Remote Sensing and Field Assessment of Tsunami Effects on Coastal Pond Aquaculture in Northern Sumatra

S. P. Kam, S. C. Liew, Z. A. Muchlisin and P. Chen

Abstract

An attempt was made to conduct spatial assessment of the pattern and extent of damage to coastal aquaculture ponds along the east coast of Aceh province in Sumatra, Indonesia, resulting from the tsunami event of 26 December 2004. High-resolution satellite imagery, i.e., SPOT-5 multispectral scenes covering the 700 km stretch of the coast, acquired before and after the tsunami, were digitally enhanced and visually interpreted to delineate pockets of aquaculture ponds that were discerned to be damaged and relatively intact. Field checks were conducted at 87 sites in the four eastern coastal districts. The results indicate that SPOT-5 multispectral imagery was minimally sufficient to detect areas of damaged and relatively intact aquaculture ponds, but the 10-m spatial resolution poses limitations to evaluating the extent of pond damage. Nevertheless, the 60 km swath of the imagery makes it reasonably affordable for large-area assessment to identify pockets of severe damage for targeting more detailed assessments. The image maps produced from a mosaic of the SPOT-5 scenes can also serve as base maps for spatial planning in the challenging task of reconstruction and rehabilitation of the disrupted livelihoods of the coastal communities.

Introduction

In the wake of the tsunami that was triggered by a magnitude 9.0 earthquake off the northwest coast of Sumatra on 26 December 2004, there was a concerted global action to assess the damage in the affected countries for emergency response. Being closest to the epicenter of the earthquake, Aceh Province in Indonesia was the worst affected. The severe damage to property and infrastructure in the province capital Kota Bandar Aceh, the surrounding district of Aceh Besar and the western district of Aceh Jaya was evident from the collection of high-resolution satellite images that were posted on many internet sites as a humanitarian response by the remote sensing and geospatial community (ASM 2005; NOAA 2005). These images proved very useful for damage assessment at a time when access to the affected areas was difficult.

The impact of the tsunami spread beyond the severely damaged areas in the northwestern part and also affected the coastal communities in other districts to the east. Aquaculture constitutes an important contribution to food production and income generation for the coastal population in Aceh. Fish and shrimp farming are carried out in brackish water ponds (tambak), freshwater ponds, cages and rice fields. Official figures released by the Provincial Marine and Fisheries Department indicate that in 2003 an estimated 26 440 households were engaged in some form of aquaculture, and that brackish water pond aquaculture accounted for 63 per cent of production and 80 per cent of the value. There were an estimated 36 600 ha of brackish water ponds, mainly located in districts east of Aceh Besar (Fig. 1). The damage caused to aquaculture ponds and cages, fishing boats and landing sites disrupted the livelihoods of fish farmers and fishers.

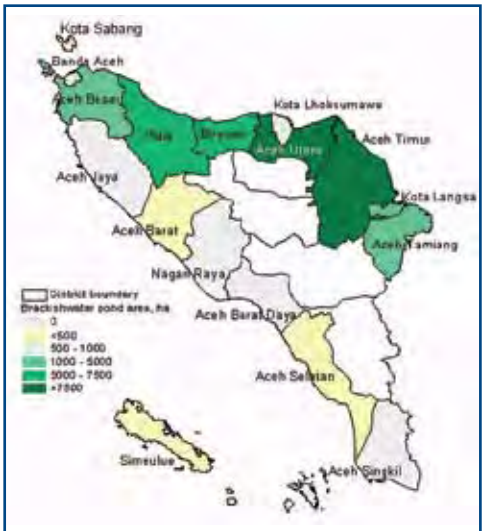

Figure 1. Brackish water aquaculture pond area in 2003, by district, for Aceh Province, Sumatra, Indonesia.

Source: Phillips and Budiman 2005

These affected communities need help to recover from their setbacks, but livelihood rehabilitation efforts need to be made judiciously and equitably within a proper planning context to avoid past mistakes that had resulted in unsustainable coastal aquaculture and fisheries development (Subasinghe and Phillips 2005; Stobutzki and Hall 2005).

Various international groups rallied to work in coordination with local agencies to carry out assessments on the extent of damage to the livelihood assets of the coastal communities as well as to the coastal natural resources that support their economic activities (FAO 2005; Wetlands International 2005). One of the key elements that was missing was good base maps for spatial assessment and for targeting initiatives for rehabilitating affected aquaculture activities. Field workers helping in the reconstruction effort also needed village level maps to carry out participatory planning with village communities. High resolution remote sensing imagery could provide these maps. The satellite imagery that was freely available through the internet was mainly focused on Kota Bandar Aceh, Aceh Besar and Aceh Jaya districts where the tsunami damage was most severe. The few coarse-resolution satellite images available covering the eastern coastal area, such as the wide-coverage Terra MODIS image (Fig. 2), did not permit identification of detailed features for damage assessment.

This paper reports on a collaborative effort of the Centre for Remote Imaging, Sensing and Processing (CRISP) of the National University of Singapore, the Universiti Syiah Kuala (UNSYIAH) in Kota Bandar Aceh and the WorldFish Center, to conduct remote sensing and field assessment of the effects of the tsunami on coastal pond aquaculture in the eastern coastal districts of Aceh province. The high-resolution satellite imagery obtained through the project can also serve as updated base maps for other general purposes of spatial planning for reconstruction and rehabilitating the disrupted livelihoods and economy in the coastal zone.

Materials and Methods

Two strategies were used to assess the impact of the tsunami on coastal aquaculture ponds. The first was to acquire sufficiently high resolution satellite imagery for mapping and determining the conditions of the ponds prior to and after the tsunami event. The second strategy was to supplement the satellite image interpretation with field checks and interviews with the local people in the affected areas.

Remote sensing assessment

Our initial investigations revealed that it minimally requires SPOT-5 multispectral images at 10-m resolution to be able to detect and assess the conditions of aquaculture ponds. Although more pond details can be seen with 1-m resolution IKONOS imagery, as evidenced by available IKONOS scenes of Kota Bandar Aceh, it would require too many IKONOS images (each having a narrow swath of about 10 km) to cover the entire 700 km coast of the study area. Therefore, four pre-tsunami and four post-tsunami SPOT-5 scenes acquired by CRISP were used in the study. The geographical coverage of these scenes is shown in Fig.2, and the dates of acquisition in Table 1. In addition, a 1-m resolution IKONOS image is also available and was used as a "training set" to aid interpretation of SPOT-5 image within the area of overlapping coverage.

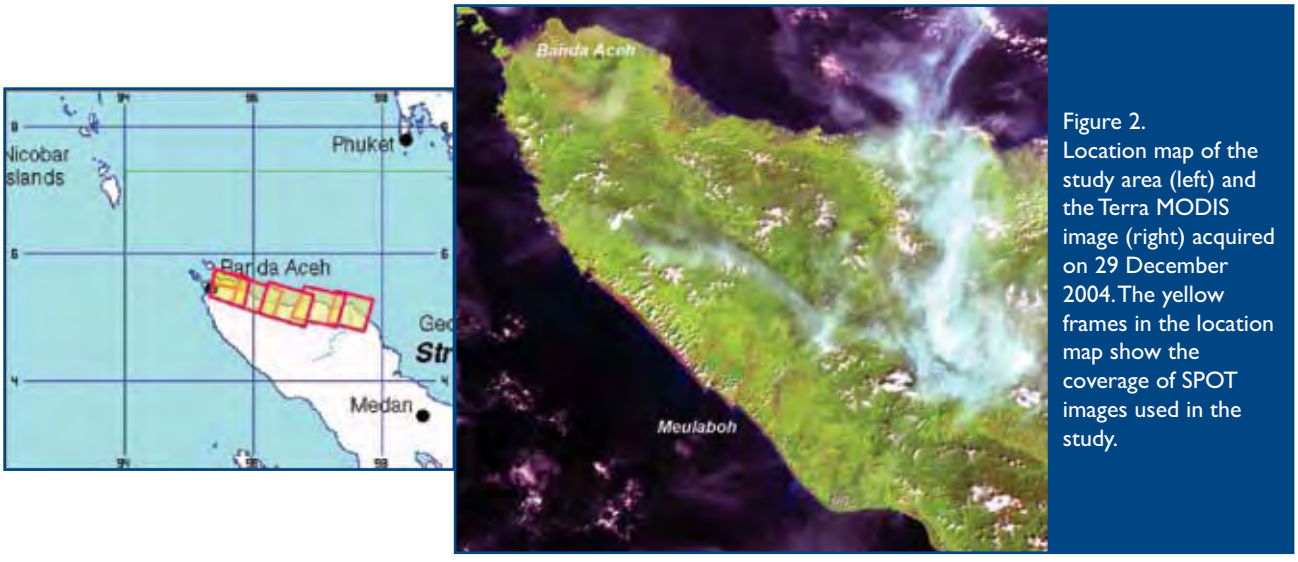

Figure 2.
Location map of the study area (left) and the Terra MODIS image (right) acquired on 29 December 2004. The yellow frames in the location map show the coverage of SPOT images used in the study.

Table 1. Satellite data used in the study.

	Data type	Acquisition date
Pre-tsunami	SPOT-5	2004-06-09
		2004-07-10
		2004-07-16
		2004-08-16
Post-tsunami	SPOT-5	2004-12-29
		2005-02-03
		2005-03-23
		2005-07-04
	IKONOS	2005-01-23

The coastal aquaculture ponds were delineated from the digitally-enhanced pre- and post-tsunami images by visual interpretation and manual, on-screen digitizing. The post-tsunami images were used to assess the conditions of the aquaculture ponds using visual clues such as damaged bunds, evident siltation and disruption to natural features (damaged coastline and disrupted river courses) in the vicinity of the ponds. As it would be tedious to delineate the individual ponds along the 700 km coastal stretch, clusters of ponds were delineated according to their general state and condition, either "intact" or "damaged", as discernible from the satellite image. In the area of coverage overlap of the SPOT-5 and the single IKONOS scene, the more detailed visual information from the latter was used to "calibrate" our interpretation of pond condition in the former. A third, "uncertain", class was assigned when it was difficult to tell from the image whether the ponds had been damaged. This work was done using the image processing facilities and technical expertise at CRISP, with WorldFish and UNSYIAH partners providing the contextual and local knowledge. The output of this exercise was a mosaic image map showing the locations of the aquaculture ponds overlaid with polygons delineating the various damage classes.

Field assessment

In addition to the remote sensing assessment, a field survey was conducted to: (1) ascertain the ground conditions corresponding to pond conditions and associated coastal features discerned from satellite image interpretation; and (2) determine other aspects of aquaculture pond rehabilitation that are not visually evident from satellite imagery.

A survey questionnaire was designed for field enumerators to make their observations, and to interview key informants on pond aquaculture operations in the general vicinity of selected sites on the extent to which these operations were disrupted by the tsunami. Questions included fish type cultured, scale of operation, sources of pond water and other pond inputs, accessibility, and livelihood dependence on aquaculture. The mapped output from the remote sensing assessment provided the basis for selecting field visit sites that represent the geographical spread of pond aquaculture areas and discerned damage condition. Another important factor considered is access to the sites, both physically and logistically as certain areas were politically unsafe to visit.

Owing to unavoidable circumstances, the field checking was delayed and was conducted in two periods. The first mission in mid-December 2005 covered Aceh Utara and Lhokseumawe districts, and the second mission in mid-January 2006 concentrated on the districts of Pidie and Bireun. The field surveys were conducted at 27 sites in 10 sub-districts of Pidie, 31 sites in 10 sub-districts of Bireun, 25 sites in 6 sub-districts of Aceh Utara, while 4 sites were visited in 2 sub-districts of Lhokseumawe.

Results and Discussion

Remote sensing assessment

Fig. 3 shows the level of spatial detail discernible from two SPOT-5 sub-scenes depicting the pre- and post-tsunami situation along the stretch of coast bordering Pidie and Biruen districts. Aquaculture ponds with intact dykes can be seen in the pre-tsunami image of 9 June 2004. The western part of the coast in this sub-scene is lined with long sand bars (annotated with 1, 2 and 3). In the post-tsunami (2 February 2005) image of the same area, the pond dykes appear less distinct, indicating damage, and the ponds appear to have fallen into disuse. Damage to other coastal features is also evident. For example, in the northwest corner of the pre-tsunami image, a small river can be seen flowing parallel to the coast, inside of the long sand bar, and discharging into the sea further eastward in the sub-scene. The post-tsunami image shows that the river discharge point has shifted more to the west (location 2) because the eastern bit of sand bar has been broken. This could have exacerbated the damage to the aquaculture ponds that were previously protected by the sand bar. The aquaculture ponds that are further inland and protected by the vegetated sandy ridges (red strips in the image) appear to be unaffected. The stretch of beach in the northwest part of the image (location 1) also appears relatively intact. Such information is also useful for assessing the impact of coastline changes on fisheries and other coastal activities that are important for rebuilding the livelihoods of the affected communities.

Fig. 4 shows a subset of the pond damage assessment map produced for the stretch of coastal area in the vicinity of Sigli town in Pidie. Delineated polygons of aquaculture

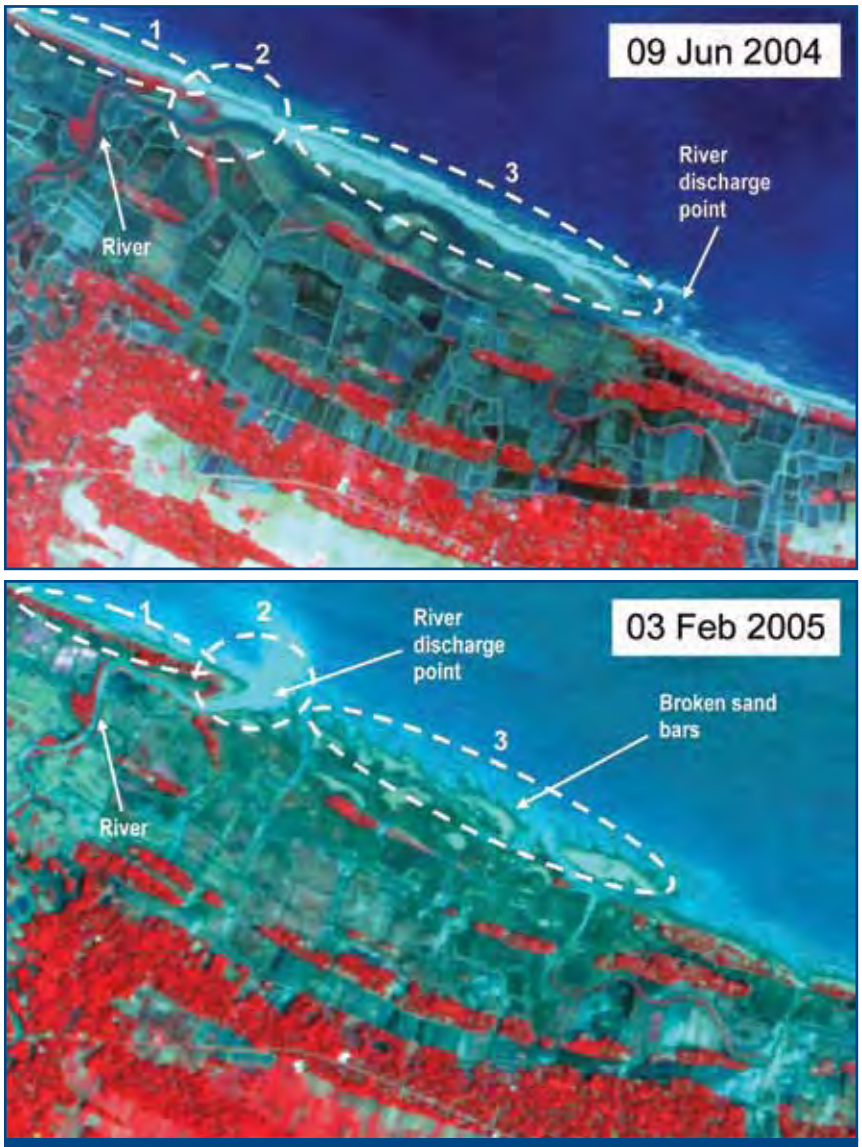

Figure 3. A pre-tsunami SPOT-5 image and a post-tsunami SPOT-5 image showing Kuala Ulim (mouth of Ulim river) in Pidie district of Aceh province.
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pond clusters, annotated with "intact", "damaged" and "uncertain" classes, are superimposed on the post-tsunami SPOT-5 image.

Also evident are other features of the coastal zone that would provide useful spatial information including the spatial pattern of human settlements and land use, coastal forests, infrastructure networks, providing sufficient detail to be directly used as a base map for various reconstruction planning purposes. Large-format prints were made of the image map, comprising the mosaic of post-tsunami SPOT-5 scenes covering the entire 700 km stretch of coast as backdrop, overlaid with the delineated polygons of aquaculture ponds and annotated with names of main towns and river mouths. The prints were brought back to Aceh for carrying out the field assessment and are available for other uses as well.

Field assessment

General pond aquaculture profile

Most (90 per cent) of the sites visited reported pond culture of both fish (mainly milk fish, tilapia and grouper) and shrimp. Almost all the sites visited (98 per cent) reported that the ponds are mainly farmer-operated, and that the operators are primarily dependent on aquaculture for their livelihoods. Most of the operators interviewed noted that they have secondary jobs such as animal husbandry, home trading and home industry. The pond operations are mainly extensive (68 per cent) and semi-intensive (26 per cent) in nature. Respondents mentioned various factors, including lack of capital, knowledge and skills as barriers to improving aquaculture productivity. Saline water is mainly sourced directly from the sea (69 per cent) or runoff from neighboring ponds; and 80 per cent of the sites reported that their pond water sources have been affected by the tsunami.

Tsunami impact

As the survey was conducted one year after the tsunami occurred, the field conditions have changed in some locations. Field observations of tsunami impact were supplemented with recall responses from the local people. Observations were made and questions asked about damage to the aquaculture ponds, water inlets and outlets, as well as surrounding coastal features such as river mouths, sand bars, and forested areas. A weighted combination of the ratings of these factors was computed as an overall impact rating, which was then categorized into one of three impact classes – low, moderate and high. As the field visit sites were geo-located using GPS receivers, the map interpretation of the aquaculture pond condition of each field visit site

Figure 4. Part of a post-tsunami SPOT-5 image near Sigli overlaid with polygons of damage classes. SPOT image © CNES 2005.

could be read off the image map that was produced.

In Table 2, the map interpretations of pond conditions for the 87 sites visited are cross-tabulated against (1) the overall impact ratings based on field assessment, and (2) the field ratings for pond dyke condition. Our map interpretation of damaged ponds is generally accurate. The extent of damage could not be easily ascertained using the 10-m resolution of the SPOT-5 imagery; about equal numbers of visited sites mapped as "damaged" were observed or reported to suffer partial and total damage, with medium and high tsunami impact. There was only one visited site where our map interpretation of intact ponds contradicted with field observations of total damage to pond dykes, while four sites that were mapped as intact were rated in the field as having experienced high tsunami impact. Rather, more of the sites mapped as "intact" were rated by field observations as partly damaged and moderately impacted than undamaged. Again, the 10-m resolution of SPOT-5 does not provide the spatial sharpness to discern if pond dykes in the post-tsunami image are really intact or may have been breached. It may be concluded that the map interpretation of "damaged" and "intact" reliably represents the two extremes of a continuum of general pond conditions as impacted by the tsunami.

Table 2. Cross-tabulation of map interpretation and field assessment of damage to aquaculture ponds.

a. Using overall impact rating of field assessment

		Map interpretation			
		Damaged	Intact	Unsure	Total
Field rating	High impact	17	4	1	22
	Medium impact	16	25	3	44
	Low impact	0	20	1	21
	Total	33	49	5	87

b. Using field rating of pond dyke condition only

		Map interpretation			
		Damaged	Intact	Unsure	Total
Field rating	Totally damaged	18	1	2	21
	Partly damaged	15	29	2	46
	Not damaged	0	19	1	20
	Total	33	49	5	87

Conclusions

With its 60 km swath and 10-m spatial resolution, SPOT-5 multispectral imagery is reasonably affordable and minimally sufficient for identifying pockets of tsunami damage to aquaculture ponds along the long coastal stretch of eastern Aceh province. However, the 10-m resolution poses limitations to evaluating the extent of pond damage. The overall assessment may be supplemented with more detailed assessments at the identified damage hot-spots, either by field evaluation or by using even higher-resolution imagery (such as IKONOS) where ground access is difficult. With minimal image processing – geo-rectification, digital image enhancement and mosaic – the satellite images can serve as base maps for assessing the ground situation and for planning reconstruction and livelihood rehabilitation strategies. Effective and prompt use of such remote sensing products in response to such natural disaster hinges upon collaborative efforts among the technology specialists, the sector experts and the local groups, in a situation where coordination of assessment and rehabilitation efforts among a diverse array of actors and response programs is a challenge (Abdulharis et al. 2006).

Acknowledgments

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