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Land cover and land use change related to shrimp farming in coastal areas of Quang Ninh, Vietnam using remotely sensed data

Thuyet D. Bui · Stefan W. Maier · Chris M. Austin

Abstract Rapid development of shrimp farming may lead to unrecognized and undesirable changes of land cover/land use patterns in coastal areas. Of special concern is the loss of mangrove forest in coastal areas such as Quang Ninh, Vietnam, which is adjacent to the World Heritage-listed Ha Long Bay. Understanding the status and changes of land cover/land use for coastal shrimp farms and mangrove forests can support environmental protection and decision-making for sustainable development in coastal areas. Within this context, this paper uses the 1999/2001 Landsat ETM+ and the 2008 ALOS AVNIR-2 imagery to investigate the contraction and expansion of shrimp farms and mangrove forests in coastal areas of Ha Long and Mong Cai, which now have a high concentration of intensive and semi-intensive shrimp farms. Images were separately analyzed and classified before using post-classification comparisons to detect land cover/land use changes in the study area. The results of this study found that the area of mangrove forest has been reduced by an estimated 927.5 ha in Ha Long and 1,144.4 ha in Mong Cai, while shrimp farming areas increased by an estimated 1,195.9 and 1,702.5 ha, respectively, over the same period. The majority of shrimp farms in Mong Cai were established at the expense of mangrove forest (49.4 %) while shrimp farms in Ha Long were mainly constructed on areas previously occupied by bare ground (46.5 %) and a significant proportion also replaced mangroves (23.9 %). The remarkable rate of mangrove loss and shrimp farming expansion detected in this study, over a relatively short time scale indicate that greater awareness of environmental impacts of shrimp farm expansion is required if this industry is to be sustainable, the important estuarine and coastal marine ecosystems are to be protected over the long term, and the capturing and storing of carbon in mangrove systems are to be enhanced for global climate change mitigation and for use as carbon offsets.

Keywords Mangrove · Shrimp farm · Land cover · Land use · Landsat ETM+ · ALOS AVNIR-2

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Introduction

Most current land cover, land use patterns on earth reflect the interaction of human activities and the natural environment (Alonso-Pérez et al. 2003), and thus understanding land cover/land use and its changes in areas can provide essential information for forming policies regarding socio-economic development and environmental management (Campbell 2002). With the rapid rise in human population and the associated economic imperatives, several regions in the world have suffered large and rapid landscape changes (i.e., urban sprawl, deforestation, changes of land use pattern from agriculture to aquaculture) (Alonso-Pérez et al. 2003; Muttitanon and Tripathi 2005). Therefore, accurate and up-to-date information on land cover/land use change is necessary for building a suitable future land use policy (Muttitanon and Tripathi 2005) as well as monitoring the

environmental consequences of recent developments especially at national or regional scales (Shalaby and Tateishi 2007).

Remote sensing-based techniques now provide vital tools for the assessment of land cover/land use on the earth (Campbell 2002). By using these techniques, it is possible to obtain a series of synoptic data for large geographic areas uniformly in time and space without exhaustive and expensive field surveys (Green et al. 1996). Multitemporal remote sensing data can be used for detecting and quantifying land cover/land use change in areas over time (Alonso-Pérez et al. 2003; Dewan and Yamaguchi 2009; Muttitanon and Tripathi 2005; Shalaby and Tateishi 2007; Singh 1989), and thereby provides significant information for monitoring environmental change and natural resource use (Seto and Fragkias 2007). There is now an abundance of images, from coarse to high resolution, captured by various satellite sensors (i.e., Landsat, SPOT, Quickbird, Geoeyes, ALOS) that can be used for land cover/land use analysis. In addition, new satellites are being launched and new sensors developed every year (Green et al. 2000) which promise to generate more and more valuable imagery for earth landscape studies.

In terms of environmental and natural resources monitoring in coastal areas, remote sensing is a promising technology to detect land cover/land use changes, and it has been used for a wide range of applications (Green et al. 2000; Seto and Fragkias 2007). Studies have mapped land cover/land use changes in coastal areas (Muttitanon and Tripathi 2005; Shalaby and Tateishi 2007), or focused on specific issues such as detecting status and changes of mangrove forest cover (Conchedda et al. 2008; Gang and Agatsiva 1992; Giri and Muhlhausen 2008; Hernández-Cornejo et al. 2005; Kairo et al. 2002; Satapathy et al. 2007; Thu and Populus 2007), and mapping of seagrass beds (Green et al. 2000). In the tropics, mangrove losses through economic development are receiving increasing attention from scientists and policy-makers because of the essential role these communities play in supporting animal species (especially economically important fish and shellfish species) and biodiversity in general, protecting against coastal erosion, and episodic storm and tsunami surges, filtering of suspended solids, nutrient recycling, storing and capturing carbon for climate change mitigation (Alongi 2008; Bouillon et al. 2008; Chmura et al. 2003; Crooks et al. 2011; Dahdouh-Guebas et al. 2005; Das and Vincent 2009; Kathiresan and Rajendran 2005; Laffoley and Grimsditch 2009; Mohammed et al. 2001; Nagelkerken et al. 2008; Seto and Fragkias 2007; Twilley et al. 1992). Beside the conversion of land-based mangroves to socio-economic-related development (i.e., road, urban development, aquaculture), actual records of mangrove clearing for other purposes (i.e., charcoal, firewood, timber) are rare

since this activity is illegal in most countries (Bouillon et al. 2009), and thus remotely sensed data can provide the most reliable and transparent information for management and decision making (Seto and Fragkias 2007).

With the exponential growth of shrimp farming in tropical coastal areas, a number of studies have used remotely sensed data to evaluate impacts of this activity on landscape changes, especially the relationship between the contraction of mangrove forests and expansion of shrimp farms (Green et al. 2000). For example, Dahdouh-Guebas et al. (2002) used aerial photographs to investigate the conversion of mangroves to shrimp farms in the Pambala-Chilaw lagoon complex, Sri Lanka and found that approximately 13 ha of mangroves and 12 ha of coconut plantations were converted to shrimp farms between 1994 and 1998. Alonso-Pérez et al. (2003) used Landsat MSS and TM imagery to detect land cover changes in the Ceuta coastal lagoon system, Mexico between 1984 and 1999 and found that annual mangrove deforestation rate of around 0.3 %, but this rate was not directly related with growth in shrimp farming (3,190 ha shrimp farms, mainly replacing bare soil and salt marsh). Tong et al. (2004), using SPOT imagery from 2001 and a 1965 topographic map, reported that approximately 30 % of mangroves had been lost in Ca Mau, South Vietnam from 1965 to 2001 due mostly to extensive shrimp farming activity. By using Landsat TM and Landsat ETM+ to detect land cover/land use changes in Giao Thuy, Nam Dinh, North Vietnam, Beland et al. (2006) found that 63 % of mangrove areas apparent in 1986 had been replaced by shrimp farms in 2001, and that 440 ha of adult mangrove trees had disappeared between 1986 and 1992, while new mangrove areas increased by 441 ha between 1992 and 2001 as a result of reforestation projects. In summary, coastal shrimp farming may cause substantial coastal landscape changes and remote sensing data can provide reliable information to detect and monitor such changes on significant geographic scales (Alonso-Pérez et al. 2003; Seto and Fragkias 2007).

As with many tropical coastal areas, shrimp farming activity had rapidly developed in Quang Ninh province, in North Vietnam over the last decade, and such development may lead to substantial and unquantified land cover/land use changes in the region. Changes of land cover/land use patterns, especially the losses of mangrove forest in coastal areas of this region may negatively impact the natural ecosystems of the adjacent World Heritage-listed Ha Long Bay. The loss of mangrove forest also leads to decrease carbon sequestration and released carbon dioxide into the atmosphere, reducing efforts to mitigate global climate change (Bouillon et al. 2009; Crooks et al. 2011). Therefore, satellite imagery acquired from the ALOS AVNIR-2 and Landsat 7 ETM+ sensors was used in this study to provide an overview and up-to-date information of shrimp

farming development and land cover/land use changes in coastal areas of the Quang Ninh between 1999 and 2008. A special emphasis was the documentation of the relationship between the contraction and expansion of mangroves and shrimp farms; and thereby contributing essential information for the management of a sustainable shrimp farming industry and at the same time for protecting the highly valued environmental and natural resources in coastal areas.

Materials and methods

Study areas

The study focused on two sites within the Quang Ninh province, North Vietnam, in the Ha Long (106°50′–107°04′E, 20°52′–21°02′N) and Mong Cai (107°53′–108°05′E, 21°24′–21°32′N) regions which both have a high density of intensive and semi-intensive shrimp farms (Fig. 1).

The Quang Ninh province is characterized by tropical climate which is hot, humid and rainy during summer and cool and dry in winter. Annual average air temperature is 21 °C and high air temperatures normally occur in June and August each year. Rainy season starts in May and ends in October. Annual rainfall ranges from 1,700 to 2,400 mm with about 90–170 rainy days per year, and is mainly concentrated in the summer, especially from July to August. Weather in Mong Cai region is slightly cooler with higher rainfall than that for Ha Long region (People's Committee of Quang Ninh Province 2011). Both study areas are coastal

plains and tidal flat that include some low hills and limestone mountains. The tidal regime at the study areas is diurnal with one daily high and one daily low tide. Tidal flats are situated outside and within mangrove stands. The study area of Ha Long is a part of the Ha Long Bay World Heritage-listed site, which attracts millions of national and international visitors each year (People's Committee of Quang Ninh Province 2011; UNESCO 2011).

In the study areas, aquaculture in general and specifically coastal shrimp farming had rapidly developed in terms of land used, aquatic biomass production over the last decade, especially after the approval and implementation of the "Master Plan for Fisheries Development of Quang Ninh Province in 2001–2010" as well as the general encouragement from pro aquaculture-related policies from the local governments (DoF Quang Ninh 2001, 2005). Annual commercial cultured shrimp product of Quang Ninh province increased gradually from 518 tons in 1995 to 903 tons in 2001, nearly doubled in 2002 (1,748 tons), reaching a peak of 7,126 tons in 2007 and slightly declining since then (General Statistics Office of Vietnam 2009). According to annual reports of districts in the study areas, shrimp farms in Ha Long and Mong Cai shared around 65–70 % of the total annual cultured shrimp product of the province for these years (see People's Committee of Hoanh Bo District 2010; People's Committee of Mong Cai City 2006, 2007, 2008, 2009, 2010; People's Committee of Yen Hung District 2008, 2009). Even though the areas used for intensive and semi-intensive shrimp farms were not clearly reported in documents of the districts and cities, the above information demonstrates that the expansion of shrimp farming in Quang Ninh

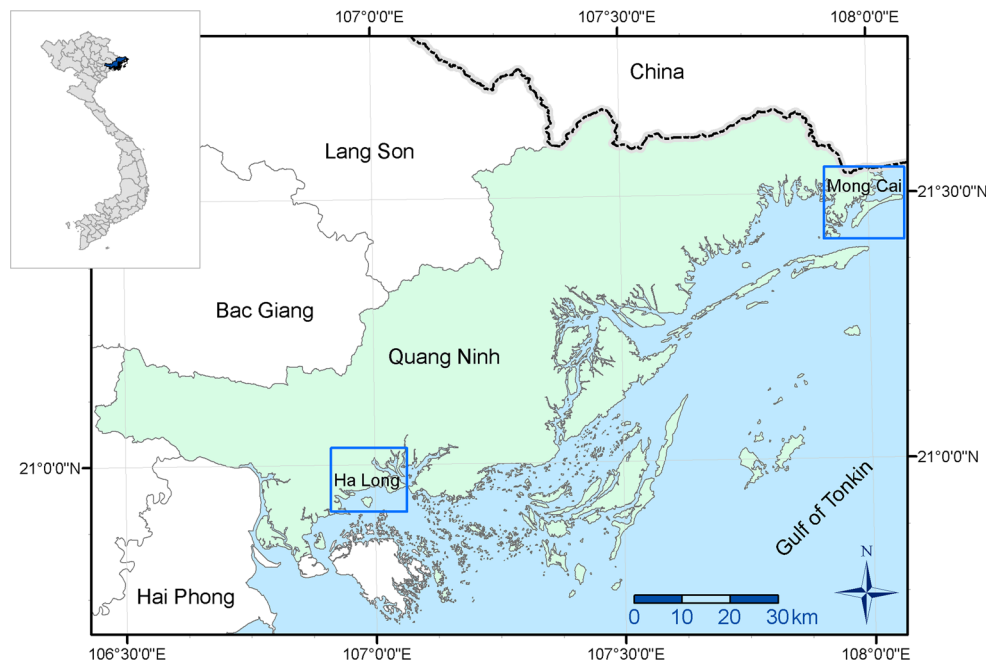Fig. 1 Location of the study areas (Ha Long and Mong Cai) in Quang Ninh province, Vietnam

Table 1 Main characteristics of acquired satellite imagery used in this study

Sensor	Spectral bands in use	Spatial resolution (m)	Path/row	Acquisition date	Study area
ALOS AVNIR-2	4 bands:	10	122	17/10/2008	Ha Long
	Band 1: 0.42–0.50 μm		120	14/12/2008	Mong Cai
	Band 2: 0.52–0.60 μm				
	Band 3: 0.61–0.69 μm				
	Band 4: 0.76–0.89 μm				
Landsat7 (ETM+)	6 bands:	30	126/45	16/11/2001	Ha Long
	Band 1: 0.45–0.515 μm		125/45	22/12/1999	Mong Cai
	Band 2: 0.525–0.605 μm				
	Band 3: 0.63–0.69 μm				
	Band 4: 0.75–0.90 μm				
	Band 5: 1.55–1.75 μm				
	Band 7: 2.09–2.35 μm				

mainly occurred from 2001 to 2007 and is concentrated in the Ha Long and Mong Cai regions.

Satellite imagery and reference dataset

The satellite imagery used in this study was acquired from the ALOS AVNIR-2 and Landsat 7 ETM+ sensors for two different time periods (2008 and 1999/2001). The selection of the 1999/2001 time period as baseline for this study is because intensive and semi-intensive shrimp farms were mainly developed in this province after 2001 as mentioned above. In addition, the satellite imagery selected for this study should be captured during the dry season, at low tide and cloud-free in the study areas. Therefore, although many Landsat TM and ETM+ images are available now-adays free of charge, only two scenes of Landsat 7 ETM+ captured in Mong Cai in 1999 and in Ha Long in 2001 were used in this study (Table 1). Tide prediction values at the moments of acquisition were around 1.6 m for the 1999 Landsat image and 2.4 m for the 2008 ALOS image in Mong Cai, 1.9 m for the 2001 Landsat image and 2.1 m for the 2008 ALOS image in Ha Long (values for the Hon Gai station in Ha Long).

In addition to the satellite data described above, Google Earth, Google Maps, digital topographic maps (1:50,000) from National Cartographic Publishing House, a soil map of Quang Ninh province from National Institute of Agricultural Planning and Projection, and Landsat images captured at high tide were used to provide ancillary data. A global positioning system (GPS) Garmin 72 was also used for ground truthing in the study areas.

Methods

Because satellite images were acquired from different sensors (Landsat and ALOS) with different spatial and

spectral resolutions, images were analyzed separately using ERDAS Imagine software (version 9.3). By using these processes, a post-classification comparison method was applied to detect land cover/land use changes in this study (Singh 1989). This method was also reported as the most accurate procedure and presented the advantage of indicating the nature of the changes (Mas 1999). ArcGIS software (version 9.3.1) was also used for mapping work in this study.

Pre-processing satellite data

Image pre-processing refers to operations before the data are used for a particular purpose, such as image enhancement, radiometric corrections, geometric correction or subset of the region of interest (Campbell 2002; Mather 2004). In this study, the dark object subtraction (DOS) method was used for atmospheric correction since this is a simple and a very common method (Campbell 2002; Chen et al. 2005; Hadjimitsis et al. 2004; Hadjimitsis et al. 2010; Song et al. 2001) and a clear water area in the deep sea was available as a dark object in the study images. For Mong Cai's images, the Mong Cai region was selected as a subset from the original large scenes before carrying out geometric corrections because such scenes include a large section of the Chinese landscape.

The geometric correction process was carried out separately for the Ha Long and Mong Cai imagery. The 2008 ALOS image was first geometrically registered to a Universal Transverse Mercator (UTM) projection with the World Geodetic System 1984 (WGS84) datum in zone 48 N using 1:50,000 scale topographic map and the image to map correction with 15 ground control points. Image to image geometric corrections was then performed on the Landsat image using the ALOS image as reference. Nearest neighbor re-sampling and first-order polynomial geometric

modeling was used for the geometric correction process, and the root mean square (RMS) errors obtained were less than 0.15 pixels in each case.

The subset areas of Ha Long and Mong Cai were created after the images were geometrically corrected. Image enhancement was carried out in order to improve the visual interpretability of images by increasing the apparent distinction between features, and thereby optimizing the complementary abilities of the human mind and the computer (Mather 2004; Shalaby and Tateishi 2007). Linear contrast stretch, histogram equalization and Gaussian stretch are methods used to "try and select" in image enhancement (Mather 2004).

Image interpretation and classification

In the early stages of this project, the unsupervised/supervised classification process when applied to the whole of Ha Long and Mong Cai imagery met difficulties due to a number of reasons. For instance, a number of classes were generated for shrimp farms (expected only one class) due to the variety of spectral reflectance for pond banks, full ponds, empty ponds, storage houses, and so on. In addition, the separation of mangroves from some forests on adjacent sloping land was problematic because they have very similar spectral signatures in all observation bands. Further digital elevation models (DEM) for the study areas are very coarse (90 m resolution) so such DEMs cannot help to enhance the classification process in this case. Therefore, in order to meet this project aim to quantify the contraction and expansion of mangrove areas and shrimp farms, image visual interpretation was applied to classify images into land cover/land use categories as provisional classification step (see Aaviksoo and Karin 2008; Alonso-Pérez et al. 2003; Shalaby and Tateishi 2007; Tong et al. 2004). Integration of visual interpretation and classification can increase the overall accuracy of final thematic maps (Shalaby and Tateishi 2007).

Key elements for image interpretation include tone, texture, shadow, pattern, shape, size and site of objects or features (Campbell 2002). In addition, ancillary data such as ground truth information through field trips, Google Earth, a topographic map and the Quang Ninh soil map was integrated for this process (Aaviksoo and Karin 2008; Campbell 2002).

Images were manually classified into categories of shrimp farm, water, intertidal zone, and other (inhabited areas, agricultural areas, terrestrial forest, mountains and so on). Shrimp farms were firstly masked out by on-screen digitizing with key criteria defined in Table 2 (see Zitello 2007) and ancillary data (i.e., field visits, aquaculture zones in master plans of local province or districts). Water was masked out by applying a threshold to the near infrared

Table 2 Description of land cover/land use classes of the study areas

Class name	Description
Mangrove	Dense mature halophile trees growing in tidal brackish or salt water
Shrimp farm	Intensive and semi-intensive aquaculture farms[a], including reservoirs and intake/drainage channels to connect with tidal waterways at concentrated shrimp farming areas. Farms were generally found with standard geometric forms of ponds (i.e., rectangular or square); having a number of ponds with high spectral reflectance of pond banks; and located in proximity to tidal waterways
Wet bare ground	Muddy and wet tidal flat, generally found in low elevation, sparsely vegetated
Dry bare ground	Sand dunes in intertidal zones, generally found in slightly higher elevation, sparsely vegetated; and road/port in intertidal zones
Water	Open sea water or other inland water bodies
Other	The remaining areas from above categories in images, including inhabited areas, agriculture, terrestrial forest, casuarinas forest, rocky areas and mountains and so on

[a] Extensive aquaculture farms are not included because they have mangrove trees inside ponds, and mangrove areas should be classified in the mangrove class. In addition, extensive farms are normally designed to harvest all kind of aquatic animal products (i.e., fish, shrimp, crab, mollusk) while this study focuses specifically on intensive and semi-intensive shrimp farms. Field visits and documents from the local government showed that most intensive, semi-intensive farms in the study areas were constructed specifically for shrimp farming; thus, it was seen as appropriate to classify intensive and semi-intensive farms detecting from study images as shrimp farms

band or near infrared/red band ratio as water strongly absorbs near infrared radiation (Mather 2004; Tso and Mather 2009). Intertidal zones were masked out by visual interpretation with criteria, such as outside sea levees or borders with other terrestrial activities, in salty soil/sandy soil classes in the soil map, having mangroves, and be submerged under water in images captured at high tide. The remaining area after masking out shrimp farms, water and intertidal zones was labeled as "other".

The full hybrid classification (unsupervised/supervised) was carried out for intertidal zones to generate classes of mangroves, wet bare ground, dry bare ground, and water (if water was not completely masked out) (Table 2). Typically, iterative self-organizing data (ISODATA) analysis technique was used in unsupervised classification to generate 20 classes as well as its signature set. The derived classes were then evaluated and regrouped to new classes of mangroves, wet bare ground, dry bare ground and water based on the original multispectral image, ground truth information from field observations, and other available ancillary data; and the new training signatures for such new classes were defined. The training signatures were finally used for supervised classification with the maximum

likelihood classifier as a parametric decision rule. Other categories (shrimp farm, water, other) were classified as one class.

Post-classification

Thematic maps for categories of shrimp farm, water, intertidal zone and other were merged together to create one whole land cover/land use map in Ha Long and Mong Cai regions. A 3 × 3 median filter was used to reduce the "salt and pepper" effect (Aaviksoo and Karin 2008; Mather 2004).

Accuracy assessment

The land cover/land use maps were assessed for their accuracy. This was done by comparing them with observations in the field. These field ground truthing points were recorded during field trips conducted in February, March, November and December 2009, March 2010, and April 2011. The accuracy of the 1999/2001 maps was not assessed due to the lack of reference data at that period of time. An error matrix was created by using the data from the output map as the rows and the reference data from ground truthing as the columns, and a number of difference accuracy indicators (i.e., overall accuracy, error of omission and commission, Kappa coefficients) were calculated using this matrix.

Land cover/land use change detection

The detection of mangrove and shrimp farm changes between 1999/2001 and 2008 was carried out by comparing the area (ha) of each land cover/land use class in the final thematic maps. In order to perform a pixel-by-pixel comparison to detect land cover/land use changes, the 2008 thematic maps were re-sampled to 30 m pixels to provide correspondence with the pixel size of the 1999/2001 thematic maps (Alonso-Pérez et al. 2003; Luque 2000). Obtaining the change detection matrix from the pixel-by-pixel comparison reveals which pixels have changed and the class to which they formerly belonged. Changes in land cover/land use class through time were determined. Land cover/land use change maps were also generated by overlaying the 2008 thematic maps on the 1999/2001 maps.

Results

Land cover/land use classification of satellite data

Land cover/land use classes (mangrove, shrimp farm, wet bare ground, dry bare ground, water, and other) in coastal areas of Ha Long and Mong Cai generated from the 1999/2001 and 2008 imagery are presented in Figs. 2 and 3. Large areas of intensive and semi-intensive shrimp farms can clearly be seen in the 2008, but not in the 1999/2001 maps.

The accuracy assessment for the 2008 thematic maps showed that the overall classification accuracy of the 2008 maps was 95.7 and 98.3 % in Ha Long and Mong Cai, respectively. The largest classification error occurred for wet bare ground in Ha Long (with 91.4 % accuracy) and dry bare ground in Mong Cai (with 87.5 % accuracy) (Tables 3 and 4). Overall Kappa statistics were 0.9473 in Ha Long and 0.9784 in Mong Cai, and the lowest Kappa coefficients were also found in the class with the highest classification error in each thematic map. Reference data were not available for the accuracy assessment of the 1999/2001 classified imagery, but because the image processing for the 1999/2001 scenes were the same as for the 2008 scenes, a similar accuracy level was assumed (see Alonso-Pérez et al. 2003; Hernández-Cornejo et al. 2005).

The resulting classifications found that while mangrove areas in Ha Long have reduced by 927.5 ha from 2001 to 2008 (34.9 %), the area of intensive and semi-intensive shrimp farms over the same time period increased by 1,195.9 ha (Table 5). A similar pattern was found in Mong Cai region with 1,144.4 ha of mangrove lost compared with 1,702.5 ha of shrimp farm constructed between 1999 and 2008. Although the bare ground area of both Ha Long and Mong Cai decreased over the study period, the area or the percentage change in "bare ground" in Mong Cai was higher than for Ha Long. There was little change in the area of "water" and land cover/land use for "other" between the 1999/2001 and 2008 imagery (Table 5).

Land cover/land use change detection

The ALOS 2008 land cover/land use maps were re-sampled to a pixel size of 30 m, which is the same as the 1999/2001 maps derived from Landsat images before the pixel-by-pixel comparison. There was little change (<0.6 %) in the area of each land cover/land use class after the re-sampling process, and this showed that the landscape matrix for the 1999/2001 and 2008 imagery were not significantly affected by the re-sampling process.

The results of the pixel-by-pixel comparison of the land cover/land use maps in Ha Long region found that 56.3 % of mangrove area was unchanged from 2001 to 2008 and that 31.6 % (840.8 ha) of mangrove was lost to water and bare grounds. Only 10.7 % (285.6 ha) of mangroves was converted to shrimp farms in 2001–2008. Figure 4 shows places of mangrove contraction and expansion in this region between 2001 and 2008, and clearly illustrates that the area of mangrove loss was much greater than new

Fig. 2 Land cover/land use map of Ha Long, **a** using the Landsat ETM+ 2001 imagery, **b** using the ALOS 2008 imagery
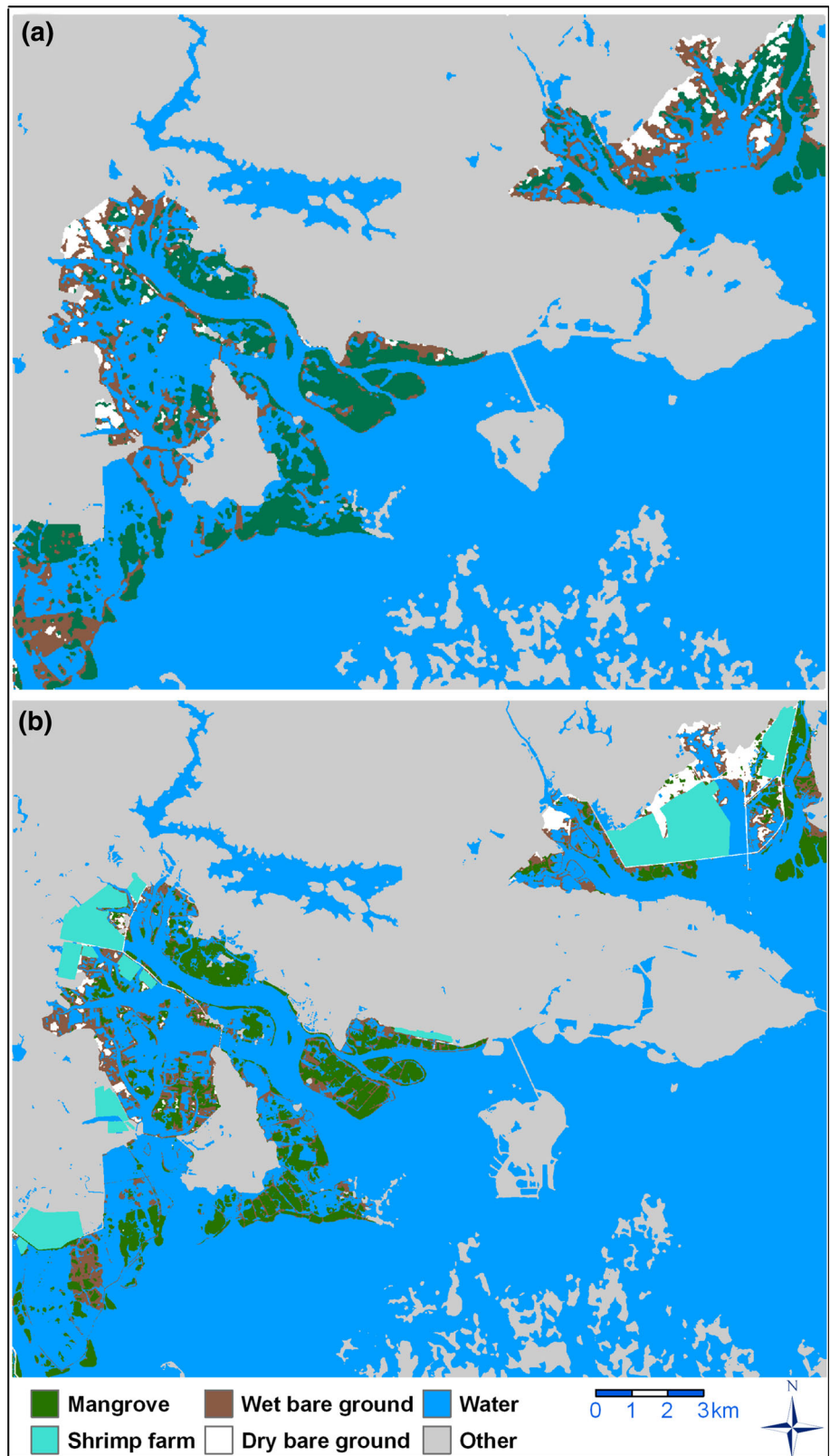
mangrove areas. The area of wet bare ground in the 2001 image mainly changed to water in the 2008 image (41.6 %). Significant part of dry bare ground (48.9 %) was converted to shrimp farms between 2001 and 2008. The areas of water and land cover/land use for "other" changed little over the study period (93.1 and 96.8 %, respectively).

Fig. 3 Land cover/land use
map of Mong Cai, **a** using the
Landsat ETM+ 1999 imagery,
b using the ALOS 2008 imagery
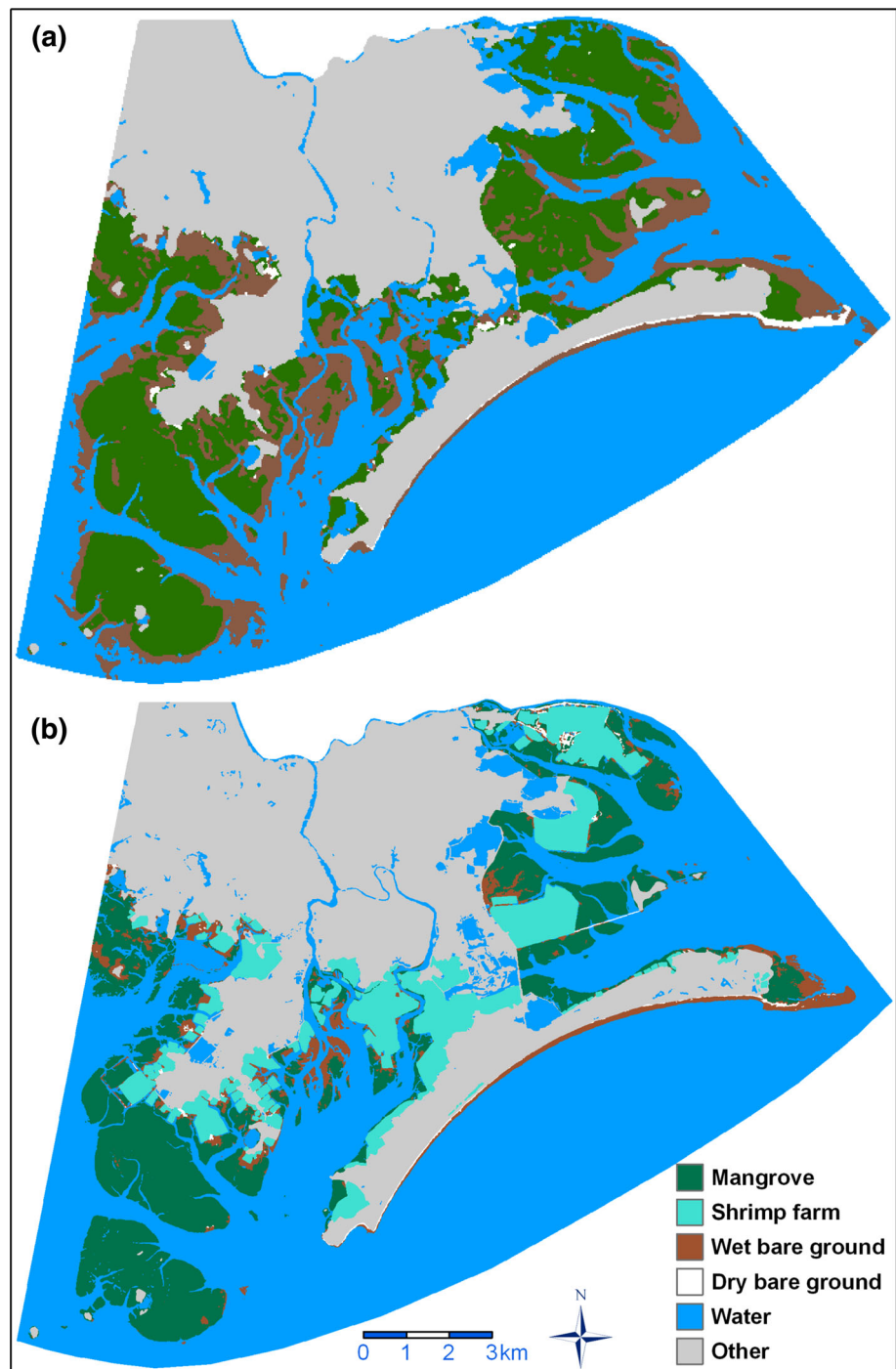
In the Mong Cai region, the results of the pixel-by-pixel comparison of the land cover/land use maps found that 65.6 % of mangrove area was unchanged from 1999 to 2008 and that 20.8 % (841.5 ha) of the mangrove area was cleared for shrimp farming activities. The location and extent of unchanged and changed mangrove area in Mong Cai between 1999 and 2008 is presented in Fig. 5, and shows a similar pattern as in Ha Long where the areas of mangrove loss were much higher than for the establishment of new mangroves. The area of "wet bare ground" in the 1999 map mainly changed to "water" in the 2008 map. A significant part of dry bare ground (41.0 %) was changed to wet bare ground and 27.9 % of this soil type was converted to shrimp farms. The classes of "water" and "other" changed little in this study with the unchanged areas accounting for 94.1 and 95.2 %, respectively.

In terms of land types converted to shrimp farms, the comparison of the 2001 and 2008 imagery in Ha Long

Table 3 Error matrix, accuracy estimates and Kappa statistics for the 2008 classified data and reference data (ground truth points) in Ha Long

Classified data	Reference data						Row total	Producers accuracy (%)	Users accuracy (%)	Kappa statistics
	Mangrove	Shrimp	Wet bare ground	Dry bare ground	Water	Other				
Mangrove	**59**	0	1	0	0	0	**60**	92.2	98.3	0.9778
Shrimp	1	**35**	0	1	0	0	**37**	100.0	94.6	0.9374
Wet bare ground	3	0	**53**	2	0	0	**58**	94.6	91.4	0.8897
Dry bare ground	0	0	0	**27**	0	0	**27**	90.0	100.0	1.0000
Water	0	0	2	0	**23**	0	**25**	100.0	92.0	0.9121
Other	1	0	0	0	0	**48**	**49**	100.0	97.9	0.9749
Column total	**64**	**35**	**56**	**30**	**23**	**48**	**256**			

Table 4 Error matrix, accuracy estimates and Kappa statistics for the 2008 classified data and reference data (ground truth points) in Mong Cai

Classified data	Reference data						Row total	Producers accuracy (%)	Users accuracy (%)	Kappa statistics
	Mangrove	Shrimp	Wet bare ground	Dry bare ground	Water	Other				
Mangrove	**84**	0	1	0	0	0	**85**	100.0	98.8	0.9835
Shrimp	0	**57**	1	0	0	0	**58**	100.0	98.3	0.9786
Wet bare ground	0	0	**47**	1	0	0	**48**	94.0	97.9	0.9748
Dry bare ground	0	0	0	**7**	1	0	**8**	87.5	87.5	0.8715
Water	0	0	0	0	**35**	0	**35**	97.2	100.0	0.9783
Other	0	0	1	0	0	**56**	**57**	100.0	98.2	1.0000
Column total	**84**	**57**	**50**	**8**	**36**	**56**	**291**			

Table 5 The area of different land cover/land use classes derived from satellite data in Ha Long and Mong Cai

Class name	Ha Long				Mong Cai			
	Area (ha)		Area change (ha)	% change	Area (ha)		Area change (ha)	% change
	2001	2008			1999	2008		
Mangrove	2,658.8	1731.3	−927.5	−34.9	4,052.1	2,907.7	−1,144.4	−28.2
Shrimp	0.0	1,195.9	+1,195.9	+100.0	0.0	1,702.5	+1,702.5	+100.0
Wet bare ground	1,512.3	1,096.0	−416.3	−27.5	2,282.2	600.7	−1,681.6	−73.7
Dry bare ground	542.3	421.1	−121.2	−22.4	118.0	65.0	−53.0	−44.9
Water	19,913.0	20,149.5	+236.5	+1.2	9,107.9	10,439.6	+1,331.7	+14.6
Other	18,224.1	18,240.7	+16.6	+0.1	6,325.2	6,123.1	−202.1	−3.2

−: reduction; +: increase in comparison with the 1999/2001 data

revealed that shrimp farms were mainly constructed on bare soil (46.5 %) and existing water bodies (29.3 %). Mangrove-based land only accounted for 23.9 % of the area converted to shrimp farming in Ha Long in 2008.

However, in Mong Cai region, the construction of shrimp farms has taken place mainly on soils previously occupied by mangroves (49.4 %), water (23.6 %) and wet bare ground (23.5 %) (Fig. 6).

Fig. 4 The contraction and expansion of mangroves in Ha Long between 2001 and 2008
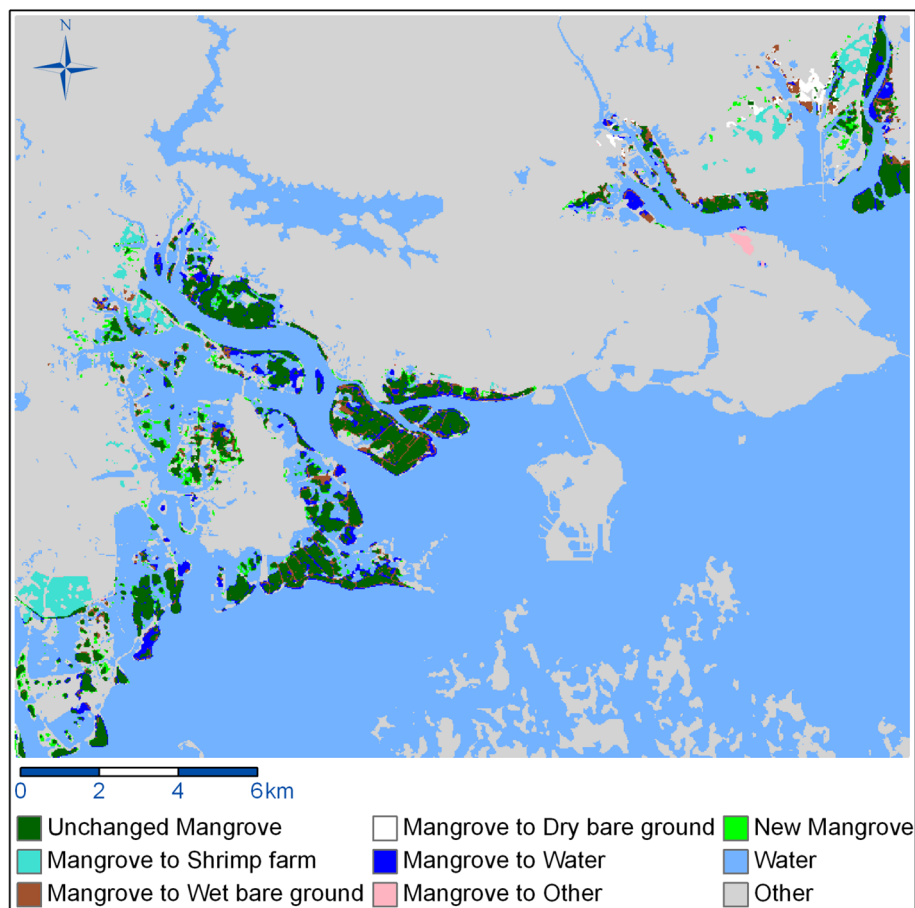
Discussion

Remarkable rapid change of land cover/land use relating to shrimp farming activities in coastal areas of Ha Long and Mong Cai regions was documented from the Landsat ETM+ and ALOS data between 1999/2001 and 2008 in this study. The Kappa coefficients showed strong agreement between the derived land cover/land use maps and reference data (see Landis and Koch 1977). Accuracy levels were consistently higher than the suggested level (85 %) by Congalton and Green (2009) for accuracy assessment of remotely sensed data. High accuracy levels most likely result from the good spectral separation of classes of interest (mangrove, wet bare ground and dry bare ground, water) in this study. In addition, combination of manual interpretation with automatic classification can lead to an increase in overall accuracy (by about 10 % as reported in the study of Shalaby and Tateishi 2007).

Land cover/land use changes

The central issue relating to landscape changes in tropical coastal areas is addressed in relation to the contraction and expansion of mangrove forest due to ecological and socio-

economic benefits of this ecosystem. Previous studies have documented the loss of large areas of mangroves in coastal areas in a number of countries (FAO 2007a, b; Satapathy et al. 2007; Thu and Populus 2007; Tong et al. 2004; Valiela et al. 2001). One of the biggest threats to mangrove forests is the continued expansion of coastal aquaculture in general and shrimp farming in particular (Dierberg and Kiattisimkul 1996; Jenkins et al. 1999; Páez-Osuna 2001; SEAFDEC 2000; Senarath and Visvanathan 2001; Seto and Fragkias 2007). As with the same pattern with many previous studies, the results of this study showed that there was a significant loss of mangroves in Ha Long (927.5 ha) and Mong Cai (1,144.4 ha) between 1999/2001 and 2008. The average annual reduction of mangroves in the study areas was 3.13–4.98 % (127.2–132.5 ha), which is much higher than that of the whole of Vietnam (2.3 % in 1980–1990, 3.0 % in 1990–2000, and 0.1 % in 2000–2005) (FAO 2007a, b).

While a significant part of mangroves in Mong Cai was cleared for shrimp farming activity (841.5 ha or 73.5 % of the total mangrove loss in 1999–2008), only 285.6 ha (10.7 %) of mangroves was converted to shrimp farms from 2001 to 2008 in Ha Long. A main part of mangrove loss in Ha Long (840.8 ha or 90.7 % of the total mangrove

Fig. 5 The contraction and expansion of mangroves in Mong Cai between 1999 and 2008
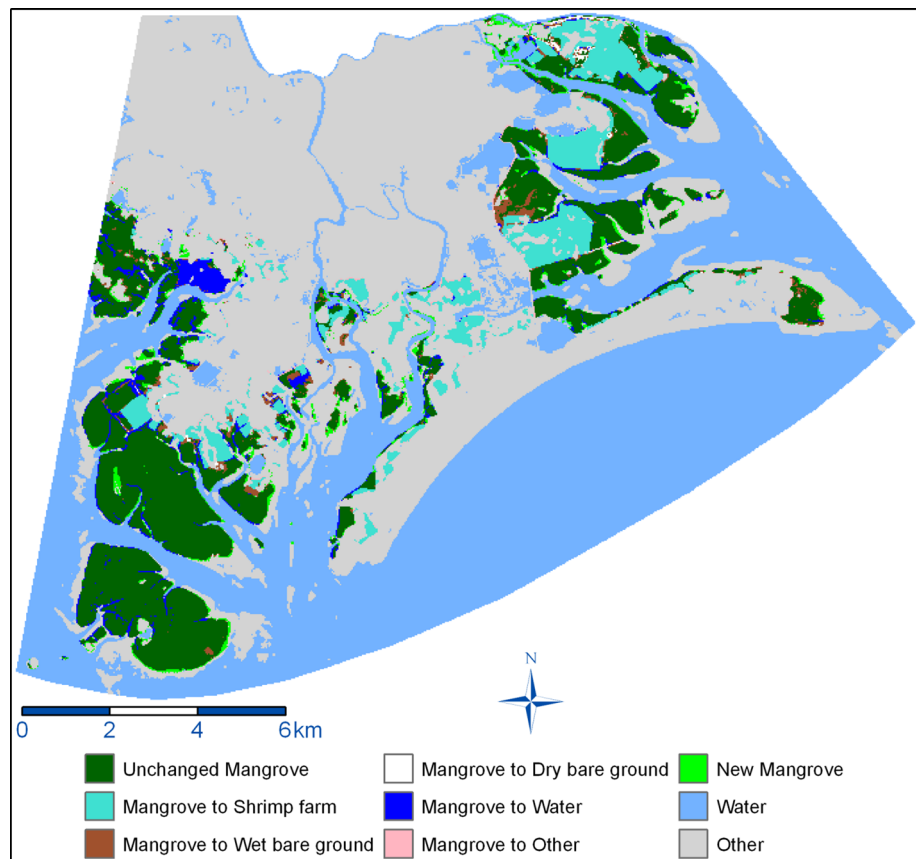
loss in 2001–2008) is to "water" and "bare ground". Field trips to the study area found that many of the sites of mangrove loss are located close to sea levees or new roads, and inside extensive aquaculture farms in Ha Long region. The construction of levees, roads may lead to environmental change (i.e., changes of tidal zones and levels, salinity) in coastal areas and the reduction of mangroves in such surrounding areas as a result. The construction of banks, digging and clearing areas to hold and harvest aquatic animal products in extensive aquaculture farm are also a cause for mangrove loss. In other words, intensive and semi-intensive shrimp farming was not the main reason for mangrove loss in Ha Long region but this industry was the main cause of mangrove loss in Mong Cai region.

The area of mangrove expansion was extremely small compared to the levels of reduction in both Ha Long (234.3 ha) and Mong Cai (245.5 ha). In comparison with the total mangrove areas extracted in the initial map (1999/2001), the average annual expansion rates of mangrove forest in Ha Long and Mong Cai were 1.3 and 0.7 %, respectively. New mangroves mainly became established on soils that were previously bare soil, especially wet bare ground. Such conversion of bare grounds in the 1999/2001 images into mangroves by 2008 may be the result of the growth of sparse and small mangrove trees in areas of previously bare grounds in the initial scenes.

Intensive and semi-intensive shrimp farms were not extracted in the initial scenes and thus shrimp farming areas were recorded as almost zero in 1999/2001. This lack of development is also supported by documents that reported that shrimp farms in Quang Ninh were developed after 2001 when the Master Plan for Fisheries in Quang Ninh Province (2001–2010) was established and aquaculture-related policies from the local government were approved that encouraged shrimp farm development. In fact, some extensive coastal aquaculture farms (in a very huge area with mangrove trees inside, various shapes and uncleared banks) were detected in the initial scenes. However, extensive farms are normally designed to harvest all kinds of aquatic products including shrimp, so such farms were not defined as shrimp farms in this study.

Over the period of interest, shrimp farming areas in Mong Cai increased by around 1.5 times more than that at the Ha Long site. In addition, a different pattern of land used to construct shrimp farms was detected from satellite data in this study. Most shrimp farms in Ha Long were built on bare areas (46.5 % of the total shrimp farming area) while they were mainly built in mangrove areas in Mong Cai (49.4 % of the total shrimp farming area). Thus, significant attention should be paid by the local government in order to protect mangrove forests from further shrimp farming activities in Mong Cai area.
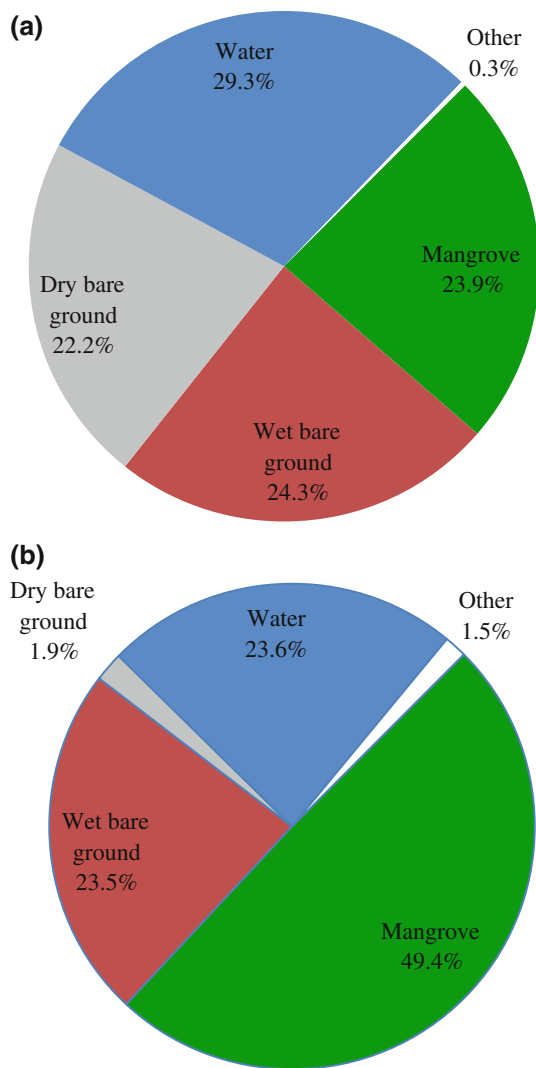
Fig. 6 The proportion of land cover/land use types converted to shrimp farms in **a** Ha Long from 2001 to 2008; and **b** in Mong Cai from 1999 to 2008

Apparent changes of bare ground to water and vice versa in intertidal zones usually occur in remote sensing-based studies because the selection of imagery captured at different time with the same tidal level for the pixel-by-pixel comparison process is very difficult or impossible. Therefore, the conversion of 1,324.6 ha wet bare ground in the 1999 imagery to water class in the 2008 imagery of Mong Cai has to be seen in this context since tide prediction values at the moments of acquisition were around 1.6 and 2.4 m for the 1999 and 2008 images, respectively. In addition, extensive aquaculture activities (with closing or opening farm gates) and the construction of sea levees and roads may lead to changes between bare ground and water class in coastal areas of Ha Long.

Impacts of mangrove loss

There was a remarkable mangrove loss in coastal areas of Ha Long and Mong Cai regions and such wetland deterioration may lead to negative impacts on natural estuarine and marine ecosystems. It is now well recognized the essential roles of mangroves as breeding grounds, nursery areas and general habitats for many wild aquatic species (i.e., crabs, shrimps, fishes, mollusks) as well as terrestrial species (i.e., birds, insects, mammals and reptiles) and for biodiversity in general (Nagelkerken et al. 2008; Páez-Osuna 2001; SEAFDEC 2000; Seto and Fragkias 2007), and thus mangrove deforestation may cause the reduction of biological and genetic diversity in coastal areas. The destruction of mangroves also depletes nutrient sources (i.e., mangrove litters) for the marine food web (Kristensen et al. 2008; Nagelkerken et al. 2008). In addition, mangroves destruction may affect nutrient processes in estuarine and marine systems because mangroves are shelters for a variety of microorganisms which form an important basis for nutrient transformations (Nagelkerken et al. 2008; Sjöling et al. 2005).

Studies have revealed that mangroves can act as biofilters for the treatment of wastewater including shrimp farm effluent (Boonsong et al. 2003; Gautier et al. 2001; Rivera-Monroy et al. 1999; Robertson and Phillips 1995; Tilley et al. 2002; Yang et al. 2008); thus, the loss of mangrove limits bioremediation functionality for local coastal ecosystems. As a consequence, environmental deterioration surrounding coastal shrimp farms becomes more severe since a large amount of effluent discharged from shrimp farms has less opportunity for remediation with mangrove-biofilters. The loss of mangrove forests also reduces its functional roles in preventing coastal erosion and saline intrusion, trapping sediments, and mitigating cyclones, flood and tsunamis damages (Alongi 2008; Dahdouh-Guebas et al. 2005; Das and Vincent 2009; Kathiresan and Rajendran 2005; Mazda et al. 2007), leading to unintended consequences for both human and natural systems (Twilley 2007).

In relation to climate change mitigation, loss of mangrove forest in coastal areas leads to decreased carbon sequestration and increased emissions of large amounts of carbon dioxide (CO_2) directly to the atmosphere. As with other coastal wetlands (i.e., salt marsh, seagrass), mangroves are long term net sinks for atmospheric CO_2 through production of standing biomass and burial of primarily root and rhizome organic matter in sediment (Bouillon et al. 2008, 2009; Crooks et al. 2011; Twilley et al. 1992). The burial of carbon in mangroves is not only by direct input of mangrove production into the sediment pool but also by increasing sedimentation rates to capture and store organic matters into sediments (Bouillon et al. 2009; Kristensen

et al. 2008). Therefore, clearing of mangroves can rapidly result in significant reduction of carbon sequestration in sediments (Bouillon et al. 2009; Granek and Ruttenberg 2008).

Although carbon can be lost from degradation in coastal wetland as well as near-shore marine ecosystems, the destruction of mangroves may disturb and allow much oxygen to enter soils which then promote microbial activities that converts carbon stocks, that have built up over millennia, into CO_2 and then releasing it into the atmosphere (Crooks et al. 2011; Kristensen et al. 2008). The emission of CO_2 into the atmosphere at cleared mangrove areas is anticipated to be most rapid during the period immediately following mangrove conversion and then to subside with time (Crooks et al. 2011). Clearly, the carbon pool lost through mangrove deforestation substantially exceeds that of simple removal of standing mangrove biomass (Bouillon et al. 2009), and this will lessen efforts to mitigate global climate change.

With a global area of mangroves of 160,000 km^2, Bouillon et al. (2008) estimated that carbon captured in the net primary production is around 218 ± 72 Tg C/year and carbon burial within mangrove system is approximately 18.4 Tg C/year. This means that 1 ha mangrove forest can sequester around 10.3–19.3 tons C per year (9.1–18.1 tons for net primary production and 1.2 tons for carbon burial). Therefore, carbon sequestration in mangrove forests at Ha Long and Mong Cai regions had reduced an estimated 2,678–5,018 tons C per year with the annual reduction of mangrove forest estimated at 260 ha for two study sites in this study.

Conclusion

Remarkable change of land cover/land use in coastal areas of Quang Ninh, Vietnam between 1999 and 2008 in relation to shrimp farming industry is documented in this study. The results from post-classification comparison of the 2008 ALOS images and the 1999/2001 Landsat ETM+ showed that shrimp farming areas increased dramatically from almost zero in 1999/2001 to an estimated 1,702.5 ha in Mong Cai and 1,195.9 ha in Ha Long in 2008. Conversely, over the period of interest, around 1,144.4 and 927.5 ha mangroves were reduced in Mong Cai and Ha Long, respectively. Although shrimp farming was the main reason of mangrove loss in Mong Cai (841.5 ha or 49.4 % of the total shrimp farming area), shrimp farms in Ha Long were mainly constructed in areas previously comprising bare soil (556.0 ha or 46.5 % of the total shrimp farming area), and only 285.6 ha of mangroves were converted to shrimp farms. The construction of sea levees, roads and mangrove destruction inside extensive aquaculture farms

also directly or indirectly lead to mangrove loss in coastal areas in Quang Ninh, especially in Ha Long region. The findings of this study indicated that greater awareness of mangrove protection in coastal areas is required in order to protect environment and natural resources in Quang Ninh, Vietnam, as well as to mitigate the effects of global climate change. It would be desirable for mangrove reforestation to expand in these regions (see FAO 2007b), especially surrounding shrimp farms in order to capture and conserve natural carbon for climate change mitigation as well as to preserve ecological and biological values for coastal areas of Quang Ninh province for the long term.

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