Evaluation of Mangrove Biomass Changes due to Different Human Activities in Batam Island, Indonesia, Determined Using MODIS EVI and ASTER Data

Takuro Furusawa,* Yukari Fuchigami,** Shigeo Kobayashi,*** and Makoto Yokota****

In Southeast Asia and the Pacific Islands, the previously substantial mangroves have been displaced by other land uses for economic purposes. It is still under debate whether or not the use of the mangrove, one of whose representative products is charcoal for the global market, for the livelihood of the local people is environmentally sustainable. The aim of this study was to examine the temporal changes in mangrove biomass due to charcoal production, land development, and eco-tourism in Batam Island, Indonesia, which has been undergoing rapid industrialization. The biomass change was analyzed based on the MODIS data (Moderate Resolution Imaging Spectroradiometer) EVI (Enhanced Vegetation Index) from 18 February 2000 to 25 June 2012 (data interval=16-day). The change in the mangrove cover area and causes of the change were interpreted on 9 ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) images taken between 2000 and 2012, as well as by field observations and interviews with local people. The long-term trend (i.e., from 2000 to 2012) suggested that the biomass was stable or slightly increased in the eco-tourism zone, whereas it was modestly decreased in zones being used for charcoal production. The main cause of the decrease was due to the occurrence of logging by the local people. A spectrum analysis in tandem with field observation detected two cycles, i.e., (1) yearly or more frequently, and (2) two-to-five-year interval, respectively. It was judged that either the logging for charcoal production or the land development has been higher than the sustainable rate, even though the recovery rate of the mangrove was high. The local people therefore needed to slow down the logging cycle so as to make charcoal production environmentally and economically sustainable.

Keywords: mangrove ecosystem, remote sensing, REDD, multi-temporal analysis, charcoal production

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* Graduate School of Asian and African Area Studies, Kyoto University, Kyoto, Japan  
  [e-mail: furusawa@asafas.kyoto-u.ac.jp]
** Center for Environmental Innovation Design for Sustainability, Osaka University, Osaka, Japan  
  [e-mail: fuchigami@ceids.osaka-u.ac.jp]
*** Graduate School of Asian and African Area Studies, Kyoto University, Kyoto, Japan  
  [e-mail: skobayashi@asafas.kyoto-u.ac.jp]
**** Center for the Promotion of Interdisciplinary Education and Research, Kyoto University, Kyoto, Japan  
  [e-mail: yokota.makoto.8c@kyoto-u.ac.jp]
1. Introduction

Global concerns have been raised about the conservation of mangrove ecosystems because of their ecological vulnerability to environmental changes. However, the economic value of the land cover, and of the trees themselves, has led to a decrease in mangroves. For example, in Southeast Asia and the Pacific Islands, the substantial areas of mangroves (26.5% and 28.7% in Southeast Asia and Oceania, respectively, from 1980 to 2005) have been displaced almost permanently by other land uses for highly industrial purposes, e.g., industrial infrastructure and shrimp aquaculture (Fuchigami 2013, Spalding et al. 2012). These problems have been complicated by poverty reduction and improvement of the quality of life of the societies that have harvested the mangroves, making it a matter beyond environmental protection. Despite the fact that several efforts have been made to harmonize mangrove conservation and rural development, such as eco-tourism, these activities have been limited either in geographic or economic scale (Tuan et al. 2013). Although in the recent debates on "reducing emissions from deforestation and forest degradation in developing countries [...] and the role of conservation, sustainable management of forests and enhancement of forest carbon stock in developing countries (REDD+)," the mangrove has been increasingly recognized as valuable in trading for carbon stocks (McLeod et al. 2011), the conservation of the mangrove seems to provide local people with equivalent benefits. Under growing pressure to increase conservation, it is necessary to ensure that the local people who live with the mangroves can develop a sustainable livelihood.

Batam Island, which used to be covered extensively by mangroves, has been influenced by rapid commercialization in Indonesia and neighboring countries; it has been developed as a backyard industrial zone for Singapore since the 1980s, and is now one of the most industrialized areas in the country. This island is an important case-study site for evaluating and predicting human-mangrove relations in Southeast Asian and the Pacific Island societies, which may face the same development in the near future.

In general, the local people's use of the mangrove for timber or fuel has been recognized as a major cause of mangrove ecosystem degradation (Tuan et al. 2013). On the other hand, other previous studies (Fuchigami 2013, Harada and Kobayashi 2012) based on field observations suggested that, while a high proportion of mangroves disappeared due to industrial land reclamation, traditional or semi-traditional mangrove charcoal production—upon which local people depend as a source of cash income and run in traditional ways—have been maintained in a potentially sustainable way. However, the spatio-temporal changes of mangrove biomass in association with human activities in a wider geographic range have rarely been analyzed.

The Moderate Resolution Imaging Spectroradiometer (MODIS), a sensor on board the Terra
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satellite launched by the United States National Aeronautics and Space Administration (NASA), is a new and useful multi-temporal imaging tool for monitoring the temporal changes of the vegetation index (Knight et al. 2006, Lunetta et al. 2006). The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), which is also aboard the Terra, also multi-temporally acquires optical images at a moderately high resolution (15 m); although the images have been taken irregularly (Kodama et al. 2010). Integration of the MODIS and ASTER images, along with field observations, will make it possible to understand the spatio-temporal changes of the land cover/land use and biomass.

The aim of this study was to examine the temporal changes of the mangrove cover due to different human activities in Batam Island, Indonesia. Special attention was paid to measuring impacts of human livelihood on mangrove biomass and the recovery rate of mangrove from such impacts.

2. Study Sites and Methods

2.1. Study Sites

This study was conducted in Batam Island, Riau Islands Province, Indonesia (Figure 1). This island (415 km² in area) is located only 20 km from Singapore, a global commercial center, and has been developed as an Indonesian industrial hub for commerce and industry; Singapore, Batam Island, and Johor Bahru are now recognized to form a “Growth Triangle” (Macleod and McGee 1996). The first industrial park was built in 1984 with an area of 32 ha, and in 2004 there were 21 industrial parks covering 1,512 ha in total. Of note, the population increased from

Figure 1. Locations of Batam Island and the Study Plots
approximately 7,000 in 1974 to approximately 1.1 million in 2010, most of whom immigrated as laborers (Fuchigami 2013). During this development period, the coastal zones were transformed into port and industrial complexes. For instance, the mangrove cover decreased from 240 km² to 25 km² during a recent five-year period (2003–2008) in three sub-districts in the northern part of the island (Priyandes and Majid 2009).

On the other hand, government efforts to conserve the mangroves and other wildlife have been strengthened, but these efforts were mainly used for controlling the local people’s livelihood rather than affecting industrial land reclamation. The production of charcoal from mangrove trees has been the main cash income source for the local Batam people since the 19th century. The first official regulation on the production of mangrove charcoal was made in the 1930s by the Batam municipality government; the production permit was thereafter issued only to those who had been engaged in production at this date (Harada and Kobayashi 2012). In the 1990s, the president of Indonesia enacted a decree banning the destruction of the living environment, and accordingly, the rural Batam government enacted relevant regulations regarding mangroves following this decree (Amri 2005). However, mangrove use continued at the community level. According to a statistical record, in 2008, there were 400 kilns and 857 individuals engaged in mangrove charcoal production in Batam Island (Pemerintah Kota Batam 2008); the charcoal export amounted to 25,709 tons and 5.4 million US$ from the province in 2008 (Fuchigami 2013). A substantial portion of the charcoal production is thought to have come from illegal logging of mangroves, but this livelihood plays important roles as a cash income source or a safety net for local people with no stable occupation. Therefore, local officers are hesitant about cracking down too rigorously on these people. However, according to both the officers and informants from the local communities, the local people have enforced their own self-regulation on the rotational cutting of mangrove forests and on the size of kilns so as to minimize their impact on the ecosystem (Harada and Kobayashi 2012).

2.2. Study Plots and Field Observations

Based on previous studies (Fuchigami 2013, Harada and Kobayashi 2012), seven sites which represented various human-mangrove relationships were chosen as study plots in 2011; locations of the study plots are shown in Figure 1. Plot 1 was mangrove situated in an area oriented for eco-tourism and building relevant infrastructure for Singaporean tourists (Figure 2); note that a river was running in the study plot, so that 46% of the MODIS pixels (to be explained later) were covered by the river without mangrove cover. It was observed that efforts were made for conserving and recovering mangrove in the eco-tourism zone. Plot 2 was an area neighboring a housing land development zone; the potential impacts were not only the building
of infrastructure, but also population growth. Plots 3 and 4 were areas used for the local people’s charcoal production (Figure 3); charcoal production in these areas was more extensive than in other study plots. Plots 5, 6, and 7 were for the local people’s daily use, as well as for charcoal production. As explained above, rural people self-regulated the size of kilns to reduce the amount of resource mangrove (sites 3–7). More detailed explanations on characteristics of study plots appear in the results section (Table 1).

The locations of all of these sites were recorded using a global positioning system (GPS) with the Trimble Juno SB Handheld (Trimble Navigation Limited, Sunnyvale, CA) in tandem with the ArcPad 8.0 software program (ESRI, Redlands, CA); a real-time correction was made by using the Trimble GPScorrect (Trimble Navigation Limited). In each plot, a vegetation survey of a 25 m × 25 m quadrat was conducted, and the results were reported elsewhere (Fuchigami 2013). In addition, the land cover and land uses were observed, and local people’s activities were recorded through open-ended interviews.

2.3. MODIS EVI Analysis for Mangrove Biomass Changes

The enhanced vegetation index (EVI) is a type of data recorded by the MODIS Terra program (launched in December 1999) operated by the US NASA program; images were provided every 16 days at a 250 m spatial resolution (product identification number=MOD13Q1, processing level=3). The concept of vegetation index (VI) comes from the fact that plant leaves absorb visible spectral energy in the process of photosynthesis (Huete et al. 1999). Absorption
Table 1. Main Characteristics of Each Study Plot from the Field Observations and Interviews, and the Characteristics Noticed in the ASTER Onscreen Visual Interpretation

<table>
<thead>
<tr>
<th>Plot #</th>
<th>Field observation and interview</th>
<th>ASTER on-screen visual interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot 1</td>
<td>Located along a riverside Used for eco-tourism and livelihood fishing No evidence of former clearance for charcoal production Affected by a development project involving the building of a tourist ferry terminal in a nearby area</td>
<td>Mangroves growing on both sides of the river A small portion of the mangrove in the pixel was cleared for the ferry terminal construction on 5 April 2003 A road was built from the main road to the river crossing the pixel, and could first be seen in the image taken 18 July 2006</td>
</tr>
<tr>
<td>Plot 2</td>
<td>Located along a road connecting industrial/commercial zones and a rural village Neighboring a newly built branch office of the sub-district Housing land development intensified in 2009 Frequent selective logging for charcoal or industrial fuel; intensive logging in 2011 or 2012</td>
<td>Between 5 June 2002 and 29 May 2004, the plot was mostly covered by mangrove; land development was expanding in the neighboring area 18 July 2006 and after: The mangrove area rarely changed, but the crown cover decreased, probably because of extensive selective logging</td>
</tr>
<tr>
<td>Plot 3</td>
<td>Located in a huge mangrove forest; near a road and settlement Used extensively for local charcoal production since 2006</td>
<td>New road construction connecting the new port to the commercial/industrial zones was being performed; small clear felling was observed in the pixel on 5 June 2002 Selective logging was visible on 18 July 2006</td>
</tr>
<tr>
<td>Plot 4</td>
<td>Located in a vast mangrove forest; far from roads and settlements Used extensively for local charcoal production since 2008</td>
<td>Due to land development in nearby plots, clear-cut logging could be seen in a small portion of the pixel on 5 June 2002 Vegetation recovery was observed in the image taken on 9 May 2004 A small amount of selective logging was seen from 18 July 2006 to 19 June 2007 Extensive selective logging was seen in the image taken on 26 May 2010</td>
</tr>
</tbody>
</table>

* See Fuchigami (2013) for more detail

values are at maximum in the blue and red wavelengths, while the near-infrared radiation is absorbed very little. Therefore, a contrast between red and near-infrared responses can be a measure of vegetation amount. In addition, it has also been found that the blue is more absorbed in aerosols scattering cross-sections than the red; when the aerosol concentration is higher, the difference between the blue and red bands increases. This information is used to minimize atmospheric influence on the vegetation index. The EVI is thus a vegetation index developed by NASA for the MODIS Terra program, and is calculated based on blue (wavelength=469 nm), red (645 nm), and near-infrared (858 nm) areas by incorporating atmospheric resistance (atmospheric resistance index) and removal of soil-brightness variations (soil adjusted vegetation index), as follows:

\[
EVI = G \cdot \frac{\rho_{\text{NIR}} - \rho_{\text{red}}}{\rho_{\text{NIR}} + C_1 \cdot \rho_{\text{red}} - C_2 \cdot \rho_{\text{blue}} + L}
\]

where \(\rho_{\text{red}}, \rho_{\text{blue}}, \rho_{\text{NIR}}\) are the full or partially atmospheric-corrected (for Rayleigh scattering and
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ozone absorption) surface reflectance; \( L \) is the canopy background adjustment for correcting nonlinear, differential NIR and red radiant transfer through a canopy; \( C_1 \) and \( C_2 \) are the coefficients of the aerosol resistance term (which uses the blue band to correct for aerosol influences in the red band); and \( G \) is a gain or scaling factor. The coefficients adopted in the MODIS EVI algorithm are \( L=1 \), \( C_1=6 \), \( C_2=7.5 \), and \( G=2.5 \). Note that the EVI is replaced by a modified two-band EVI in case of over-high-reflectance surfaces (e.g., clouds and snow/ice). Note also that compared with the normalized difference vegetation index (NDVI), the EVI is more sensitive to biomasses with reduced atmospheric influences (Huete et al. 1999).

The MOD13Q1 image is composited from multiple observations (theoretical maximum=64 observations, though usually ranging 1–5 observations) during a 16-day period; the composite data are generated by filtering algorithm on quality, cloud, and viewing geometry (e.g., pixels with cloud cover, views captured from extremely off-nadir). In this study, all data from 18 February 2000 to 25 June 2012, i.e., 287 images in total, were obtained through the online Data Pool at the Land Process Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov/get_data).

All 287 images were opened, and pixels which included the seven study sites were identified as the target pixels by using GPS ground truth information. The EVI values of 287 time points for each pixel were then extracted and compiled as time-series data. In the MODIS EVI, digital values were not recorded for pixels with thick cloud or water cover. If one or two successive values were lacking (i.e., 32 days at maximum) for such reasons, these values were substituted by the average of the two values prior to and following these periods. The study sites where values were lacking for three or more consecutive periods were excluded from further analyses. As a result, Plots 5–7 were excluded from further analyses.

Multi-temporal MODIS EVI data were then decomposed into trend and cycle (TC), seasonal changes (S), and irregular changes (I) by using the R software program (The R Project for Statistical Computing). In the concept of time-series data analyses, seasonal changes can be detected by comparing values among different seasons over a range of years. Irregular changes are recognized as residuals of the sum of moving averages and seasonal changes. Trend and non-yearly cycles are recognized as the main analytical target since these reflect time-series changes; however, these cannot be directly separated in the algorithm. In this study, the TC values were thus calculated by a one-year moving average after S (i.e., fluctuations repeated every year) and I were separated (Cleveland et al. 1990).

The TC values were then used to visually interpret the overall trend and non-seasonal cycles of changes. To detect and measure the impact and lengths of cycles that change according to
human impact and/or the mangrove ecosystem (e.g., succession changes after clearance), but not seasonal or random effects, the cycle of change was analyzed by the spectrum-analysis method after Fourier transformation of the TC values (N=263). Discrete Fourier transformation is generally used to detect periodicities in data and relative strengths of such periodic components; wavelengths of time-series data are decomposed into various frequency spectrums. Fast Fourier transformation algorithm was used for the decomposition in this study.

It should be noted that our methods were advantageous for tracing the temporal changes at a stable and consistent quality. Another advantage was that the multi-temporal MODIS data were available free of cost.

2.4. ASTER Analysis for Land Cover/Land Use Changes

The ASTER was also used to assess the pattern at a higher resolution than was provided by the MODIS. ASTER’s visible and near-infrared (VNIR) optical sensor consists of three band images at a resolution of 15 m; the ASTER is also onboard the Terra satellite, and is operated by the Ministry of Economy, Trade and Industry (METI) of Japan. Onscreen visual interpretation of the ASTER optical-band images was performed (1) to observe the causes of changes in the study plots, and (2) to provide an accuracy assessment of the MODIS EVI data. Data were searched and downloaded from the Global Earth Observation (GEO) Grid project of the National Institute of Advanced Industrial Science and Technology (AIST) of Japan (Kodama et al. 2010). The data available with high quality were those collected 5 June 2002, 5 April and 7 May 2003, 9 May 2004, 18 July 2006, 31 March and 19 June 2007, and 26 May and 11 June 2010. For the first purpose, the ASTER-VNIR images in the Keyhole Markup Language (KML) file formats were displayed on the Google Earth maps (Google Inc., Mountain View, CA). For the latter purpose, the ASTER images in GeoTIFFs (Tagged Image File Formats) were opened using the ArcGIS 10 software program, and the tree vegetation cover was manually identified. The proportion of the vegetation cover in each MODIS pixel (i.e., 250 m × 250 m) was thus calculated; if part or all of the pixels in the ASTER were covered by cloud or shadow in each plot on each acquisition date, the vegetation cover was not analyzed.

3. Results

3.1. Detection of Time-series Trend in MODIS EVI Data

Figure 4 shows the MODIS EVI multi-temporal observations of the seven study plots. Plots 5 and 6 were located in one EVI pixel, and Plots 5, 6, and 7 were frequently covered by clouds in the MODIS imagery. Therefore, further analyses were performed only for Plots 1–4.
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Figure 5 shows the trend plus cycle (TC), seasonal, and irregular changes of the EVI values. As shown in the figure, the TC of Plot 1 fluctuated between 0.3 and 0.4, and had a minimum value of 0.2959 at the end of 2005; after this point, the EVI started to show an increasing trend, achieving the maximum value of 0.4201 in mid-2011. The TC dramatically changed in Plot 2; i.e., after a rapid increase from 2000 to 2002 (to a maximum of 0.5706), the EVI decreased until 2007 (to a minimum of 0.2915). The EVI then showed an increasing trend with a cyclic fluctuation. In Plots 3 and 4, the EVI gradually decreased throughout the study period. In Plot 3, remarkable decreases were observed in 2003 and 2007; after 2007, the EVI showed a decreasing trend with fluctuation. The maximum (0.5052) was recorded in 2000, while the values were around 0.35 during and after 2010. In Plot 4, the TC increased to 0.5347 in 2003, then the EVI decreased; rapid decreases were also observed in 2007 and 2011, and reached a minimum at the end of 2011. Throughout the study period, the TC value was the highest on average in Plot 4 (0.4434), followed by Plots 3 (0.4152) and 2 (0.4022). It should be noted that Plot 1 (0.3611) included a river stream in its MODIS pixel. The variation observed in the SD was highest in Plot 2 (0.0782).

In Plots 3 and 4, it was also observed that the EVI recovered from the decrease in about a year or less: e.g., in 2007, 2009, and 2010 in Plot 3, and in 2008 and 2009 in Plot 4.

Figure 4. The Multi-temporal MODIS EVI Values from 18 February 2000 to 25 June 2011 for Seven Study Plots on Batam Island
3.2. ASTER Images and Interpretation of Causes of Changes

The changes in the vegetation cover estimated from the onscreen visual interpretation of the ASTER images are shown in Figure 6. Descriptive explanations for changes both from the onscreen interpretation and the field observations are shown in Table 1. In Plot 1, it was found that 46% of the MODIS pixels were covered by the river without mangrove cover, but that both sides of the river were densely covered by the mangrove crowns. The mangrove cover decreased in 2006 because of the construction of a road connecting the ferry terminal and the river, but recovered until 2007 because of regrowth of the mangrove; part of the regrowth looked like artificial reforestation for tourism. Except for these characteristics, the vegetation cover rarely changed, which was confirmed in the EVI observations.

In Plot 2, the vegetation cover rapidly decreased from 75.2% in 2004 to 49.1% in 2006. This seemed to be due to intensive selective logging of mangrove trees; that is, the “mangrove area” did not decrease, but the “crown cover” decreased in the “mangrove area,” and in the ASTER images, the patches of black soil cover increased. The house and land development nearby did not directly destroy the mangroves in the MODIS study pixels, but expansion of the development seemed to be negatively correlated with the vegetation cover; from the field observation, it was speculated that new settlers or companies used the mangrove for home or industrial fuel and other purposes.
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Figure 6. The Proportions of Vegetation Cover on Different Acquisition Dates in Each Plot
The decomposed EVI Trend + Cycle (TC) value for each date is also shown

In Plot 3, the vegetation cover slightly increased in 2004, and rapidly decreased in 2006 and 2007. The onscreen interpretation disclosed that the vegetation cover was low in 2002 because of the construction of a new road nearby, but this area recovered gradually until 2004. However, the local people started selectively logging the mangrove for charcoal production in 2006, so the vegetation cover, as well as the EVI value, decreased. Although the decrease was dramatic in this period, the vegetation cover rarely changed after this point.

In Plot 4, clear-cutting of the mangrove in the marginal area of the MODIS pixel was observed in 2002, although this area recovered until 2003. Selective logging was observed in 2006 on a small scale, and in 2008 on an extensive level. According to the field observations, local people moved to this place and started charcoal production in 2006 in the area near the settlement (Plot 3), then they extended the area to Plot 4 in 2008.

As shown in Figure 6 and Table 1, the findings from the MODIS EVI analysis were strongly coincident with the ASTER onscreen visual interpretation and the field observation.
3.3. Impacts and Lengths of Change Cycles

Figure 7 shows the periodgram of the TC of the MODIS EVI. The highest peaks were found at the longest cycle for all plots but Plot 4, suggesting a strong effect of trend rather than a periodic cycle. The peak of Plot 4 was observed at a cycle of approximately 5.9 years. In addition, the second peak of Plot 3 was at 3.0 years. Peaks were also found at 2.4 and 3.0 years, respectively, for Plots 2 and 1. Figure 8 shows the periodgram of Plots 3 and 4 after 1 January 2006 and 1 January 2008, respectively; these periods correspond to the onset of the local people’s mangrove use in these plots. Both peaks were found between 2.1 and 4.2 years. Other peaks were also found at 8.3 months and 14.9 months, respectively, for Plots 4 and 3.

![Figure 7. A Periodogram Drawn from the Fourier Transformation of the EVI Trend + Cycle (TC) Values for All Time Periods](image-url)
4. Discussion

4.1 Various Patterns and Causes of Biomass Changes

The most important finding of the present study was the differences in biomass due to land uses. The long-term trend (i.e., from 2000 to 2012) suggested that the vegetation in the eco-tourism zone was stable or slightly increased (i.e., Plot 1), while there was a decrease in the residential development zone (Plot 2) and zones being used by the local people for charcoal production (Plots 3 and 4). This suggests that, without active conservation efforts (as for eco-tourism), either industrial or small-scale human activities had adverse effects on the mangroves. Dramatic changes (i.e., a rapid decrease within a couple of years) were also observed in industrial zones. For instance, in Plot 2, a residential development zone, the EVI decreased by approximately 20% in one year. This was thought to be caused by the new residents or companies using the mangroves for fuel or construction. Plot 1, the area used for eco-tourism, also experienced a rapid decrease during the construction of a road and a bridge connecting the town and tourism villages, although this decrease was compensated by the later recovery, including
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reforestation. On the other hand, the changes of the charcoal production zones (Plots 3 and 4) were relatively gradual but consistent. This is thought to be because the local people's destruction is limited, but their activities are ongoing.

4.2. Cycles of Human Impacts and Ecological Recovery

The spectrum analyses revealed that the vegetation index and the vegetation cover repeatedly recovered. For instance, the decrease of the TC value in the EVI in the local charcoal production zones (Plots 3 and 4) recovered within a year or less after the decrease. The large decrease in the house and land development zone (Plot 2) also recovered after two years, from 2006 to 2008. In the spectrum analyses by the Fourier transformation, peaks were found between two and five years, with another peak at about a year in the local charcoal production zones. These cycles are thought to have reflected the recovery rate of the mangroves.

The peak at approximately five years in this study was thought to be due to the onset of elevation of the mangrove growth rate. A previous vegetation survey (in 100m² quadrats) showed that the regrowth rate was low until two years, but that the rate accelerated after five to 15 years (Fuchigami 2013); the rate is thought to be slowed down as the biomass increases to a stable level until 30 years of age, following a logistic line (Asaeda and Kalibbala 2009). On the other hand, the cycle near one year is thought to be related to human activities, e.g., the people changed logging sites. It should be noted that each MODIS EVI pixel included a number of patches, some of which were being used for logging, while others were under recovery, so that the pixel value change was a combination of a number of different cycles.

4.3. Sustainability of Mangrove Biomass and Human Livelihoods

Based on the findings of this study, it is reasonable to judge that the rate of the local people's harvest is higher than the mangrove's natural recovery rate. These findings support conventional understanding that the local people's use of the mangrove for timber or fuel is a major cause of mangrove ecosystem degradation (Tuan et al. 2013). However, this study also found a high rate of recovery for mangrove biomass. The latter finding implies that the small-scale traditional charcoal production is potentially able to continue if the rate of harvest is controlled under a sustainable limit (Fuchigami 2013). Judging from our results—though further analyses are necessary for more detailed estimation—the cycle of harvest needs to be slowed down to less than half of the present one. However, it seems difficult for the people to reduce their harvest cycle, because the present intensive logging is associated with other complicated factors, such as the increased population, a higher need for cash, or a decrease in available mangroves due to land reclamation. A governmental or community-based regulation should include an intervention.
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for the provision of other cash income sources, with encouragement to avoid excessive or short-fallowed logging (Tuan et al. 2013).

5. Conclusions

In conclusion, our remote-sensing analysis (i.e., MODIS EVI and ASTER-VNIR analyses) in tandem with field observation showed that human activities, including both industrial use and local people’s use, had adverse effects on the mangrove biomass. Our findings also suggested that the mangrove can repeatedly recover from clearance, unless the area is totally converted to a cemented infrastructure.

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