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A Brief Description of Recovery Process of Coastal Vegetation after Tsunami: A Google Earth Time-Series Remote Sensing Data

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Abstract

The recovery of land cover/use after the disaster is sometimes disorderly, especially in developing countries. It is necessary to continuously monitor the progress of land cover/use recovery after disaster in order to sustain vegetation around estuarine and coastal areas. The purpose of this study was to assess the recovery progress of vegetation around estuarine and coastal areas after the Indian Ocean tsunami using a simplified method which consisting Google Earth and visual photo interpretation. Vegetation areas were able to be detected with high accuracy (80%−100%) using simplified method which consisting Google Earth and visual photo interpretation. We were able to show that all most of area including mangrove forests recovered relatively smoothly. However, the area which has a large vegetation areas have not enough recovered, which reached to half or less than half compare with before tsunami. This may be significant in affecting the role of the coastal ecosystem and bioshield. A large number of small mangrove patches (less than 0.1 ha) were able to found around ponds, a number that rapidly increased after the tsunami. Some site in 2013 was double that in 2004. Fish farmers might have planted them for supplying nutrients to ponds and maintain the water quality. Dozen years have passed since the 2004 tsunami, and it might be time to more focus on the recovery of large vegetation area.

Keywords:coastal management, fish and shrimp cultivation, GIS, tree planting

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Introduction

Vegetation around estuarine and coastal areas as represented by mangroves is a valuable ecological and economic resource, being important nursery grounds and breeding sites for birds, fish, crustaceans, shellfish, reptiles, and mammals. They are also a renewable source of wood, accumulation sites for sediment, contaminants, carbon and nutrients and offer protection against coastal erosion (Alongi 2002). On the other hand, globally, 1.2 billion people (23% of the world's population) live within 100 km of the coast, and 50% are likely to live there by 2030 (Small & Nicholls 2003). Green space is also important for residents who live in the coastal area as living environments (Lee & Maheswaran 2010; Leeuwen *et al*. 2010; Lestan *et al*. 2014).

Recently, devastating natural disasters have occurred all over the world (UNESCAP & UNSDR 2012; Guha-Sapir *et al*. 2016). Estuarine and coastal areas are exposed to hazards such as coastal flooding, tsunamis, hurricanes, and transmission of marine-related infectious diseases (Fleming *et al*. 2006; Szczuciński *et al*. 2006; Wong 2009a; Knap & Rusyn 2016). Although the recovery of land cover/use is started relatively soon after the disaster, sometimes it is disorderly, especially in developing countries (Wong 2009b; Noy & Vu 2010; Phaup & Kirschner 2010; Kligerman *et al*. 2015). Building and road construction are often given preference than conserving/recovering vegetation. It is necessary to continuously monitor the progress of land cover/use recovery after the disaster in order to sustain vegetation around estuarine and coastal areas.

Remote sensing technology such as aerial photographs and satellite images is useful for monitoring land use/cover changes in the large area, especially for after disasters. Giri *et al*. (2008) assessed and monitored mangrove forests in the tsunami-affected region of Asia using the historical archive of Landsat satellite images. Kamthonkiat *et al*. (2011) also monitored damage and recovery in Thailand after the Indian Ocean tsunami of 2004 using Aster satellite images. Although they were able to obtain useful information from remote sensing data, high-resolution remote sensing data are very expensive (Altamirano *et al*. 2010; Hirata *et al*. 2010). Moreover, in order to analyze satellite images fully utilizing their multiple wavelengths, expensive softwares are required. We had to find the low price and simplified method to continuously monitor the progress of land cover/use recovery. Meanwhile, satellite images on Google Earth are free to the public (Yang *et al*. 2012; Yu & Gong 2012), and time-series images can be used. The visual photo interpretation is the method which identifies land cover/use without expensive tools based on color, texture, and shape etc. of objects on images (Setzer & Mead 1988; Harvey &

Hill 2001; Morgan & Gergel 2013). It has been used for a long time in a photogrammetry technique.

The purpose of this study was to assess the recovery progress of vegetation around estuarine and coastal areas after the Indian Ocean tsunami using a simplified method which consisting Google Earth and visual photo interpretation. The Indian Ocean tsunami on December 26th, 2004 completely devastated the coastal region of Banda Aceh. The biggest tsunami for several decades swept across the coastal area and submerged land more than 4 km inland from the coast (Borrero 2005; Lavigne *et al*. 2009).

Methods

Study site Banda Aceh is the capital of Aceh Province, which is located on the island of Sumatera, Indonesia

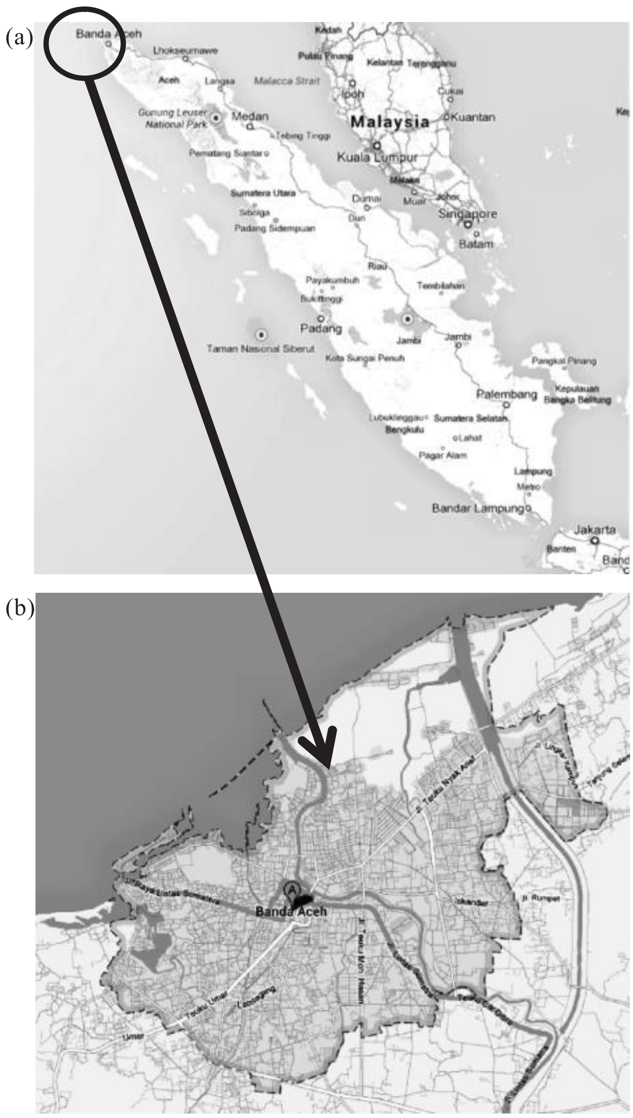

Figure 1 Banda Aceh city in Aceh Province (b), Sumatra (a), Indonesia (Google Maps 2013).

(5°33'N, 95°19'E, 61.36 km^2, Figure 1). A magnitude 9.0 earthquake triggered a tsunami that caused extensive damage to many coastal regions lining the Indian Ocean on December 26th, 2004. Aceh province was one of the regions severely affected by the tsunami. Chen *et al*. (2005) and Griffin *et al*. (2013) estimated that over 90% of mangroves within Aceh were destroyed.

In order to observe time-series coastal vegetation changes, five study plots (A−E) were established along a coast on Google Earth. Areas of each plot were 42.79−103.04 ha, which was rectangular-shaped plots (Figure 2). A−D included fish/shrimp ponds and river/and canal, and E included an estuarine wetland.

Detecting vegetation area by visual photointerpretation Satellite images on Google Earth were used in this study. They were taken in June 2004, in June 2009, in May 2011, and in May 2013. These images were provided by Google Earth by DigitalGlobe, Inc., which was taken by QuickBird and GeoEye-1. The source of them was made sure on the website of DigitalGlobe (ImageFinder: https://browse.digitalglobe.com/imagefinder). Each image resolution was less than 1m. The coastal vegetation distribution before the tsunami was obtained from the 2004 image, whilst other images showed the coastal vegetation afterward.

Free form polygons can be drawn using the Add Polygon tool and recorded them on Google Earth. We made polygons by tracing the extent of coastal vegetation using this Google Earth function while the visual photo interpretation. These polygons were saved as kmz files. The kmz files which saved the coastal vegetation polygons were imported into GIS (ArcGIS 10.0/ESRI), and transformed to the shapefiles. The number of polygons was counted, and their areas were calculated using the Calculate Geometry tool in ArcGIS. Each polygon was termed a vegetation patch in this study. The changes were detected from time series data of patches and the progress of vegetation recovery was examined.

Ground truth data for 10 sites were obtained based on the field survey in 2013 and the survey using Google Street View in Google Maps. We selected sites that have continued to be vegetation from 2004 to 2013. The field survey was carried out in March 2013, and the information about vegetation types was collected and the progress of vegetation recovery was surveyed. Google Street View is a relatively new technology featured in Google Earth that provides 360° horizontal and 290° vertical panoramic views at the street level from a height of about 2.5 m. Thus, Google Street View gives the viewer the feeling of virtually being on the street and the capacity to virtually walk down that street (Clarke *et al*. 2010). Accuracies were calculated as the ratio of the number of sites by visual photo interpretation to the number of ground truth sites.

Results and Discussion

Visual photo interpretation of satellite images on Google Earth Accuracies of the image photo interpretation was higher, and they were from 80% to 100% (Table 1), and vegetation areas were able to be detected with high accuracy using a simplified method which consisting Google Earth

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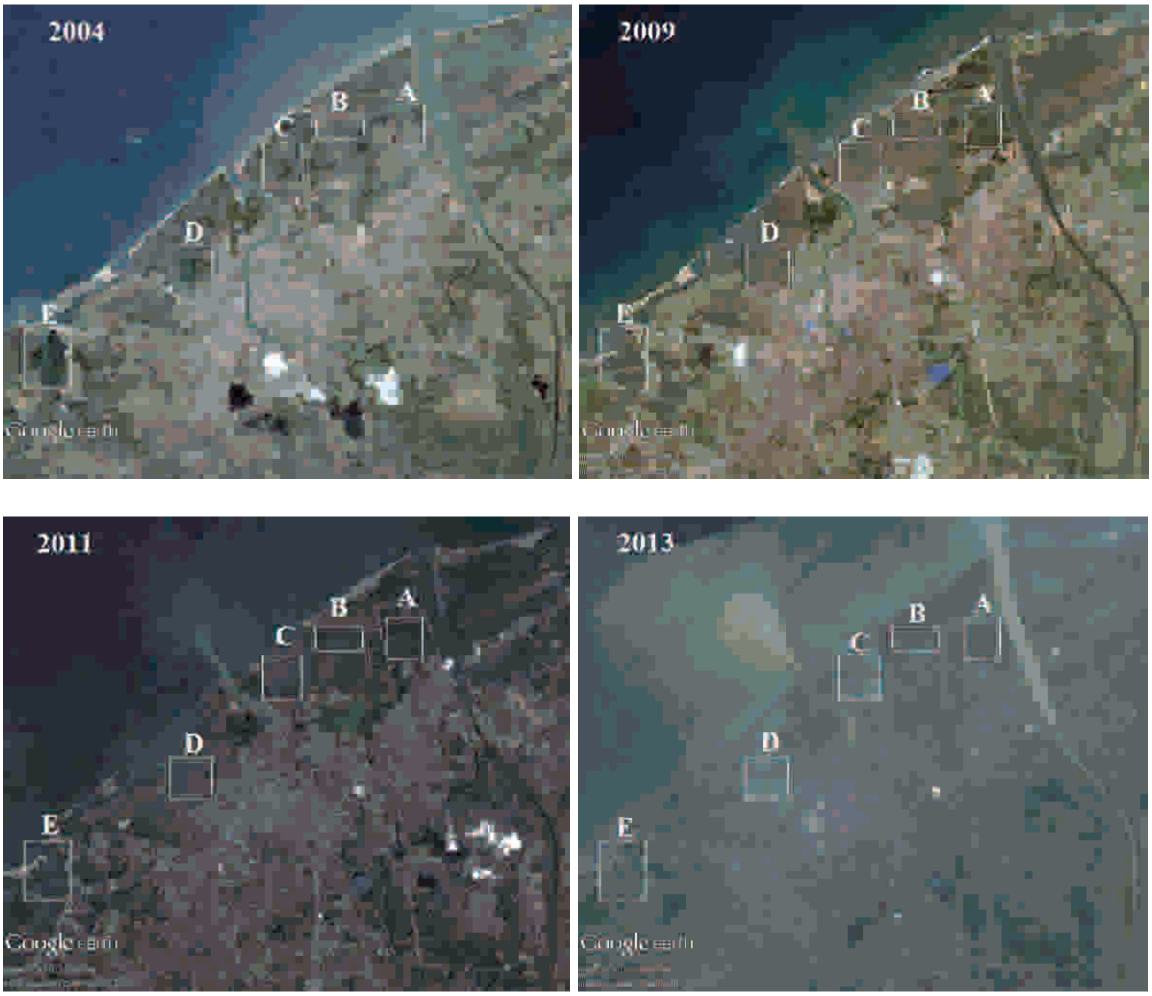

Figure 2 Five study plots (A - E) on Google Earth images were surveyed. Surveyed images were taken after the tsunami except for the 2004 image. A - D were included fish/shrimp ponds and river/and canal, and E was included an estuarine wetland.

Table 1 Accuracy of visual photo interpretation in order to detect vegetation areas.

Year	Accuracy
2013	100%
2011	90%
2009	80%
2004	80%

and visual photo interpretation. We indicated the possibility that the public remote sensing data provided by web map systems such as on Google Earth and Yahoo map will play an important role in the monitoring of damage and recovery in large areas after a disaster at low cost. The distribution of vegetation areas by our method was saved as kmz files, they can be imported into GIS. Therefore, these areas can be analyzed with another thematic map such as topography maps and land use master plans provided by government (World Bank 2010; Taylor *et al*. 2011; Wibowo *et al*. 2016). However, it is important that one knows what is lacking from the data that Google Earth and Yahoo map provide. Indeed, we could not obtain half of the 2005 image for the area we were studying. Our analysis is limited by the data provided by vendor. We also tried a new method for field survey. Sometimes, it is difficult to obtain enough ground truth data from field survey. Although the available area is limited, several ground truth data were able to be obtained by Google Street View.

Recovery progress of vegetation around estuarine and coastal areas Figure 3 shows the distribution of vegetation in a coastal area which was observed from high spatial resolution images on Google Earth. We could find vegetation suffered catastrophic damages just after the tsunami by comparing the 2004 and 2009. The total area of vegetation before the tsunami in each study plot was estimated to be 4.02−33.80 ha. The highest vegetation ratio was found in Plot E (33.80 ha, 32.80 % of a plot), while the lowest one was in Plot B (4.02 ha, 9.39 % of a plot). Plot B had included

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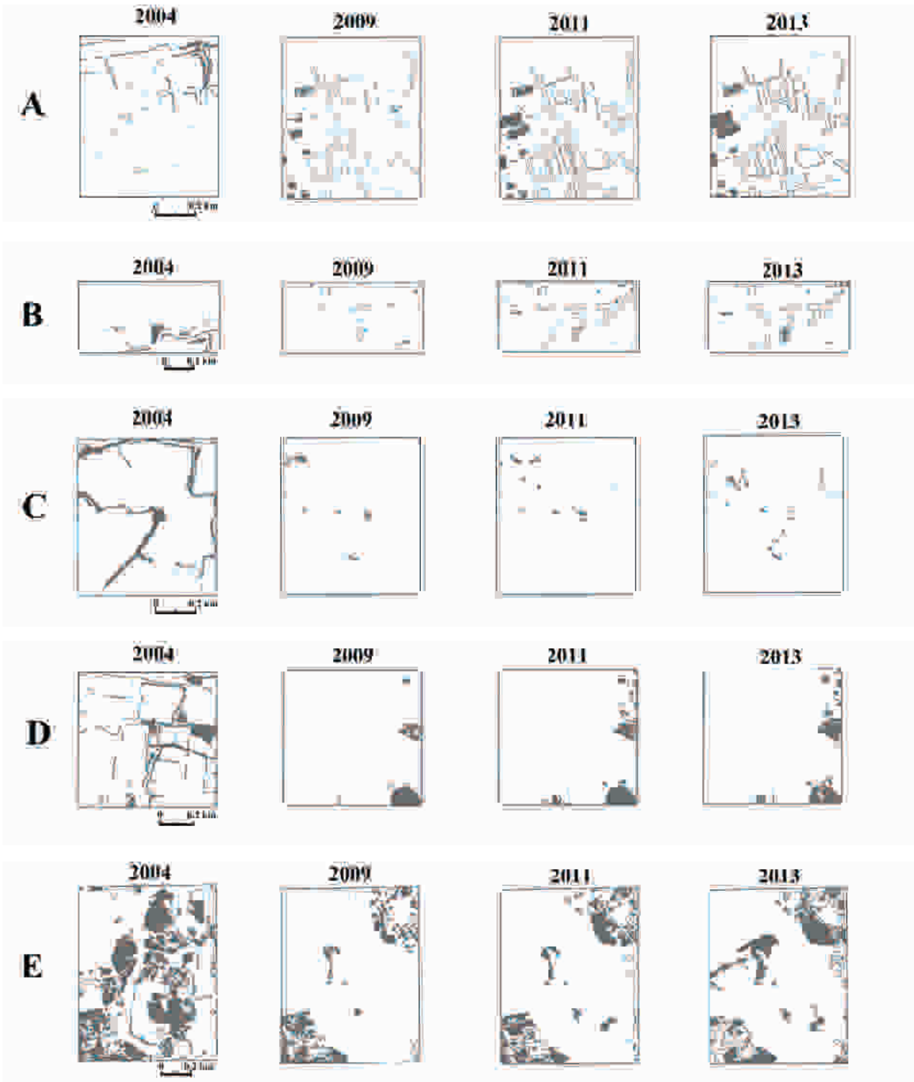

Figure 3 Detected vegetation area. Grey area showed vegetation, which was detected by visual photo interpretation.

fish/shrimp ponds, and there were small vegetation areas around them. Plot E had an estuarine wetland, and there were relatively large vegetation areas in 2004.

Vegetation areas except for Plot C, they had steadily recovered after the disaster (Figure 4). Although Plot A and B were reached or nearly reached to before the tsunami (148.00%, 89.70% of the vegetation area in 2004), Plot D and E were half or less than half. Plot E which had a large vegetation area have not enough recovered and this may be significant in affecting the role of the coastal ecosystem and bioshield. As the damage from the tsunami was so great, most mangrove habitats were lost or altered by landform changes (Chen *et al*. 2005; Griffin *et al*. 2013). The beach was destroyed and the wetlands covered in sand (Liew *et al*. 2010). The chance to self-seed was lost because of deleted parent trees. Mangroves in these areas may be unable to recover naturally. In Plot C and D which include a lot of fish/shrimp ponds, fish/shrimp ponds still have not recovered, and they have been submerged. First of all, it may be necessary to recover of the fish/shrimp ponds.

Although the number of vegetation patches kept on increasing and decreasing, they were on a recovery trend in every plot (Figure 5). Especially, Plot A, B, C in 2013 was double that in 2004. The size distribution of vegetation patches is shown in Figure 6. In all plot, the number of smaller patches (less than 0.1 ha) was highest over an entire period. In Plot A, B, and C, they increased rapidly after the tsunami. In the traditional shrimp ponds, mangroves had been retained along the banks of canals and rivers as well as on the sides of shrimp ponds in order to supply nutrients and maintain the water quality (Rajendran & Kathiresan 1999; Ahmad *et al*. 2003; Haris *et al*. 2013). After the tsunami, fish farmers might have planted them for supplying nutrients to ponds and maintain the water quality. On the other hand, some of large vegetation areas have disappeared in Plot D.

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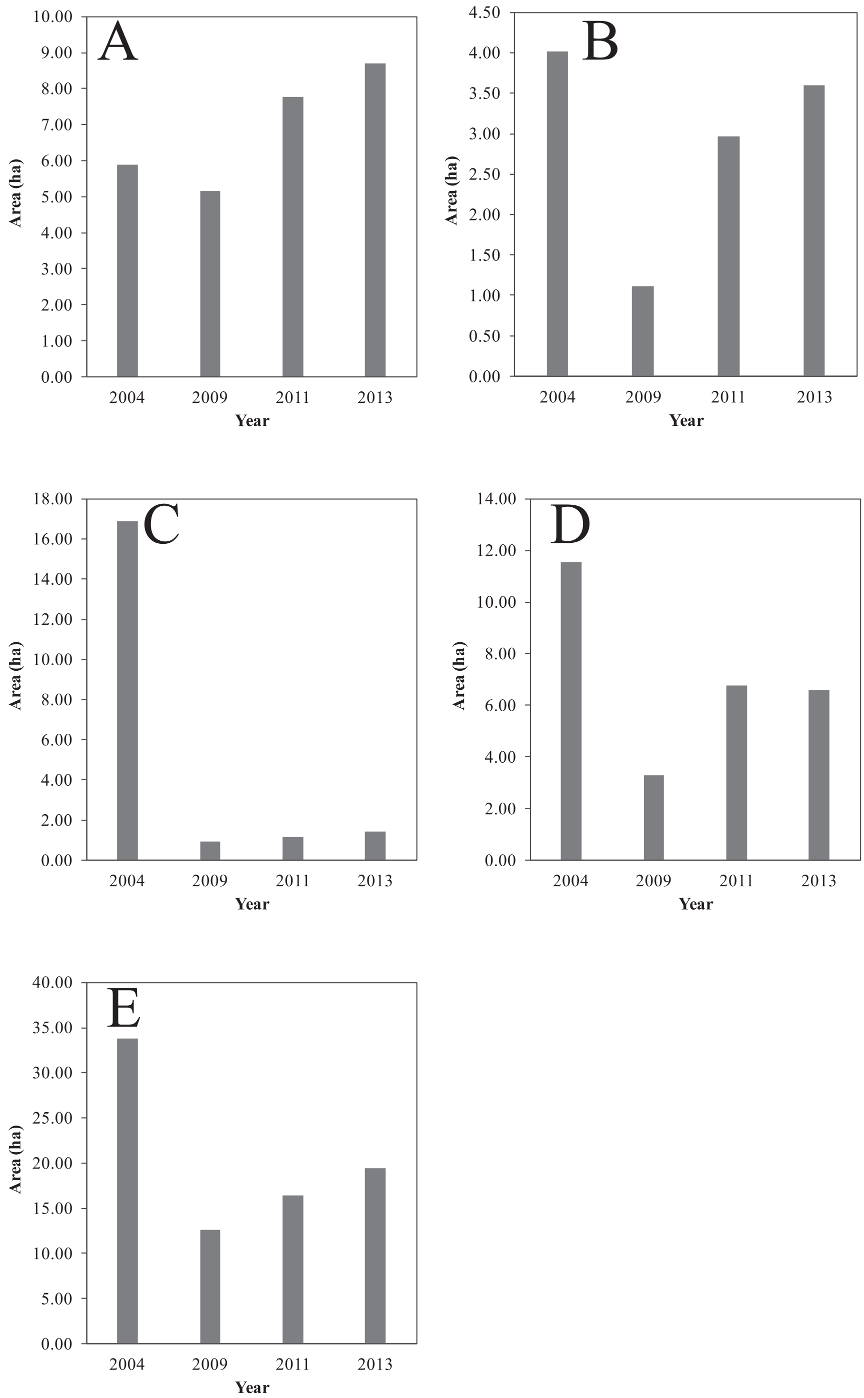

Figure 4 Change in areal extent of vegetation in each study plot over 9 years.

Conclusion

The recovery progress of vegetation around estuarine and coastal areas after the Indian Ocean tsunami was assessed using a simplified method which consisting Google Earth and visual photo interpretation. Google Earth and visual photointerpretation were able to detect vegetation areas with high accuracy. Some of the ground truth data were able to obtain using Google Street View. We could show that these tools were effective under a limited budget. It was found that there was not enough recovery at the sites where there had been large vegetation area before the tsunami. Meanwhile, the number of small vegetation patches was increasing around ponds. Fish farmers might have planted them for supplying nutrients to ponds and maintain the water quality. Dozen years have passed since the 2004 tsunami, and it might be time to more focus on the recovery of large vegetation area.

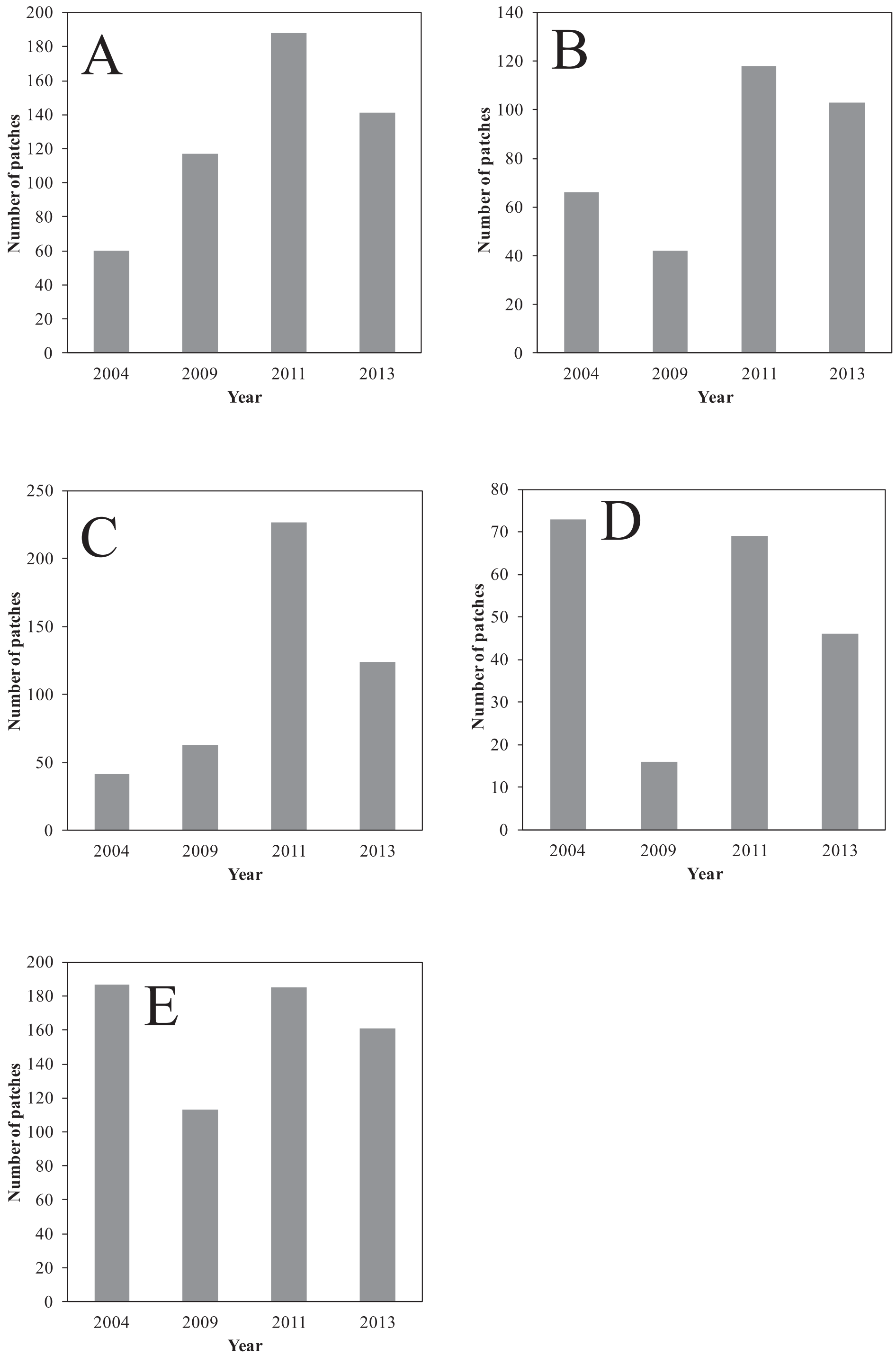

Figure 5 Change in the number of vegetation patches in each study plot over 9 years.

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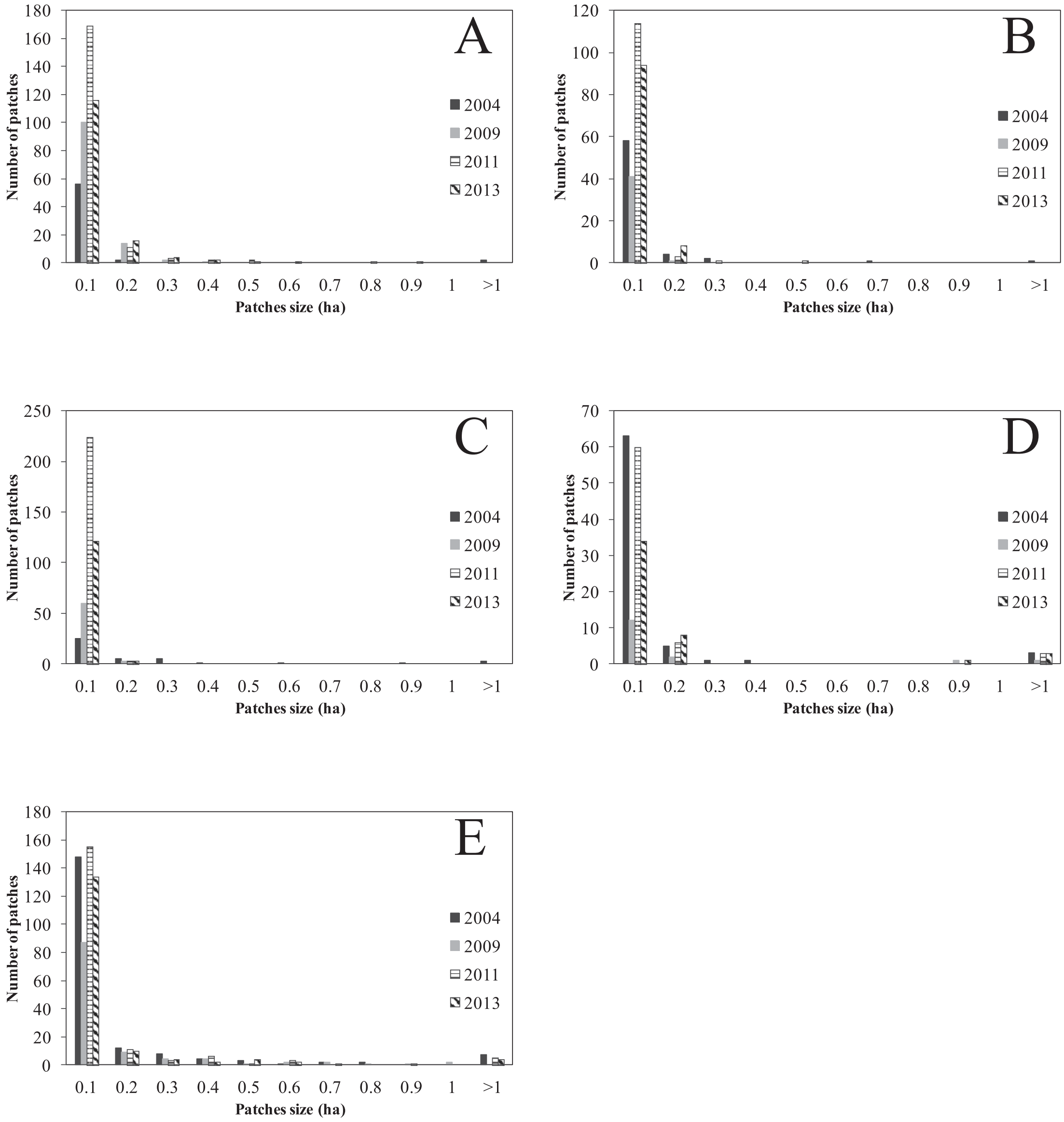

Figure 6 Change in the size of vegetation patches in each study plot over 9 years.

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