Application of Landsat 5 & High-resolution Optical Satellite Imagery to Investigate Urban Tsunami Damage in Thailand as a Function of Pre-tsunami Environmental Degradation

Beverley J. Adams[a], Colette Wabnitz[b], Shubharoop Ghosh[c], Jacqueline Alder[b],
Ratana Chuenpagdee[d], Stephanie E. Chang[e], Philip R. Berke[f] and William E. Rees[e]

Abstract

In the aftermath of the Indian ocean tsunami, the media indicated that the clearing of coastal mangrove ecosystems for tourism and aquaculture may have exacerbated infrastructure damage and human loss. This paper documents the use of moderate- and high-resolution remote sensing imagery to furnish a multi-disciplinary international project team with data to begin scientifically investigating this assertion for the coast of Thailand. Moderate resolution coverage was acquired spanning the northern part of the Andaman coast. High-resolution imagery in turn focused on selected study sites within the provinces of Ranong and Phang Nga. Of the multiple analyses that were conducted, this paper first documents the use of an historical sequence of Landsat 5 imagery spanning the past two decades to map changes in mangrove extent as an indicator for pre-tsunami environmental degradation. It goes on to describe the assessment of damage to coastal communities using high-resolution Quickbird and IKONOS imagery collected before and soon after the event. Following a description of the analytical methodologies employed, this paper further describes deployment of the VIEWS™ field data collection and visualization system for "ground-truthing" preliminary results. The paper presents provisional findings and concludes with a summary of future work.

1. Introduction

Following the catastrophic 2004 Indian Ocean tsunami, media reports suggested that the historic clearing of coastal mangrove ecosystems for tourism and aquaculture may have exacerbated infrastructure damage and human loss (Sharma, 2005; Dahdouh-Guebas et al., 2005; Badola and Hussain, 2005). From a scientific standpoint, previous studies suggest that tidal wetlands perform an important coastal protection function, by dissipating incoming tidal energy (Moeller et al., 1995; Shi et al., 2000; Harada & Imamura, 2003). Poor environmental management leading to ecosystem degradation or coastal squeeze may reduce, or even eliminate this protective capability.

The relationship between mangrove health and urban damage caused by the Indian Ocean tsunami is currently being investigated by an interdisciplinary National Science Foundation-funded team, comprising researchers from the US, Canada, the UK and Thailand. From a theoretical standpoint, the conceptualization in Figure 1 suggests how tsunami-driven risk or loss at a given location is a function of hazard and vulnerability. These dependent and independent components may be parameterized using a series of biophysical indicators (see Figure 1). Thus, the relationship is being investigated by studying "location pairs" for which all biophysical characteristics are similar, except for mangrove degradation.

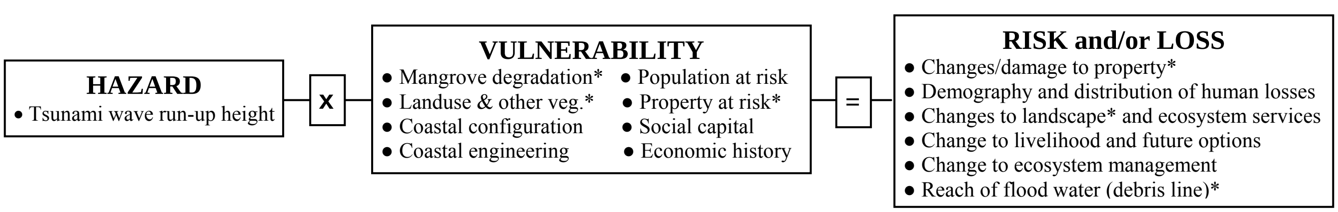

Figure 1. Conceptualization of the theoretical relationship between tsunami-driven risk and/or loss, hazard and vulnerability. * Denotes parameters characterized using remote sensing technology.

[a] ImageCat Inc., European Operations, 246 Barnett Wood Lane, Ashtead, Surrey, KT21 2BY, UK.
[b] Fisheries Centre, University of British Columbia, 2202 Main, Vancouver, BC V6T 1Z4, Canada
[c] ImageCat, Inc. 400 Oceangate, Suite 1050, Long Beach, California, 90802, USA.
[d] International Ocean Institute, Dalhousie University, 1226 LeMarchant St., Halifax, Nova Scotia, B3H 3P7, Canada
[e] School of Community and Regional Planning (SCARP), 242-1933 West Mall, University of British Columbia, Vancouver, BC V6T 1Z2, Canada
[f] Department of City and Regional Planning, UNC-CH, New East Building, Chapel Hill, NC 27599-3140, USA

Remote sensing technology is playing a pivotal role in evaluating this theory for the Andaman coast of Thailand, specifically seeking to characterize a subset of the indicators for vulnerability and risk and/or loss. The derived parameters were also used to inform the selection of focus study sites and location pairs, for conducting intensive field-based interviews and ground truthing. Table 1 identifies the remote sensing-derived parameters that have been computed, of which this paper will document:

i) Coastal landuse
ii) Historic mangrove change
iii) Urban damage assessment.

Section 2 of this paper introduces the methodologies used to characterize these three parameters. Details are given for the spatial extent of these respective analyses, ranging from the geographically extensive landuse and mangrove change assessment, to the site-specific study of urban damage. It also describes deployment of the VIEWS™ field data collection and visualization system for "ground truthing" these datasets. Preliminary results are presented in Section 3, while Section 4 identifies provisional findings and directions for future research.

Table 1. Remote sensing-derived vulnerability and risk/loss parameters employed for evaluating the relationship between mangrove degradation and urban tsunami damage, and for informing the selection of field study sites. * Denotes parameters documented in detail by this paper.

Parameter	Approach	Imagery	Source
i. Coastal landuse*	Map landuse using pre-tsunami imagery	Landsat 5	Landsat 5: GISTDA www.gistda.or.th Landsat 5: USGS ftp://edcftp.cr.usgs.gov /pub/data/disaster/ Quickbird: DigitalGlobe www.digitalglobe.com IKONOS: Space Imaging www.spaceimaging.com
ii. Historic mangrove change*	Map change between historic and pre-tsunami imagery	Landsat 5	
iii. Asses urban and ecosystem damage*	Identify visible building damage and changes between pre- & post-tsunami images	Quickbird, IKONOS	
iv. Mangrove quality	Quantify distance between shore and back of mangrove	Landsat 5	
v. Urban structure type	Characterize building structural type	Quickbird, IKONOS	
vi. Tsunami inundation zone	Map landward debris line	Landsat 5, Quickbird, IKONOS	

2. Methodology

2.1 Coastal landuse

The analysis of coastal landuse employed pre-tsunami 7-band Landsat 5 imagery, spanning the Thailand coast northward from Phuket Island. From Figure 2, this encompasses Landsat 5 scenes 130-53 and 130-54 dating from April 2004, which were provided to the project team courtesy of Thailand's Geo-informatics and Space Technology Development Agency (GISTDA www.gistda.or.th). A sequence of pre-processing steps was initially performed on the data. Using ENVI image processing software the datasets were first reformatted as a 7-band 'stacked' image. The image stacks were then registered to an historic MRSID Landsat TM composite (UTM, WGS84 zone 47N) obtained from the US Geological Survey (USGS https://zulu.ssc.nasa.gov/mrsid), which was employed as the reference baselayer throughout this study. For the registration, the "image to image GCP function" as used to identify a series of 20 tie points per scene (RMSE ~0.70) and a 1st order polynomial transformation applied with nearest neighbor re-sampling.

Coastal landuse was obtained using maximum likelihood supervised classification (class membership probability 0.8). A set of input training regions were manually selected within each image for visually distinct landuse classes of interest, including: (1) mangrove; (2) edge of mangrove/ mudflat (3) aquaculture; (4) urban/rural/sand/cleared land; (5) other vegetation; (6) water; (7) cloud; and (8) shadow. The output classification image was subjected to a 3x3 majority filter in order to remove rogue outliers falling within otherwise homogenous classified regions. The final result was saved in GIS format (Arcview *.bil) and imported to Arcview 3.2 for detailed visual inspection and integration with other layers. A quantitative accuracy assessment has yet to be performed for this classification result.

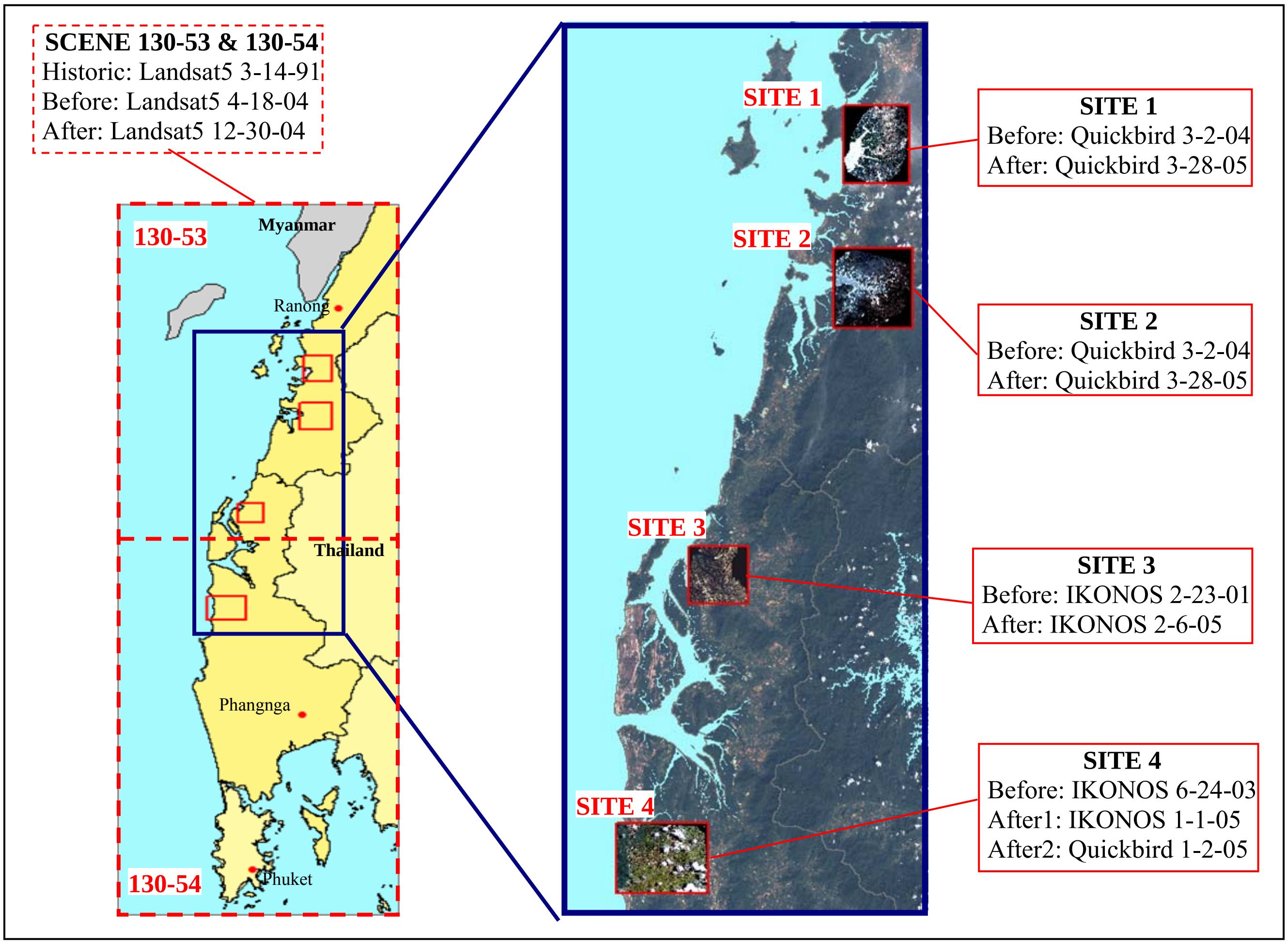

Figure 2. Thailand study sites, showing the and extent of historic, pre- and post-tsunami Landsat 5 coverage, and the location of high-resolution pre- and post-tsunami Quickbird and IKONOS imagery overlaid on a Landsat5 true color composite image (see also Table 1).

2.2 Historic mangrove change

For the analysis of mangrove degradation, the landuse classification methodology described in Section 2.1 was repeated for the historic Landsat 5 image for March 1991 (see Figure 2). Following classification, the mangrove and edge of mangrove classes were combined to yield a "master" mangrove class. The 'historic' and 'before' classification results were input to the ENVI change detection routine, outputting a "change" image and statistics for each permutation of class change. The changes of interest (mangrove to urban, mangrove to aquaculture, and 'other' classes to mangrove) were converted to a GIS-compatible format for visualization.

2.3 Urban damage assessment

A temporal sequence comprising high-resolution 'before' and 'after' satellite imagery was used to detect urban damage within four study sites. The study sites were selected based on the criteria in Figure 1, together with the availability of high-resolution remote sensing coverage. From Table 1 and Figure 2, the imagery comprised both Quickbird and IKONOS datasets, either purchased directly from the vendor, or obtained by the National Science Foundation courtesy of the Clearview license. In terms of timeliness, the 'after' data for site 4 was acquired just 1 week following the tsunami, and as such provides an extremely accurate record of damage prior to clean-up operations. The first available imagery for sites 1 through 3 is less timely, being collected 1-2 months afterwards.

Pre-processing was conducted to prepare the imagery for visually-based damage assessment; and field deployment within the VIEWS^{TM} field data collection and visualization system. Imagery for site 1 through site 3 was provided by in georeferenced true color pan-sharpened format. Following visual inspection, 2% color and/or Gaussian enhancements were used to maximize contrast within the scenes. However, Quickbird "after" images remained subject to a phenomenon called "flaring" over the water, caused by saturation of the sensor at the time of acquisition. For site 4, the IKONOS "before" and "after" scenes were provided as separate panchromatic and color bands. A pansharpened product was produced using an HSV algorithm. Due to significant spatial offsets, the pansharpened "after" scene was re-registered to the "before", using a series of 20 tie points (RMS ~3.5pi). For the Quickbird "after" scene, the data was delivered in non-registered NITF format, with separate panchromatic and color bands at respective resolutions of 0.81 and 2.46m, covering different geographic extents. The color bands were registered to the panchromatic image, subset to the same extent, and pansharpened. The resulting true color image was then registered and subset to correspond with the "before" IKONOS scene, which given the differences in pixel resolution (1m versus 81cm) necessitated "map to image" registration. Finally, the pre-processed high-resolution images were output in GIS- and VIEWS™–compatible formats.

In order to identify focus areas within the four study regions warranting in-depth analysis of building damage, a rapid visual inspection was conducted using the 'before' imagery. For these focus areas, a comprehensive pre-tsunami inventory of building stock was performed using the before imagery, with each building added to a GIS layer. The damage state of each structure was then determined by expert interpretation of the 'before' and 'after' coverages (Figure 3a). Finally, the percentage of collapsed structures was computed within a series of zones defined at 100m intervals from the pre-tsunami shoreline(s) experiencing greatest tsunami exposure (Figure 3b). Assessing the accuracy of this damage map using ground truth data collected using VIEWS™ (see Section 2.4) is a topic for future work.

(a) Building damage (b) Sample zones

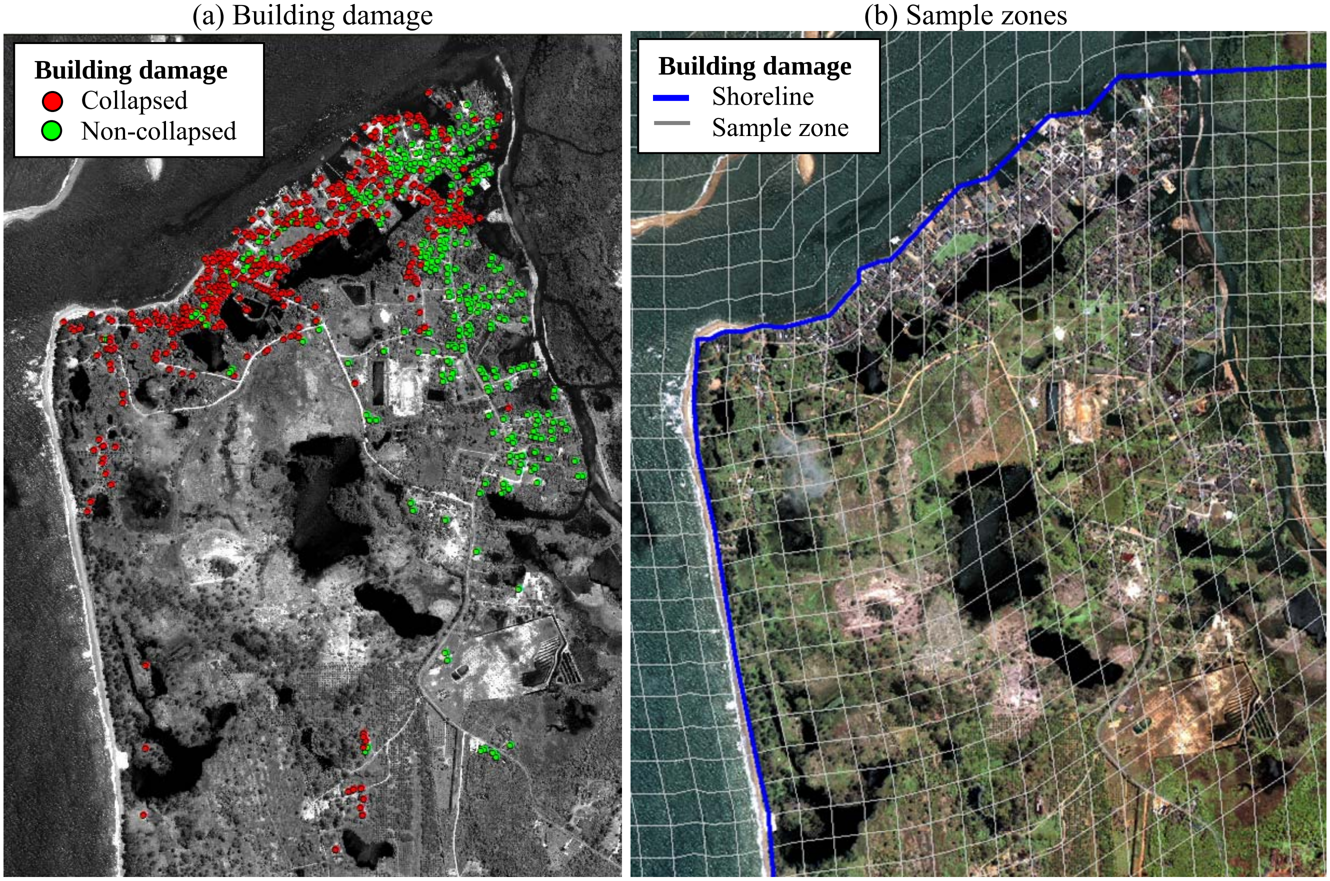

Figure 3. Building damage assessment methodology for the Ban Nam Khem region of site 4. (a) Damage state determined by expert interpretation for 760 structures; and (b) Sample zones for computing % collapsed structures at 100m intervals from the open coast and inlet shores that are subject to extreme tsunami exposure.

2.4 VIEWS™ Deployment

The VIEWS™ field data collection and visualization system (Adams et al., 2004, Ghosh et al., 2004) was deployed to study sites 1 through site 4 from August 16-25th 2005, in order to "ground truth" the preliminary remote sensing results. VIEWS™ was equipped with satellite base layers including the Landsat landuse classification (see Section 2.1), the mangrove change/loss map (Section 2.2), and the high-resolution satellite imagery (Section 2.3). The system was deployed by a 3-person team, from a moving vehicle, on foot, and for the first time by boat. Georeferenced video and photographs were collected, documenting ground characteristics of the major landuse classes, and urban building damage. Additional information concerning urban structural characteristics and flooding extent was collected, but falls beyond the scope of this paper.

3. Results

3.1 Coastal landuse

Figure 4 shows sample of the Landsat 5 landuse classification, focused on study site 3 (see Figure 1). Photographs captured using the VIEWS system are included to illustrate the key landuse classes. Preliminary results from spot field checks performed during the August 2005 deployment suggest that the landuse classification performed reasonably well for most classes, although the 'aquaculture class was subject to misclassification as 'water', and vice versa. Further evaluation of the results is reserved for future work.

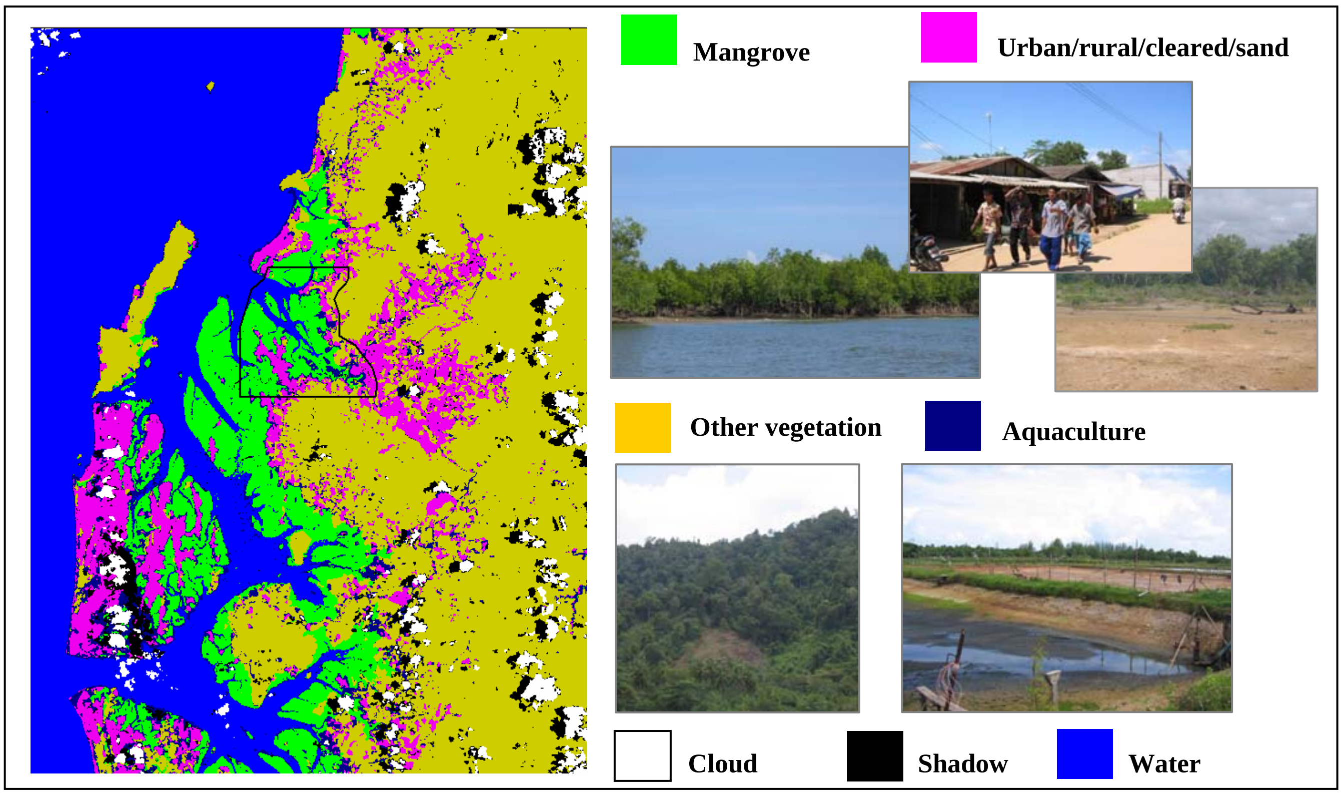

Figure 4. Sample of landuse classification results focused on the site 3 study area (black polygon). Illustrative photographs for the classes were collected during the August 2005 field deployment.

3.2 Historic Mangrove Change

Figure 5a shows the historic mangrove change map developed for the Andaman coast using a temporal sequence of historic and 'before' Landsat 5 coverage. The enlarged subset in Figure 5b shows in detail areas where mangrove has been converted to urban/cleared land or aquaculture. This map was used by the project team to help guide the selection of study sites for the field deployment. A visually-based comparison between areas thus identified as experiencing mangrove reclamation and changes independently derived from an historic series of paper topographic maps suggests that the remote sensing analysis performed favorably.

Figure 5b also shows areas where mangrove landuse has been restored between 1991 and 2004, a pattern which is evident within many of the low-energy coastal settings where mangroves form. Observations made by the field team confirm that in general, mangrove restoration is ongoing throughout the Andaman coast, and is attributable to the fact that: i) mangrove areas are often not considered as productive nor economically competitive with agriculture or aquaculture elsewhere, ii) heightened public awareness that mangrove values extend beyond the mangrove themselves and as a result of the latter iii) no renewal of concessions (mainly for tin and charcoal) for mangrove forests starting in the early 1990s, with all existing concessions expiring in 2003 and no new concessions issued thereafter (Fast & Menasveta 2003)

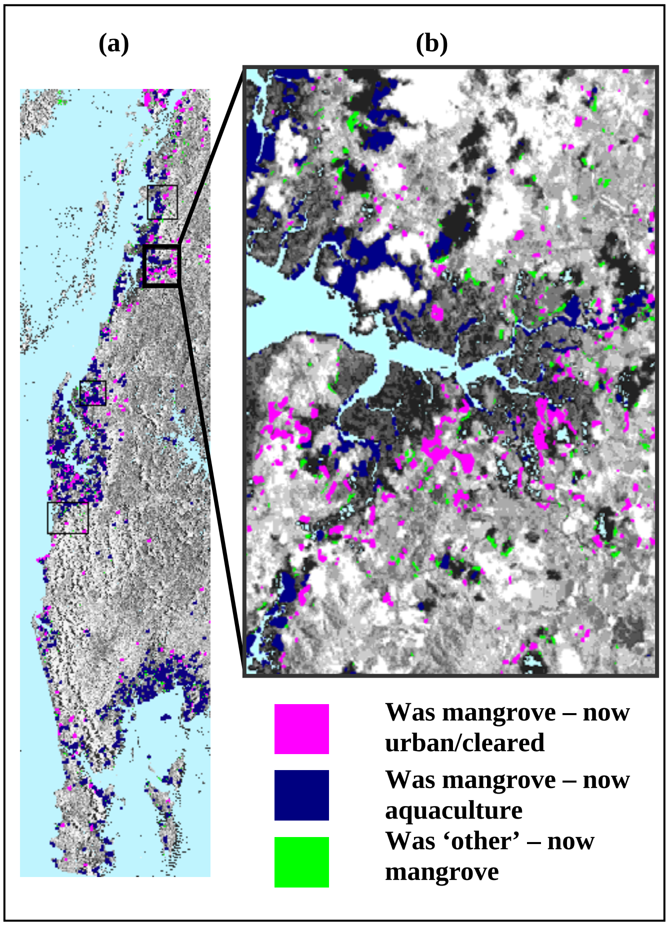

Figure 5. Historic mangrove clearance along the Andaman coast of Thailand, obtained from analysis of a temporal sequence of Landsat 5 images

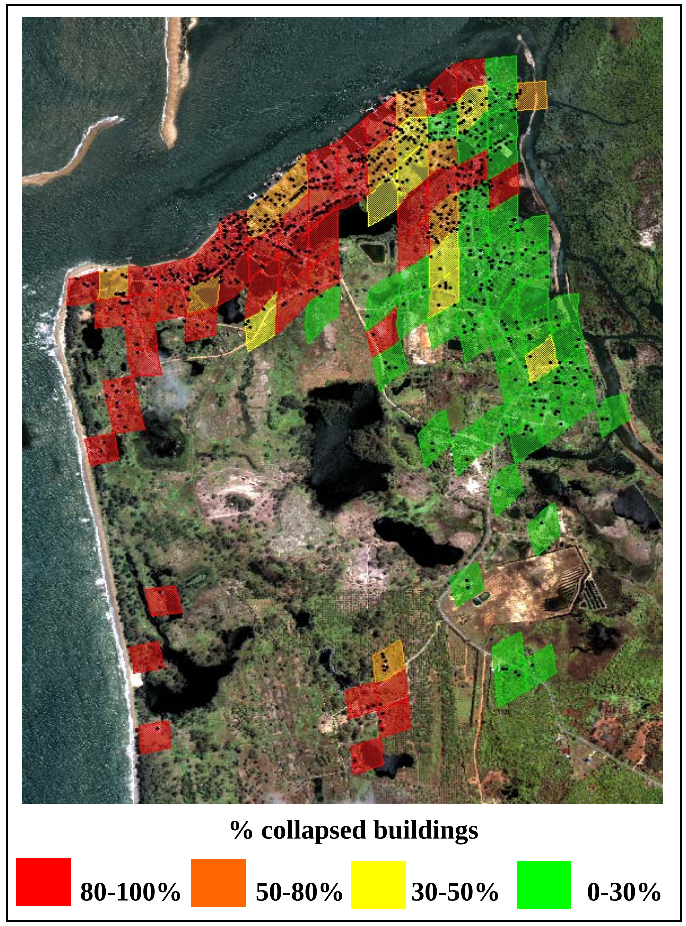

Figure 6. Damage map for Ban Nam Khem, developed using high-resolution Quickbird and IKONOS imagery for an urban area at site 4 (see also Figure 3).

3.3 Urban damage assessment

Figure 6 shows an example of the damage map developed for site 4 through expert interpretation of high-resolution pre- and post-tsunami imagery. The degree of damage is most extreme bordering the open coast and inlet, where between 50-100% of the houses were destroyed. The degree of damage captured by the remote sensing coverage rapidly diminishes moving inland, reaching 0-30% at a distance of approximately 500m from the these shorelines. Validation of these damage states through comparison with VIEWS™ footage is a topic for future work.

3.4 VIEWS™ Deployment

During the field deployment, 14 hours of georeferenced video and photographic VIEWS™ footage was collected, comprising approximately:

- 50 miles from a moving vehicle
- 20 miles from a boat
- 5 miles conducted as a walking tour.

At site 4, damage state characteristics were observed for between 500- 700 new and existing structures. The field team observed that recovery is proceeding apace, with widespread reconstruction occurring at the urban development within site 4 that sustained the most severe damage (see Figure 7). Inspection of the VIEWS footage will proceed over the forthcoming weeks. It will also serve as ground truthing data for the remote sensing analysis, and as a permanent source of reference information for other aspects of the project.

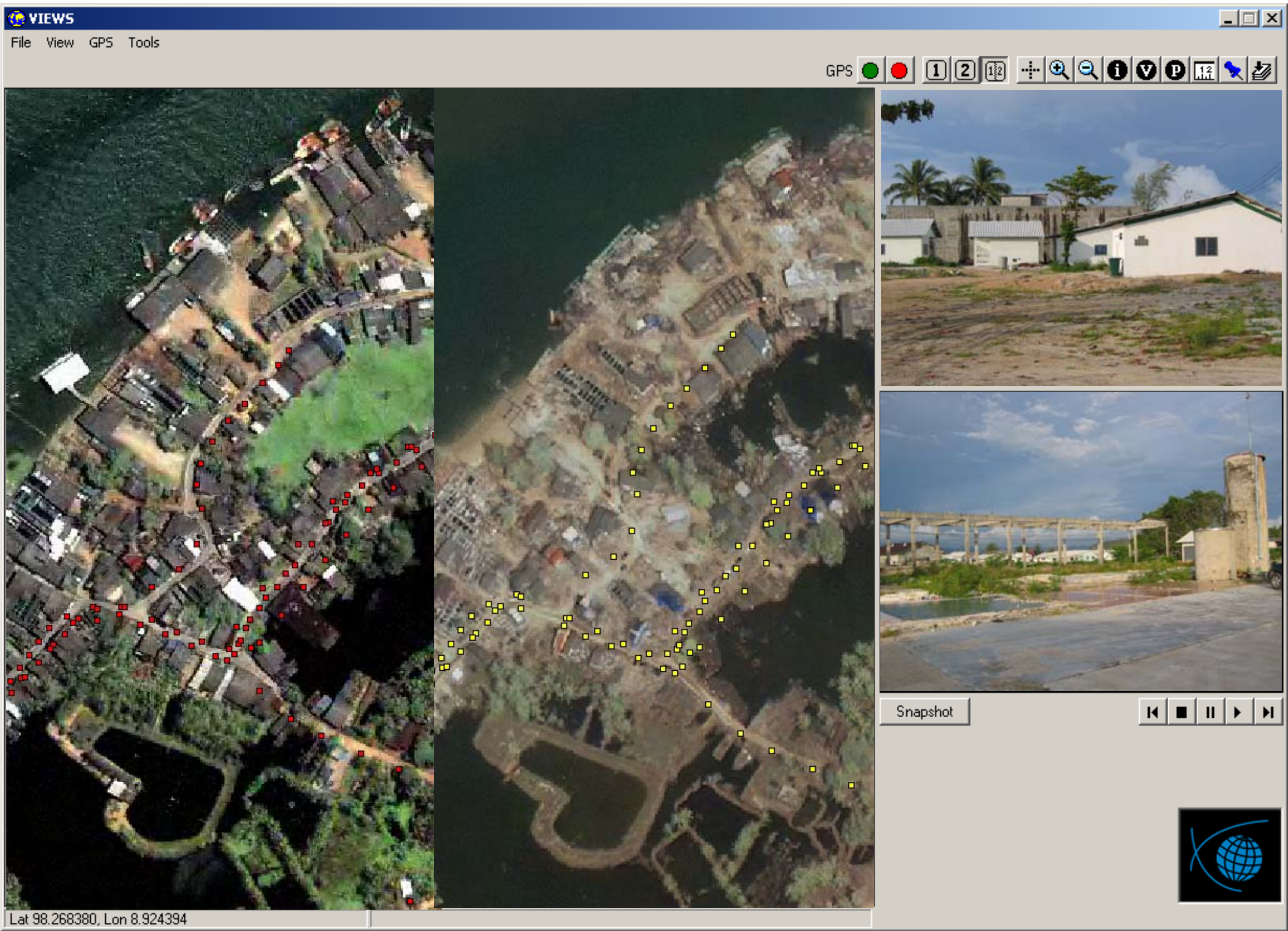

Figure 7 VIEWS™ interface showing 'before' and 'after' high-resolution imagery and part of the GPS route followed by the field team in Ban Nam Khem (site 4). The upper photograph shows an example of the rapid reconstruction that is occurring, and the lower digital video shows remaining building damage. After imagery courtesy of DigitalGlobe (www.digitalglobe.com)

4. Future Work

Future remote sensing work will focus on qualitative and quantitative validation of the analyses for landuse, mangrove change and urban damage, using ground truth data collected during the August 2005 field deployment. The VIEWS™ footage for study site 1 through site 4 will constitute the principal data source. Additional research funding will be sought to facilitate the development of additional findings from the remote sensing-derived parameters in Figure 1, such as a library of structural types for Thailand, and a methodology for surge line delineation.

Returning to the broad aim of this research project, work will also be conducted by team members to integrate the remote sensing results with other components of the study (e.g. social capital and community-based management of resources), to help understand the extent to which prior coastal ecosystem degradation - in the form of mangrove clearance – contributed to urban tsunami damage.

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Landsat 5 ‘historic’ and ‘before’ imagery was provided to the project team courtesy of GISTDA. High-resolution satellite imagery for site 4 was provided to the National Science Foundation courtesy of the Clearview license.