RESEARCH ARTICLE
doi: 10.2306/scienceasia1513-1874.2016.42.159

*ScienceAsia* 42 (2016): **159–170**

# Beach forest changes (2003–2013) in the tsunami-affected area of Phang Nga, Thailand from multi-temporal satellite data

**Pasu Kongapai, Penjai Sompongchaiyakul*, Somrudee Jitpraphai, F. Gerald Plumley**

Department of Marine Science, Faculty of Science, Chulalongkorn University, Bangkok 10330 Thailand

*Corresponding author, e-mail: spenjai.@hotmail.com, penjai.s@chula.ac.th

*Received 17 May 2015*
*Accepted 4 May 2016*

**ABSTRACT**: Beach forests are important ecological zones in many coastal regions. Many are under increasing anthropogenic and natural stress. Beach forest changes and their causes were examined in three tsunami-impacted sites with different land-use/cover (LULC): Ban Nam Khem (BNK, fishing village), Khao Lak (KL, tourist destination), and Thai Mueang (TM, part of a national park). Vegetation surveys, GIS, and interpretation of time series IKONOS and THEOS imagery using supervised classification (ENVI 4.7) from 2003–2013 were performed. Six beach forest tree and shrub species were found in BNK and KL, dominated by *Casuarina equisetifolia*, while 24 tree/shrub species, dominated by *Syzygium grande*, were observed at TM. After the tsunami, beach forests were severely damaged in BNK (45%), KL (40%), and TM (23%). Recovery of beach forests in 8 years varied from BNK (58%), KL (39%) with low rates in KL and high rates in TM (62%). Substantial portions of the three sites were still characterized as beach forest in 2013, though the forests now included areas that had recovered from the tsunami damage and/or altered LULC (e.g., barren land to beach forests and vice versa). Anthropogenic factors represented 40% (BNK), 56% (KL), and 5% (TM) of the changes with urbanization being a leading cause in tourist areas (KL; 24%). The study highlights the need for improved understanding of beach vegetation, tsunami impacts, and LULC to provide sustainable management of beach forests in Thailand in three sites with different anthropogenic characteristics.

**KEYWORDS**: IKONOS, THEOS, GIS, land-use/cover, anthropogenic activities

## INTRODUCTION

Beach forests are typically found above the high-tide mark in sandy soils. Vegetation species are adapted for growing in extreme conditions and are resilient to the effects of wind, rain, waves, and salt spray from the ocean[1]. This habitat experiences wide variations in temperature, salinity, and humidity which influence the composition of plant species[2]. Beach forests are typically classified by their dominant species: in the Indo-Pacific Region, the dominant tree species are *Barringtonia asiatica* (L.) Kurz, *Calophyllum inophyllum*, *Terminalia catappa*, *Pandanus tectorius* Parkinson ex Zucc, *Hibiscus tiliaceus*, and *Casuarina equisetifolia* J.R. & G. Forst.[3].

In Thailand, the dominant species of beach forests are influenced to a large extent by soil substrate characteristics; larger sand grains are present closer to the beach while smaller grains are found landward[4]. The plant communities vary by distance from the high water mark based largely on sand grain size. As a general rule, starting from the high water line, beach forest communities are dominated by creeping plants, such as *Vitex trifolia* var. *simplicifolia*, *Ipomoea pes-caprae* Sweet, *Spinifex littoralis* (Burm f.) Merr., and *Canavalia maritima* (Aubl.) Thouars. Further inland creeping plants are replaced by shrub species represented by *Scaevola taccada* (Gaertn.) Roxb., and *Tephrosia purpurea* (L.) Soland. ex Correa[2]. Further landward, trees become dominant; in Thailand *Casuarina equisetifolia* is a dominant species on sandy beaches or sand dunes frequently seen as a pure stand[2]. As a more specific example the natural beach forest comprised 104 species in Sirinart national park, Phuket province, Thailand; a herbaceous zone with creeping plants extends 10–15 m from the beach, then a 5–10 m shrub zone which becomes dominated by trees further landwards[4].

The once large and mostly contiguous beach forests of Thailand now commonly exist as fragmented patches, a result of human activities[2]. This fragmentation has had many consequences, for example land-use/cover (LULC) changes are responsible for loss of biodiversity[5–8] and potentially minimizes their ability to sustain costal ecosystems.

Beach forests play important roles in sustaining coastal ecosystems and local communities. The ecosystem functions by protecting sandy beaches against coastal erosion and the effects of winds and storms, and protects against damage caused by salt spray to human settlements or cultivation[9,10]. Adjacent sandy beaches are important nesting sites for sea turtles[3,5].

The 2004 tsunami impacted coastal areas of the Andaman Sea coast and the Bay of Bengal. Several studies were conducted dealing with the assessment of tsunami impacts to shorelines and the role of coastal vegetation in protecting local communities[11,12]. As specific examples in this region, *Pandanus odoratissimus* L.f. and *C. equisetifolia* mitigated destructive tsunami forces, their effectiveness depending on the magnitude of the tsunami and vegetation structure[13]. *Casuarina* forests are generally negatively impacted by tsunamis in the Andaman Sea[14], however, a surprising finding was that *Casuarina* forests remained undamaged after the 2004 tsunami devastated Hambantota City in southern coastal Sri Lanka[10].

Spatial details of coastal vegetation are often studied by, remote sensing, which can play an important role in assessing and monitoring at local scales[15,16]. Satellite images in a time series sequence can assess changes from the present to several decades earlier[17]. On a larger scale, and directly relevant to this study, Quick Bird and IKONOS satellite images have been used for pre-tsunami and post-tsunami assessment of woody vegetation and *Casuarina* forests, showing how they provided protection to landward areas[18].

Previous literature[2,5–7] describes how natural disasters and human uses of the coastal zone have impacted beach forest function. Accurate and reliable information on the rate and causes of deforestation of beach forests is not available for Thailand. Such information is needed to understand the ecology of beach forests and temporal changes over the long term. To address this knowledge gap, this study determined the distribution of beach forest diversity by employing a three-fold approach, using vegetation surveys, remote sensing, and geographic information system (GIS). The overall goals were to determine how much beach forest remains and to uncover the reasons for beach forest changes over the long-term, with emphasis on the 2004 tsunami event and delineation of natural versus anthropogenic causation over the 10-year study period in three coastal sites with different LULC characteristics.

### Study sites

The study area as shown in Fig. 1 comprises three sites in a 41-km$^2$ long coastal strip of 1000 m width in Phang Nga province, Thailand, along the Andaman Sea coast. These three sites were intensively impacted by the 2004 tsunami. All three study areas still contain remnants of beach forests. However, one of the sites, Khao Lak, is under significant economic pressure from tourism and as a result likely to be further changed to urban or barren land. The areas are representative of different types of LULC that have impacted vegetation. Three study sites were also selected due to their unique characteristics, as follows. Ban Nam Khem (BNK) in the North (8° 51′ 32″ N, 98° 15′ 46″ E) represents a fishing village and is sparsely populated. The housing density is relatively low[19]. The topography is a flat area with a ground elevation of approximately 2–3 m, and in some areas up to 6 m. Several ponds are located in the village[19]. BNK was strongly impacted by the 2004 tsunami with run-up wave surges reaching 8–9 m in height and inundation extending up to 3 km landwards[20].

Khao Lak (KL) is situated between the two other study sites (8° 44′ 26″ N, 98° 13′ 10″ E). It is a rapidly growing tourist centre with large hotel complexes and sparsely distributed resorts in hilly terrain. The study area is interspersed with smaller freshwater ponds resulting from tin mining activities of the last century[21]. KL was the most heavily impacted area in Thailand following the 2004 tsunami with 80% of hotel capacity lost[22,23]. The coastal area was strongly impacted by the tsunami with run-up elevations mostly ranging from between 5 and 10 m, but up to 10–12 m were also observed[24].

Thai Mueang (TM) in the South (8° 33′ 9″ N, 98° 12′ 18″ E) represents a natural beach forest within a national park (Khao Lampi–Hat Thai Mueang national park). The national park covers the coastal area between Tap Lamru and Thai Mueang city.

## MATERIALS AND METHODS

The study used multi-date IKONOS imagery acquired from the centre of Remote Sensing and Processing (CRISP) in Singapore and Spatial Dimension Solutions in Bangkok (Thailand). IKONOS imagery dates are 13 January 2003 (pre-tsunami)

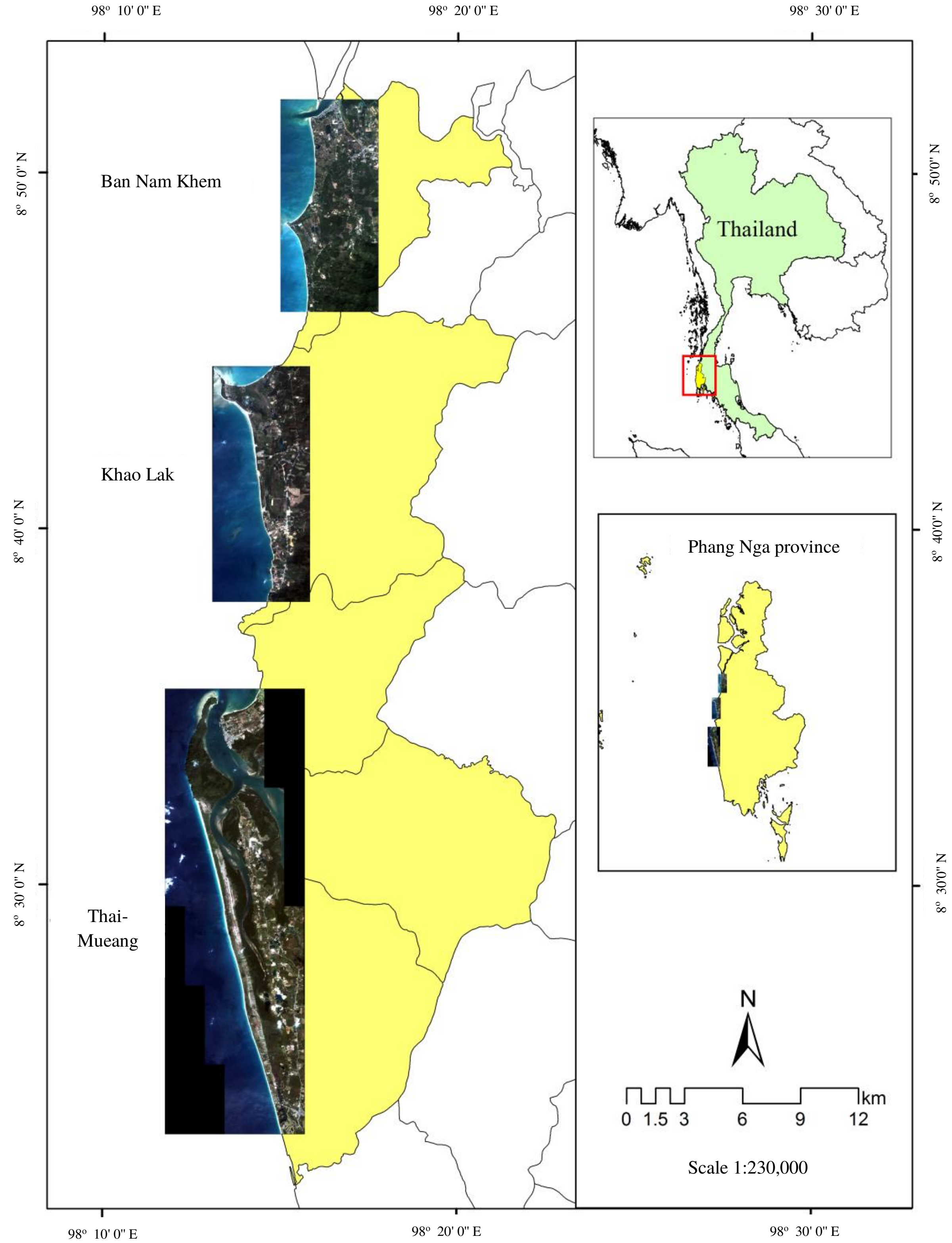

**Fig. 1** The study area. Satellite images are based on IKONOS multispectral data from 13 January 2003. Three sites shown: (1) Ban Nam Khem, (2) Khao Lak, and (3) Thai Mueang, Phang Nga province, southern Thailand.

and 15 January 2005 (post-tsunami). THEOS imagery was acquired on 4 February 2013 from the image archives of Geo-Informatics and Space Technology Development Agency (Public Organization) (GISTDA), Bangkok.

A land use map was created from the pre-tsunami IKONOS image (2003) by supervised classification with maximum likelihood algorithm (using ENVI 4.7 software) and coastal land use and vegetation types were classified in the three study sites. To classify pre-tsunami vegetation and distinct land use types, a historical IKONOS image (2003), from which all categories could be discerned visually by pan-sharpened IKONOS images (resolution = 1 m), was used in combination with digital classified surface/vegetation maps generated by the Thailand Department of Land Development (LDD) in 2000. To confirm historical (2003 and 2005) land use and vegetation types, current THEOS images (2013) were analysed as described above, with select areas collaborated by ground truth analysis (as described below). Digital results generated here (for 2003 and 2005) agreed to a high level with previous work in Phang Nga Province[25,26].

## Image preprocessing

Preprocessing of multi-temporal satellite images first involved registering imagery using a set of 53 ground control points (GCPs). The GCPs were selected from building corners, crossroads and noticeable landmark objects. The pre-tsunami scene of 2003 was initially registered. The GCPs and co-registration between the images gave co-registration errors of less than one-half pixel. Cloud masking was conducted using the 2003 and 2013 images; all images were trimmed by applying a function to a spatial subset of the image to the same size.

## Ground truth

Fieldwork supported the classification of images and delineation of land cover and vegetation types. A total of 12 classes were established: agricultural land, aquaculture, beach forest, mangrove, coconut, *Melaleuca* forest, rain forest, swamp forest, other vegetation, barren land, urban, and water bodies.

The 12 LULC classifications in the study were observed and confirmed by ground truth surveys. Ground truth data were collected in July–August 2012. Beach forest areas are difficult to classify from satellite imagery, in part because they generally comprise mixed species[25,27] and because they generally lack a coherent boundary. Hence extensive vegetation surveys of beach forest were used for their classification. Beach forests in BNK and KL are dominated by *C. equisetifolia* such that ground truth work was crucial. In TM the beach forests are far more diverse, but the forests have clear boundaries with adjacent *Melaleuca*, swamps, and mangrove forests.

Beach forest surveys were conducted to identify tree species diversity and distribution. Transects lines were mostly of 100 m in length, while some transects in BNK and KL were less than 100 m because the beach forest zones were frequently fragmented. Transects were sampled at 10 m intervals moving landwards using $10 \times 10$ m quadrat surveys conducted at random locations as selected by GIS. The quantitative analysis of tree species in beach forest community forests by using 10 vegetation transect surveys to calculate density, frequency, basal area and their relative values and Importance Value Index (IVI)[28]. The IVI value is scored from 0–300, and utilizes three characteristics such as density, frequency, and abundance by using the following formula:

$$\mathrm{IVI} = \mathrm{Density}_{\mathrm{rel}} + \mathrm{Frequency}_{\mathrm{rel}} + \mathrm{Abundance}_{\mathrm{rel}}.$$

## LULC classification procedure and accuracy assessment

Supervised classification was employed to generate LULC maps. Images were classified using signatures from training sites in Table 1. Vegetation surveys in July–August 2012 were used to identify vegetation types and their distribution. A total of 12 classes were established: agricultural land, aquaculture, beach forest, mangrove, coconut, *Melaleuca* forest, rain forest, swamp forest, other vegetation, barren land, urban, and water bodies.

High resolution pan-sharpened imagery was used to visually select training areas to assess the accuracy of classifications[29] to ensure accurate change detection results. Images were used to visually select validation points for the 2003 and 2005 classification maps, and verified from the field trip, for accuracy assessment of classification maps for 2013. The number of reference test pixels[30] used for the assessment of accuracy varied with the representatives of each class. The number of training areas comprised at least 73 pixels for the assessment of classification results. The accuracy assessment process, it uses overall accuracy, kappa statistics, producer's accuracy, and user's accuracy to evaluate the performance of classifications.

**Table 1** Images of LULC class definitions.

| LULC classes [a] | Class definitions |
|---|---|
| Agricultural land | Oil palm, orchard plantation, and rubber plantation. |
| Aquaculture | Farming of aquatic organisms, including fish, shrimp, molluscs, crustaceans, and aquatic plants. |
| Beach forest | Vegetation types of beach forest differ in each area. Ban Nam Khem and Khao Lak were covered by *Casuarina equisetifolia* and in Thai Mueang by mixed beach forest. |
| Barren land | Exposed soil surface such as beach, sand dunes, construction sites, and low sparse plant cover. |
| Coconut | Coconut plantations. |
| Mangrove | Mangrove forests dominated by *Rhizophora apiculata*, *R. mucronata*, *Ceriops tagal*, and *Bruguiera cylindrica*[31]. |
| *Melaleuca* forest | Forest dominated by *Melaleuca leucadendron*. |
| Rain forest | Natural rain forests are located in the mountainous terrain east of the study areas. They are protected by two national parks: Khao Lampi–Hat Thai Mueang and Khao Lak Lam–Ru. |
| Swamp forest | Swamp forest is adjacent with mangrove but not *Melaleuca* forest. |
| Other vegetation | Open woodland, semi-open landscape, grass, and shrub land. |
| Urban | Hotel, resort, residential, commercial services, transportation, roads. |
| Water bodies | River, permanent open water, lakes, ponds, reservoirs, and open water channels and waterways. |

[a] Modified from land use classification[32].

## Change detection

Change detection techniques were used to compare classification results to evaluate beach forest areas before (2003) and after the 2004 tsunami (2005–2013). This technique was applied to three different time periods (2003–2005, 2005–2013, and 2003–2013). Using ENVI 4.7 software to conduct the change detection analysis, raster images of LULC classes were exported to perform cross-tabulation manipulation. It was assumed that the three sets of classified images represented the temporal changes. The visual display of the outputs showed results in the form of colour maps, where each colour uniquely represents a change from one class to another.

## RESULTS AND DISCUSSION

In this study, LULC was quantitatively accessed in three sites in Phang Nga Province, southern Thailand, that have substantial differences in anthropogenic activities, including a fishing village, a tourist area, and part of a national park. Beach forest vegetation diversity was analysed by combined remote sensing, GIS and ground truth surveys before, immediately after, and again eight years following the 2004 tsunami. Results were considered in terms of baseline conditions (2003), destruction, and changes that occurred during the recovery period (2003 versus 2005), and those that occurred throughout the 10 year study period (2003–2013). Ten-year results were analysed in terms of anthropogenic (e.g., urban, agriculture land) and natural (e.g., grasslands, shrubs) changes. Results are presented in three parts: vegetation data, LULC classification, and change detection of beach forest areas.

## Vegetation data

A total of 24 tree and shrub species (Table 2) were identified in a total of 8300 $m^2$ from 10 beach forest transect lines. Four plant species dominated the overstory of the three study sites: *C. equisetifolia*, *T. catappa*, *S. taccada*, tree species, and *P. odoratissimus*, a shrub. These four species always occur in natural beach forests[2,4,27]. However, the characteristics of coastal morphology and soil substrates (e.g., sandy soil versus rocky shore) in each study site influenced species composition. Coastal study sites were located mostly in sandy shore areas, but rocky substrate was also present in areas of KL and TM.

In terms of tree species, the dominant species at BNK and KL was *C. equisetifolia*, which had the highest IVI value. This species extended from the vegetation line to 100 m landward. The lowest IVI value (36) for *C. equisetifolia* was observed in TM, a site that can be described as a mixed beach forest (Table 2) and as described below under comments about species diversity at the three sites. Another dominant species, *T. catappa*, was found in KL and TM more than at BNK.

As points of discussion (as background), it is important to consider why *C. equisetifolia* is dominant at two sites. A characteristic of *C. equisetifolia* is that it can establish and grow in barren land or sandy soil because of the root suckering habit and its

**Table 2** The quantitative analysis of beach forest species (IVI values) and distribution in three study sites.

| Tree and shrub species | IVI values | | | Distance landward (m) | | | Plant habitats |
|---|---|---|---|---|---|---|---|
| | BNK | KL | TM | 10–20 | 30–40 | 50–100 | |
| *Casuarina equisetifolia* J.R. & G. Forst. | 223 | 208 | 36 | + | + | + | T |
| *Cocos nucifera* | 14 | | 3 | − | + | + | T |
| *Pandanus odoratissimus* L.f. | 13 | 14 | 12 | + | + | − | S |
| *Terminalia catappa* | 13 | 28 | 23 | + | + | + | T |
| *Scaevola taccada* (Gaertn.) Roxb. | 12 | 21 | 27 | + | + | − | S |
| *Hibiscus tiliaceus* | | 16 | 9 | + | − | − | T |
| *Calophyllum inophyllum* | | 13 | 32 | − | + | − | T |
| *Syzygium grande* (Wight) Walp. | | | 48 | − | − | + | T |
| *Lepisanthes rubiginosa* (Roxb.) Leenh. | | | 34 | − | − | + | T |
| *Barringtonia asiatica* (L.) Kurz | 25 | | 9 | + | + | + | T |
| *Allophylus cobbe* (L.) Raeusch. | | | 9 | − | + | + | S |
| *Guettarda speciosa* | | | 7 | + | + | + | T |
| *Crinum northianum* Bak. | | | 7 | + | − | + | S |
| *Vitex pinnata* | | | 7 | − | − | + | T |
| *Acacia mangium* Willd. | | | 5 | − | + | + | T |
| *Barringtonia macrocarpa* Hassk. | | | 5 | + | + | + | T |
| *Atalantia monophylla* Correa | | | 4 | − | + | − | T |
| *Morinda citrifolia* | | | 4 | − | + | − | T |
| *Ardisia elliptica* Thunb. | | | 4 | − | − | + | T |
| *Salacia chinensis* | | | 3 | − | − | + | S |
| *Carallia brachiata* (Lour.) Merr. | | | 3 | − | − | + | T |
| *Diospyros wallichii* King & Gamble | | | 3 | − | − | + | T |
| *Syzygium cumini* (L.) Skeels | | | 3 | − | − | + | T |
| *Barringtonia acutangula* (L.) Gaertn. | | | 3 | − | − | + | T |

+: present; −: not found. Plant habitats: T: trees; S: shrub trees.

rapid growth[10]. In addition, *C. equisetifolia* is more resilient than other tree species and out competes other trees that cannot grow well under a closed canopy[9,33]. Further, it is of note that these two sites where *C. equisetifolia* was dominant are the most anthropogenically impacted sites, suggesting that prior activities had altered the species diversity.

Rocky shores are prevalent at KL and TM. The dominant species, as expected, differ with this substrate relative to sand. Dominant tree species in rocky shore areas include *Syzygium grande* (Wight) Walp., *Lepisanthes rubiginosa* (Roxb.) Leenh., and *Calophyllum inophyllum*. These species become established at a distance 50–100 m landwards away from the salt spray zone.

Regarding shrubs, the dominant species at all three sites was *Pandanus odoratissimus*, with similar IVI values (12–14, Table 2). *Scaevola taccada* was also present at all three sites, with the highest IVI at TM; this is a common species of shrub zonation[4], and co-occurs with other shrub species *Allophylus cobbe*, *Crinum northianum*, and *Salacia chinensis* (Table 2).

In terms of species richness, the vegetation survey results indicated that BNK and KL have low species diversity of trees/shrubs (Table 2) relative to healthy beach forests[4], signifying that these sites are under stress. It is impossible to determine from single-point-in time vegetation surveys if the pressures are natural and/or anthropogenic, but these questions are addressed below. However, it is of note that these two anthropogenically impacted sites also have *C. equisetifolia* as dominant, by a wide margin, suggesting that prior activities had altered the species diversity prior to our initial analyses in 2003. In contrast, species diversity is high at TM as exemplified by IVI values (Table 2) and confirmed by Shannon-Wiener Index analyses[34]. These figures are indicative of a healthy, non-perturbed environment, as might be expected for a national park within a larger and diverse ecosystem comprising rain forests, mangroves, *Melaleuca*, and swamp forests.

In terms of species richness, the vegetation surveys indicated that BNK and KL have low species diversity of trees/shrubs, with only six species present

(Table 2). Inclusion of creeping plants would increase diversity to only 10 and eight species at these two sites, respectively. In contrast, species diversity was high at TM as exemplified by IVI values (Table 2) and confirmed by Shannon-Wiener Index analyses[34]. Trees/shrubs were dominant (24 species) at TM, and the presence of rocky substrates did not increase the number of species present (i.e., the same species were present on sandy soils and rocky substrates).

Initial conclusions are possible from these vegetation surveys. The low species diversity at BNK and KL, relative to healthy beach forests[4], signify that these sites are/may be under stress. It is impossible to determine from single-point-in time vegetation surveys if the pressures are natural and/or anthropogenic, but these questions are addressed below. However, it is of note that these two anthropogenically impacted sites also have *C. equisetifolia* as dominant, by a wide margin, suggesting that prior activities had altered the ecosystem/species diversity prior to our initial analysis in 2003. The higher number of species, as confirmed by Shannon-Wiener index analysis, for TM are indicative of a healthy, non-perturbed environment, as might be expected for a national park within a larger and diverse ecosystem comprising rain forests, mangroves, *Melaleuca*, and swamp forests.

### LULC classification

Determinations of LULC characteristics in the study areas were derived from high-resolution IKONOS and THEOS satellite imagery. Verification was done by visually detecting land covers (e.g., rivers, shorelines, roof of a specific building, mangrove forests) from the pan sharpened images (2003 and 2005) and by ground truth surveys from site visits mapped by GPS in 2013. The overall kappa statistics of classified images in 2003, 2005, and 2013 were 0.82, 0.80, and 0.70, respectively (Table 3). The lowest kappa value was from 2013 which comes from classification of THEOS imagery. The lowest value was related to the inherent properties of pan-sharpened images. The THEOS pan-sharpened image was sharpened with a panchromatic band and a multispectral band, the consequence of such a technique can cause discolouration, which affects classification[35].

LULC classification of the coastal zone was conducted for the pre-tsunami (2003) and post-tsunami (2005 and 2013) images, and divided into 12 classes (Table 1, Fig. 2, and Table 4). Beach forest area represented 4% (BNK), 3% (KL), and 18% (TM) of the total study sites in 2003. Beach forests represent a small percentage of the total area, especially in BNK and KL, likely because they have experienced greater anthropogenic influences than TM. Regardless of their current coverage, beach forests are extremely important habitats in terms of ecology and conservation of coastal communities.

**Table 3** Summary of classification accuracies (%) for 2003, 2005, and 2013.

| | 2003 | | 2005 | | 2013 | |
|---|---|---|---|---|---|---|
| LULC class. | Prod. | User | Prod. | User | Prod. | User |
| Agricultural land | 100 | 75 | 100 | 100 | 60 | 60 |
| Aquaculture | 50 | 100 | 100 | 100 | 100 | 100 |
| Barren land | 100 | 95 | 91 | 83 | 33 | 67 |
| Beach forest | 83 | 63 | 50 | 100 | 75 | 67 |
| Coconut | 83 | 71 | 75 | 75 | 60 | 60 |
| Mangrove | 71 | 100 | 83 | 100 | 100 | 100 |
| *Melaleuca* forest | 0 | 0 | 100 | 50 | 100 | 33 |
| Other vegetation | 64 | 88 | 67 | 100 | 75 | 71 |
| Rain forest | 83 | 100 | 100 | 100 | 100 | 100 |
| Urban | 100 | 100 | 33 | 33 | 88 | 70 |
| Swamp forest | 100 | 100 | 100 | 100 | 0 | 0 |
| Water | 100 | 100 | 100 | 83 | 100 | 100 |
| Overall accuracy | 85 | | 85 | | 74 | |
| Kappa coefficient | 1 | | 1 | | 1 | |

Prod. = producer.

Regarding additional LULC classification (Table 4), data analyses revealed that BNK displayed the highest amount of barren land at 37% in 2003, decreasing to 25% in 2013. In this study, barren land comprised areas destined to be used for construction and/or agriculture. Urban areas increased from 5% to 11% of the total in 2013 in BNK. This slight increase of urban areas in BNK over the last 10 years suggests the small fishing community did not encroach substantially on these areas.

LULC characteristics of KL were similar to BNK. Barren land in KL in 2003 represented the greatest cover at 31%, decreasing to 18% in 2013. During the same period, urban area increased from 10% to 19%, likely representing conversion of barren land into urban properties. Increased urban area may be due to increasing pressure from tourism-related development. Nevertheless, classification of LULC in KL showed that coconut plantations covered 17% of the total area in 2003, decreasing to 10% and 11% in 2005 and 2013, respectively, likely reflecting damage from the 2004 tsunami couple with the slow recovery of coconut plantation. Low recovery can be consequence of human activity (e.g., burning, cutting, and building) this area[31].

The site at TM is partially protected by its national park status. Associated ecosystems include

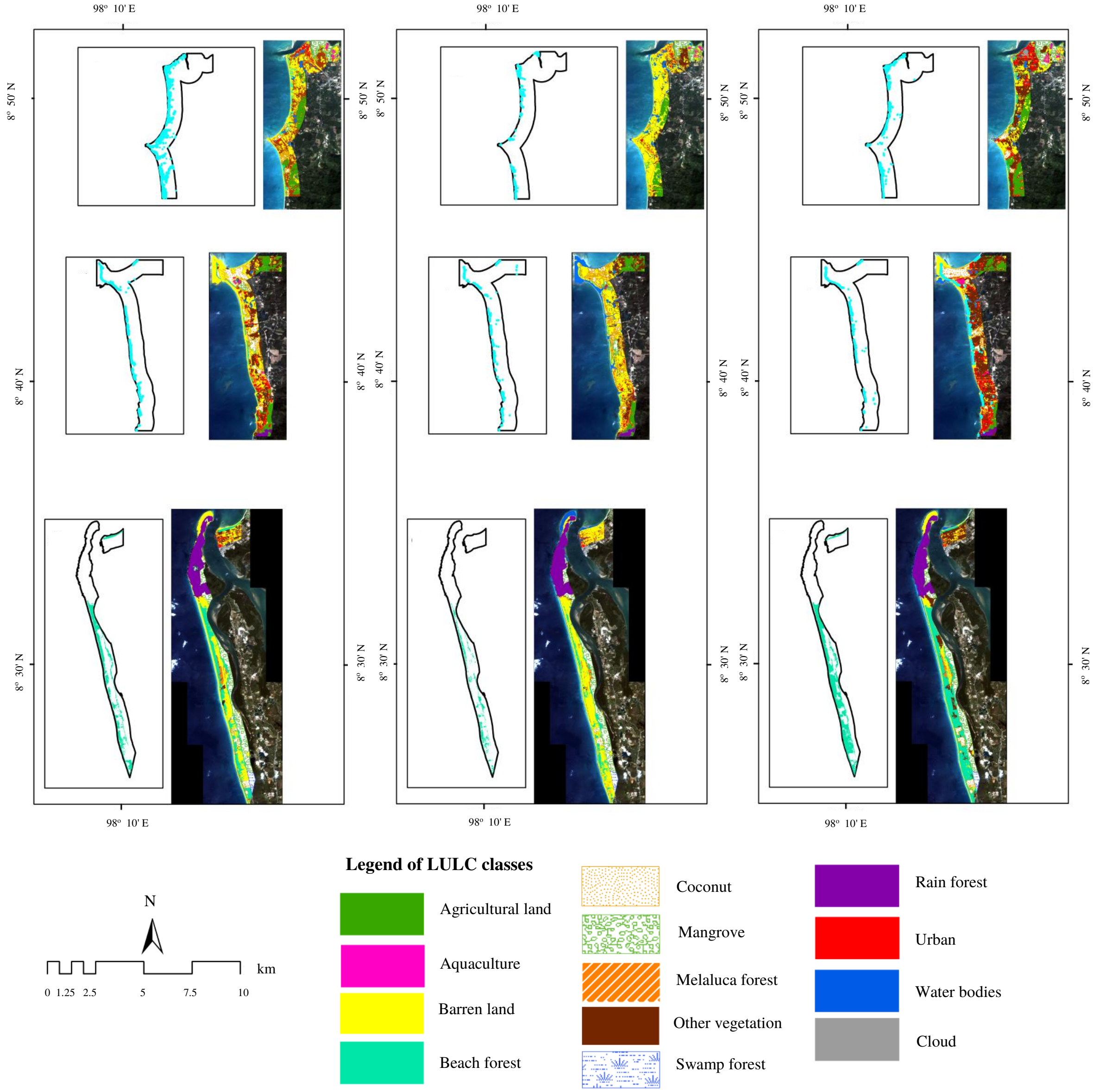

**Fig. 2** LULC mapping derived from classification of IKONOS and THEOS imagery showing beach forest distribution at three sites in 2003 (left), 2005 (middle), and 2013 (right): BNK (top); KL (middle); and TM (bottom).

natural rain forests, mangroves, *Melaleuca* forests, and swamp forests. The greatest percent of vegetation cover is represented by rain forests while mangroves and beach forests account for 19%, and 18%, respectively. However, in 2003 coconut plantations covered 3% of the total area, which has been the case since establishment of the national park[34].

## Change detection of beach forest from 2003 to 2013

Results from change detection analysis showed that beach forest coverage changed in two periods from 2003 to 2005 and 2005 to 2013 (Table 5). The greatest change was observed after the tsunami, from 2003 to 2005 at all three sites. The largest change in beach forest cover was observed in 2005 in BNK (−45%), followed by KL (−40%), and TM (−23%). At both KL and BNK, the unaffected (i.e., no change) areas were 0.1 km$^2$ while TM had 1.3 km$^2$ of undamaged coverage. The more severe damage at KL and BNK is likely related to the dominance of *Casuarina* forests at these sites, as revealed by vegetation surveys (see above) and described in the next paragraph.

**Table 4** LULC use changes from 2003–2013 at Phang Nga province.

| LULC | Cover area (km$^2$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2003 | | | 2005 | | | 2013 | | |
| | BNK | KL | TM | BNK | KL | TM | BNK | KL | TM |
| Agricultural land | 1.76 (13) | 1.79 (11) | 0 (0) | 1.44 (10) | 1.52 (10) | 0 (0) | 2.17 (16) | 1.21 (8) | 0 (0) |
| Aquaculture | 0.22 (2) | 0.14 (1) | 0 (0) | 0.18 (1) | 0.0 (0) | 0 (0) | 0.31 (2) | 0.16 (1) | 0 (0) |
| Barren land | 5.14 (37) | 4.87 (31) | 5.39 (30) | 8.05 (58) | 6.68 (42) | 7.07 (40) | 3.5 (25) | 2.75 (18) | 2.49 (14) |
| Beach forest | 0.49 (4) | 0.41 (3) | 3.16 (18) | 0.11 (1) | 0.24 (2) | 1.56 (9) | 0.45 (3) | 0.27 (2) | 5.02 (28) |
| Coconut | 0.45 (3) | 2.77 (17) | 0.59 (3) | 0.05 (0) | 1.64 (10) | 0.36 (2) | 0.45 (3) | 1.76 (11) | 0.54 (3) |
| Mangrove | 0.96 (7) | 0.51 (3) | 3.32 (19) | 0.89 (6) | 0.36 (2) | 3.27 (18) | 1.3 (9) | 0.20 (1) | 3.04 (17) |
| *Melaleuca* forest | 0 (0) | 0 (0) | 0.34 (2) | 0 (0) | 0 (0) | 0.19 (1) | 0 (0) | 0 (0) | 0.33 (2) |
| Other vegetation | 3.67 (26) | 3.39 (21) | 0.56 (3) | 1.47 (11) | 2.41 (15) | 0.19 (1) | 3.56 (26) | 5.43 (35) | 1.84 (10) |
| Rain forest | 0 (0) | 0.26 (2) | 3.34 (19) | 0.0 (0) | 0.29 (2) | 3.34 (19) | 0.0 (0) | 0.31 (2) | 3.38 (19) |
| Urban | 0.65 (5) | 1.51 (10) | 0.37 (2) | 0.51 (4) | 0.76 (5) | 0.33 (2) | 1.49 (11) | 2.96 (19) | 0.22 (1) |
| Swamp forest | 0.0 (0) | 0.0 (0) | 0.4 (2) | 0.0 (0) | 0.0 (0) | 0.39 (2) | 0 (0) | 0 (0) | 0.34 (2) |
| Water | 0.58 (4) | 0.24 (2) | 0.03 (0) | 1.21 (9) | 1.82 (12) | 1.02 (6) | 0.51 (4) | 0.66 (4) | 0.53 (3) |
| Cloud | 0 (0) | 0 (0) | 0.26 (1) | 0 (0) | 0 (0) | 0 (0) | 0.17 (1) | 0 (0) | 0 (0) |
| Total area | 13.92 | 15.89 | 17.76 | 13.91 | 15.72 | 17.72 | 13.91 | 15.71 | 17.73 |

The number in brackets is the percentage of total area at the study site.

**Table 5** Changes in beach forest cover from 2003 to 2013 at Phang Nga province, Thailand.

| Changes | Cover area (km$^2$) | | |
|---|---|---|---|
| | BNK | KL | TM |
| No change | 0.1 (7) | 0.1 (21) | 1.3 (15) |
| Change to others | 0.4 (45) | 0.3 (40) | 1.9 (23) |
| Recovery areas | 0.5 (58) | 0.3 (39) | 5.1 (62) |

The number in brackets is the percentage of total area at the study site.

Coastal forests, including beach (and *Casuarina*) forests and mangrove forests in Thailand, play a vital role in affording protection against natural events such as storms and tsunamis[36]. From previous observations by Römer[25], using remote sensing techniques to assess impacts on coastal forests in Phang Nga province, *Casuarina* forests were reported as being severely damaged by tsunami impacts (38% damaged), which is similar to damage reported here for BNK (45%) and KL (40%). According to IUCN[37], *Casuarina* trees taller than 20 ft were broken yet survived in southwest Thailand following the tsunami. Also, Tanaka[33] noted that small diameter ($d < 0.07$ m) *C. equisetifolia* were broken by a 5-m high tsunami at Sri Lanka and western cost of Thailand. On the other hand, the slightly older plantations of *C. equisetifolia* ($d >$ 0.1 m) proved more resilient. Regarding the heavy damage at BNK and KL beach forests observed in this study, the *Casuarina* forests, which were dominant at BNK and KL, were almost certainly composed of young/small diameter trees, a theory supported by interviews with local inhabitants of these areas held as part of the vegetation survey research.

Römer[25] reported that mangroves suffered greater tsunami-related damage (55%), relative to *Casuarina*, in Phang Nga. This contrasts with vegetation analyses conducted here. The results here show small changes at all three sites over the entire 10 year study period, including 2003 versus 2005, the time frame analysed by Römer[25] (Table 4). This difference in mangrove damage probably is because mangrove forests at BNK, KL, and TM are further inland than those studied previously[25].

The rate of beach forest recovery was examined from 2005 to 2013 (Table 5). During this period, the recovery rate at BNK and KL was 58% and 39%, respectively, and the highest by 62% occurred in TM, likely reflecting that is an undisturbed area protected by the national park.

Römer[26] studied coastal vegetation recovery after the tsunami in Phang Nga Province by remote sensing, reporting that the recovery of *Casuarina* was less than grassland and coconut plantations, but more than mangrove. The *Casuarina* recovery rates are similar to data reported here (Table 5), but are discussed in more detail in the next section dealing with anthropogenic (i.e., coconut plantations) and natural (grasslands) factors influencing causes and rates of LULC changes. In terms of

**Table 6** Beach forest change (2003 to 2013) to other LULC categories at Phang Nga province.

| LULC | Cover area (km$^2$) | | |
|---|---|---|---|
| | BNK | KL | TM |
| Other | 0.14 (29) | 0.04 (10) | 0.21 (7) |
| Water | 0.01 (1) | 0.00 (0) | 0.02 (1) |
| Urban | 0.03 (7) | 0.10 (24) | 0.00 (0) |
| Barren land | 0.13 (27) | 0.12 (29) | 0.16 (5) |
| Agricultural land | 0.03 (6) | 0.01 (3) | 0.00 (0) |
| No change | 0.15 (30) | 0.14 (34) | 2.74 (87) |

The number in brackets is the percentage of total area at the study site.

recovery from natural events, such as tsunamis, *C. equisetifolia* is a pioneer species, permitting early colonization. Furthermore, *C. equisetifolia* does well in competition with other vegetation, frequently existing as pure stands and sparse understory vegetation[26]. If sufficiently extensive, coastal vegetation can absorb enough of the tsunami energy, it would reduce the flow velocity and depth of the wave, but its effectiveness depends on the magnitude of the tsunami, as well as stand size, density, species composition, structure, and homogeneity[1,36]. Tanaka[33] suggested that the leading edge of the forest close to the sea should have dense vegetation such as a *Pandanus-Casuarina* belt.

### Beach forest LULC changes—causes and rates

Change detection results based on beach forest classification categories from 2003 to 2013 are shown in Table 6. For the change detection analysis, six categories were defined: no change (relates only to beach forests), water, urban, barren land, agricultural land, and other (defined here, more broadly than above, as mangrove, *Melaleuca* forests, rain forests, swamp forests, and other vegetation).

Beach forest area remained unchanged at TM (87%) followed by BNK (30%) and KL (34%). These findings suggest that considerable change did occur in the beach forest areas, over the 10 year period, especially at BNK (70%) and KL (66%). The causes and rates of these changes are described below.

Beach forests were transformed over the long-term (10 years) into various other categories (Table 6). In BNK, the greatest LULC change was to other (29%) and barren land (27%). However, both classes of change may lead to a wide range of utilization in the future (e.g., barren land may be converted to construction and/or agriculture, while the ‘other vegetation’, a component of other, is subject to urban development). Human activities led to changes in urban area (7%) and agricultural land (6%), the latter dominated by coconut plantations and orchard plantations.

A major change in beach forest cover in KL was the conversion to barren land (29%), urban area (24%) and agricultural land (3%), which is dominated by coconut plantations. Conversion to urban area was larger at KL than in the other study sites. At KL, a popular coastal tourism spot on the Andaman Sea, the 2004 tsunami destroyed approximately 90% of the hotels and buildings in the coastal areas[38].

In TM, beach forest changed by only 13%, being converted to barren land (5%) and other class (7%); the other classes were grass land areas and other vegetation. However, the greatest area of unchanged beach forest was observed in TM (2.47 km$^2$), followed by BNK (0.15 km$^2$), and KL (0.14 km$^2$).

## CONCLUSIONS

Beach forests are important components of marine ecosystems in tropical coastal regions, yet they have been studied only sparsely in Thailand. In three sites, with different LULC characteristics, in Phang Nga Province, the beach forest species and distribution was, more or less, similar to sites found elsewhere. Species diversity of beach forests however was low at the two sites with higher anthropogenic activity, while the most preserved site, within a national park, had high species diversity.

This study presents a quantitative assessment of beach forest species, and applied remote sensing for assessing beach forest distribution and change in tsunami-affected areas from 2003 to 2013. Vegetation surveys indicated lower beach forest tree/shrub species richness at BNK and KL (6 spp.), and much higher tree/shrub richness at TM (24 spp.). The study integrated remote sensing and change detection techniques to effectively reveal the spatial and temporal dynamics of beach forests following the tsunami.

The greatest destruction by the tsunami occurred in BNK, followed by KL and least in TM because the beach forest areas at BNK and KL were disrupted by human intervention on the coastal zone. Recovery varied from BNK (58%), KL(39%) with low rates in KL probably due to beach forest areas disturbed by anthropogenic factors (e.g., hotel construction, coconut plantations and agricultural activities) while high rates in TM (62%) ascribed to undisrupted areas. Findings will contribute to providing support to decision makers in identifying possible areas for beach forest restoration and highlights the need for a better understanding of plant community diversity.

The LULC mapping demonstrated that coastal areas had changed; the data can be applied for land use planning in the coastal zone. Future research should focus on using imagery of equivalent and higher spatial resolution for mapping beach forest species. Additionally, more detailed spatial information, such as environmental conditions for specific plant species, would be informative.

*Acknowledgements*: This study was supported by the National Research Council of Thailand under the Thai-German Research Cooperation (NRCT-DFG) grant under the project "Development of guidelines to assess coastal community risk and vulnerability to tsunami disaster in Phang-Nga province" and the 90th Anniversary of Chulalongkorn University Fund (Ratchadaphiseksomphot Endowment Fund). THEOS images were acquired from the image archives of Geo-Informatics and Space Technology Development Agency (Public Organization), Thailand. We would like to acknowledge Assist. Prof. Sasitorn Poungparn, Department of Botany, Faculty of Science, Chulalongkorn University for giving the recommendations of beach forest community and vegetation surveys. Special acknowledgement also to Dr Richard T Cooper, Southeast Asia START Regional Centre (SEA START RC), Chulalongkorn University, for reviewing the manuscript.

## REFERENCES

1. Cochard R, Ranamukhaarachchi SL, Shivakoti GP, Shipin OV, Edwards PJ, Seeland KT (2008) The 2004 tsunami in Aceh and Southern Thailand: A review on coastal ecosystems, wave hazards and vulnerability. *Perspect Plant Ecol Evol Systemat* **10**, 3–40.
2. Smitinand T (1977) *Vegetation and Ground Cover of Thailand*, Kasetsart Univ Department of Forest Biology Technical Paper No 1, pp 167–78.
3. Whitten T, Damanik SJ, Anwar J, Hisyam N (2000) *The Ecology of Sumatra*, 1st edn, Tuttle Publishing, North Clarendon, VT, pp 1–13.
4. Thunthawanich R (2001) Vegetation and environmental gradients across the beach forest in Sirinath National Park, Changwat Phuket. MSc thesis, Univ of Kasetsart.
5. Department of Marine Coastal Resources (2005) *Rapid Assessment of the Tsunami Impact on Marine Resources in the Andaman Sea, Thailand*, Chulalongkorn Univ Printing House, Bangkok, p 4.
6. Falcucci A, Maiorano L, Boitani L (2007) Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. *Landsc Ecol* **22**, 617–31.
7. Fasona M, Omojola A (2009) Land cover change and land degradation in parts of the southwest coast of Nigeria. *Afr J Ecol* **47**, 30–8.
8. Almeida D, Neto C, Esteves LS, Costa JC (2014) The impacts of land-use changes on the recovery of saltmarshes in Portugal. *Ocean Coast Manag* **92**, 40–9.
9. Goltenboth F, Langenberger G, Widmann P (2006) Beach forests. In: Goltenboth F, Timotius KH, Milan PP, Margraf J (eds) *Ecology of Insular Southeast Asia: The Indonesian Archipelago*, Elsevier, Amsterdam, pp 281–95.
10. De Zoysa M (2008) Casuarina coastal forest shelterbelts in Hambantota City, Sri Lanka: assessment of impacts. *Small Scale Forest* **7**, 17–27.
11. Chang SE, Adams BJ, Alder J, Berke PR, Chuenpagdee R, Ghosh S, Wabnitz C (2006) Coastal ecosystems and tsunami protection after the December 2004 Indian Ocean tsunami. *Earthquake Spectra* **22**, 863–87.
12. Kaplan M, Renaud FG, Lüchters G (2009) Vulnerability assessment and protective effects of coastal vegetation during the 2004 Tsunami in Sri Lanka. *Nat Hazards Earth Syst Sci* **9**, 1479–94.
13. Tanaka N (2009) Vegetation bioshields for tsunami mitigation: Review of effectiveness, limitations, construction, and sustainable development. *Landsc Ecol* **5**, 71–9.
14. Günthert S, Wieland M, Siegmund A (2011) Change detection analysis for assessing the vulnerability and protective effect of beach forests in case of the tsunami 2004 in Thailand. *Photogramm Fernerkund Geoinform* **2011**, 247–60.
15. Giri C, Zhu Z, Tieszen LL, Singh A, Gillette S, Kelmelis JA (2008) Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia. *J Biogeogr* **35**, 519–28.
16. Römer H, Willroth P, Kaiser G, Vafeidis AT, Ludwig R, Sterr H, Revilla Diez J (2012) Potential of remote sensing techniques for tsunami hazard and vulnerability analysis—a case study from Phang-Nga province, Thailand. *Nat Hazards Earth Syst Sci* **12**, 2103–26.
17. Xie Z, Xu X, Yan L (2010) Analyzing qualitative and quantitative changes in coastal wetland associated to the effects of natural and anthropogenic factors in a part of Tianjin, China. *Estuar Coast Shelf Sci* **86**, 379–86.
18. Olwig MF, Sørensen MK, Rasmussen MS, Danielsen F, Selvam V, Hansen LB, Karunagaran VM (2007) Using remote sensing to assess the protective role of coastal woody vegetation against tsunami waves. *Int J Rem Sens* **28**, 3153–69.
19. Kaiser G, Scheele L, Kortenhaus A, Løvholt F, Römer H, Leschka S (2011) The influence of land cover roughness on the results of high resolution tsunami inundation modeling. *Nat Hazards Earth Syst Sci* **11**,

2521–40.

20. Choowong M, Murakoshi N, Hisada K, Charusiri P, Daorerk V, Charoentitirat T, Kanjanapayont P (2007) Erosion and deposition by the 2004 Indian Ocean tsunami in Phuket and Phang-nga provinces, Thailand. *J Coast Res* **23**, 1270–6.
21. Szczucinski W, Chaimanee N, Niedzielski P, Rachlewicz G, Saisuttichai D, Tepsuwan T, Lorenc S, Siepak J (2006) Environmental and geological impacts of the 26 December 2004 tsunami in coastal zone of Thailand—overview of short and long-term effects. *Pol J Environ Stud* **15**, 793–810.
22. Karlsson JM, Skelton A, Sandén M, Ioualalen M, Kaewbanjak N, Pophet N, Matern A (2009) Reconstructions of the coastal impact of the 2004 Indian Ocean tsunami in the Khao Lak area, Thailand. *J Geophys Res* **114**, C10023.
23. Wong PP (2012) Impacts, recovery and resilience of Thai tourist coasts to the 2004 Indian Ocean tsunami. *Geol Soc Lond Spec Publ* **361**, 127–38.
24. Thanawood C, Yongchalermchai C, Densrisereekul O (2006) Effects of the December 2004 tsunami and disaster management in southern Thailand. *Sci Tsunami Hazards* **24**, 206–17.
25. Römer H, Kaiser G, Sterr H, Ludwig R (2010) Using remote sensing to assess tsunami-induced impacts on coastal forest ecosystems at the Andaman Sea coast of Thailand. *Nat Hazards Earth Syst Sci* **10**, 729–45.
26. Römer H, Jeewarongkakul J, Kaiser G, Ludwig R, Sterr H (2011) Monitoring post tsunami vegetation recovery in Phang-Nga province Thailand based on IKONOS imagery and field investigations—a contribution to the analysis of tsunami vulnerability of coastal ecosystems. *Int J Rem Sens* **33**, 3090–121.
27. Kutintara U (2008) Vegetative cover types classification system of Thailand. *J Trop Plant Res* **1**, 1–21.
28. Curtis JT, McIntosh RP (1951) An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* **32**, 476–96.
29. Foody GM (2002) Status of land cover classification accuracy assessment. *Rem Sens Environ* **80**, 185–201.
30. Maingi JK, Kepner SE, Edmonds WG (2002) *Accuracy Assessment of 1992 Landsat-MSS Derived Land Cover for the Upper San Pedro Watershed (US/Mexico)*, National Exposure Research Lab, Sponsored by Environmental Protection Agency, Las Vegas, NV.
31. Paphavasit N, Teratanatorn V, Siriboon S, Piumsomboon A, Punnarak P, Mongkonsamgsuree N (2009) General background of project. In: Paphavasit N, Aksornkoae S, Silvia JD (eds) *Tsunami Impact on Mangrove Ecosystem*, Thailand Environmental Institute, Nonthaburi, Thailand, pp 1–20.
32. Di GA (2005) *Land Cover Classification System: Classification Concepts And User Manual: LCCS (No 8)*, Food & Agriculture Org.
33. Tanaka N, Sasaki Y, Mowjood MIM, Jinadasa KBSN, Homchuen S (2007) Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami. *Landsc Ecol Eng* **3**, 33–45.
34. Kongapai P (2015) Assessment of beach forest change in Phang Nga province from 2003 to 2013. PhD thesis, Chulalongkorn Univ, Thailand.
35. Kongapai P, Sompongchaiyakul P, Jitpraphai S (2016) Assessing coastal land cover changes after the 2004 tsunami using remote sensing and GIS approaches. *Walailak J Sci Tech* **13**, 689–702.
36. Mascarenhas A, Jayakumar S (2008) An environmental perspective of the post-tsunami scenario along the coast of Tamil Nadu, India: Role of sand dunes and forests. *J Environ Manag* **89**, 24–34.
37. International Union for Conservation of Nature (2005) *Early Observations of Tsunami Effects on Mangroves and Coastal Forests*, Statement from the IUCN Forest Conservation Programme.
38. Calgaro E, Lloyd K (2008) Sun, sea, sand and tsunami: examining disaster vulnerability in the tourism community of Khao Lak, Thailand. *Singapore J Trop Geogr* **29**, 288–306.