure that aquaculture development is ecologically sustainable (....)".

Within this framework, developing tools to assess shrimp pond status (ecological, sanitary, environmental pressure) and its resilience over time (historical or future) is pivotal to support decision makers in the elaboration of long-term planning of activity. Geographic information systems (GIS) and remote sensing tools using very high spatial resolution (VHSR) images have been already implemented for accurate mapping of aquaculture facilities (Dwivedi and Kandrika, 2005; Virdis, 2014; Gusmawati et al., 2016) and for environmental surveys of aquaculture systems (e.g. Meaden and Aguilar-Manjarrez, 2013). This spatial data can include information on mangrove, shoreline, infrastructures, water, and soil condition. In the present work, we propose a methodology (Fig. 1) to develop an integrated indicator from GIS information and satellite images time series. This indicator should allow us to monitor changes in the activities of shrimp farms and should be able to discriminate active ponds from abandoned ponds. The indicator has been built from several combinations of criteria determined by cross-referencing field survey information and visually extracted information on satellite images at a given time period (2014–2015). A validation of this classification has been performed by applying a supervised classification method and an extractor of criteria association rules. Once the process is validated, we applied it to images from 2001 to 2015 to survey the dynamic of abandonment in a declining aquaculture area over this long period and to cross it with shrimp production and climate environment. Thus, we acknowledged the lesson learned from this site to steer all stakeholders towards a science-based approach to ensure long-term planning of activity and livelihood opportunities in an integrated coastal zone management (ICZM) framework.

2. Materials and methods

2.1. Study site

Perancak estuary system is located in the Jembrana Regency in southwestern Bali, Indonesia, near the city of Negara at 8°23′20″S and 114°37′20″E. Jembrana Regency is the second largest regency in Bali. The 2010 census noted rapidly growing urban population at approximately 273.3 thousand inhabitants. Perancak estuary covers approximately 7.5 km^2 (Fig. 2). The main river is divided into four branches (Tukad Sowan, Tukad Daya Timur, Tukad Ijo Gading and Tukad Daya Barat) composing this estuarine system with the main orientation from North (mountainous area) to South (Indian Ocean). The central catchment region is mainly occupied by aquaculture ponds and mangrove-forested areas. This study site is particularly interesting due to the diversity of farming practices and the dynamics of mangrove (natural and anthropic settlements). It includes active shrimp ponds using semi-intensive or intensive culture systems, abandoned shrimp ponds, fish ponds, polyculture ponds (algae/fish and shrimp), natural mangrove and mangrove plantations (Rahmania et al., 2015; Gusmawati et al., 2016). Furthermore, the study area is a typical example of land cover changes in coastal zones of Indonesia since the 80's. At that time, Perancak estuary was subject to aquaculture development and most of the mangrove forest was destroyed. Since the 90's, mangroves were reintroduced through plantations (Proisy et al., 2014, Proisy, this issue). Now, many shrimp ponds are abandoned but most of the pond dykes are kept operational by local government and owners. Perancak estuary thus experienced strong variability regarding land use and aquaculture effort. In order to support our comprehension of this aquaculture system in the Perancak area, shrimp production data within the Jembrana Regency over the 2000–2015 period was kindly provided by the Jembrana Regency government. Brackish water aquaculture production in Perancak estuary represents about 50% of the total production of Jembrana Regency (Pemkab Jembrana, 2013).

2.2. Data collection

2.2.1. Time series of satellite images

Fourteen VHSR images of Perancak estuary, acquired between 2001 and 2015, were purchased within the frame of the Indeso (Infrastructure Development of Space Oceanography) project. These optical images came from four different satellite sensors, namely IKONOS (images acquired on 12/10/01, 09/03/02, 21/02/03, and 27/06/03), Quickbird (22/09/07, 19/07/08, and 09/07/09), Worldview-2 (16/08/10, 15/04/11, 23/10/12, 10/12/13, 26/03/14, and 11/10/14) and Worldview-3 (16/04/15). Images covering the 2004–2006 period were not available. They were delivered in a GeoTIFF format. Pixel size varied from 50 cm to 1 m for panchromatic channel whereas the resolution of visible and infrared wavelengths ranged between 1.5 and 4 m. Image analyses were based on multi-channel images composed of multi-spectral channels pan-sharpened to the spatial resolution of the panchromatic channel using ArcGIS® software. Those images were registered in UTM projection (WGS 84 datum, UTM zone 50s) using 40 ground control points (GCPs) that were collected in 2014 during a GPS survey (Garmin® GPSMAP 62SC). The co-registrations of all images were refined using the Worldview-3 image of 16 April 2015 as the reference image for superposition. The images used in this study were in sun-backward angular configurations to avoid amplification of sun backscattering and high brightness on water, which may mislead the identification of objects in the shrimp ponds.

2.2.2. Field surveys

Field surveys were conducted in May 2014, November 2014 and June 2015. These surveys were dedicated to spatially reference aquaculture farming landscape: pond structures, aerators, bridges, status of ponds, mangrove extents, rivers, and human infrastructures. These

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