Forest transition in an ecologically important region: Patterns and causes for landscape dynamics in the Niger Delta

Alex O. Onojeghuo *, G. Alan Blackburn
Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK

1. Introduction

The fragile mosaic of aquatic, wetland and terrestrial ecosystems of the Niger Delta region in Nigeria is faced with a diverse range of environmental problems resulting from factors such as agricultural land degradation with consequent soil erosion and flooding; shoreline development; changes in local hydrology resulting from sea level rise; pollution from the oil industry, pipeline construction and seismic activities; over exploitation of forest resources for food and construction, illegal felling of trees, agricultural activities and rapid urbanisation (Moffat and Linden, 1995; NDES, 1997; Wang et al., 2005). In particular, deforestation is a major threat affecting the natural ecological status and biodiversity of the region, as well as the human population that depends upon resources and services provided by the ecosystems of the delta for their livelihood. The economically viable resources derivable from the Niger Delta forest landscape can be classified into timber and non-timber forest resources. Some of the major timber resources derivable from the forests of the Niger Delta are saw-logs, chewing sticks, transmission poles, building and furniture wood/poles, and fuel wood which are obtained from the mangroves, rain forest areas, coastal ridges and fresh water swamps, all of which are being over exploited (NDES, 1997). It has been recognized for some time that
deforestation is a large-scale problem in the freshwater swamps and barrier island forests of the Niger Delta region with an estimated 5–10% of primary mangrove forests having been lost (Moffat and Linden, 1995). Much of the deforestation has been attributed to urban growth and intensified human activities such as logging and the expansion of agriculture (Moffat and Linden, 1995; NDES, 1997). In the pre-colonial and colonial periods the great demand of tropical hardwoods by Europe heralded the threat of deforestation in the Niger Delta region of Nigeria. This led to the introduction of intensive lumbering activities and tree crop exportation from the lowland forests of the Niger Delta to Europe (Areola, 2001). The rapid increase in the over exploitation of these forest resources increased as timber export and plywood companies came into the heart of the then Bendel state (now known as Delta and Edo states) of the Niger Delta. This was done in order to facilitate the harvesting of timber from forests in Benin, Edo state and Sapele, Delta state. Development activities like road construction, urban expansion and establishment of industries resulted in the once fertile and flourishing lowland forest becoming an over-exploited region with most of the forest resources lost to intensified human activity (Moffat and Linden, 1995).

At present, information concerning the current rates of deforestation for the region is lacking, as, indeed, is knowledge of the rates and patterns of afforestation. The Federal Department of Forestry (FDF), which has the responsibility of coordinating forestry related issues in Nigeria, has embarked on a number of nationwide studies in the past through the Forestry Management, Evaluation and Coordinating Unit. Over the last three decades projects have been executed to determine the state of the country’s forests, producing information on land-use and vegetation cover from a variety of sources. Such studies have demonstrated that deforestation has been particularly prevalent in the types of forests such as mangroves, swamps and riparian forests that dominate the Niger Delta (Areola, 2001; Olaleye and Ameh, 1999; Treveet, 1979). However, Areola (2001) observed that the major problems facing the FDF were the absence of up-to-date information on the state of forests in the country and lack of a properly coordinated system to manage such information, hence resulting in information being distributed across different organisations in the country. Similarly, Olaleye and Ameh (1999) identified limited coverage of forest inventories and the absence of up-to-date information across states in Nigeria as major problems facing the government in determining the country’s current status of forest changes.

The Niger Delta region is faced with the difficulty of inaccessibility during ground surveys thus making most parts of the region unreachable due to the dense forest cover and difficult undulating terrain. Moreover, the volatile communities present in many parts of the Niger Delta can compromise the personal safety of non-indigenes and prevent in situ surveys. In such circumstances, the use of remotely sensed data offers numerous advantages for providing forest related information across the study area. Furthermore, the possibility of repeated image acquisitions over long periods of time and with a synoptic view covering large spatial areas, provides a means of monitoring forest dynamics across the entire Niger Delta. Indeed, this has been demonstrated to some extent in a study conducted by Godstime et al. (2007) where Landsat satellite imagery covering the Niger Delta was used to map the spatial extent of mangrove loss in the region. The study also identified as the primary cause of deforestation urbanisation, dredging activities, oil exploration and the spread of the invasive Nypa Palm.

Deforestation can lead to intensified fragmentation resulting in the reduction of forest patches and increased isolation. Studies aimed at quantifying the nature and consequences of forest fragmentation have been conducted and vital results obtained. For example, it has been found that the tropical forests of the Amazon are subject to accelerating deforestation rates resulting in forest fragmentation and changing patterns of ecosystem loss (Laurance et al., 2000; Lima and Gascon, 1999). The study of Armenteras et al. (2006) on the Colombian Amazon examined the pattern of ecosystem diversity, deforestation and fragmentation through the temporal and spatial analysis of biotic and abiotic data using remote sensing and geographic information system. The pattern of deforestation and annual rates of deforestation for different parts of the region were investigated. The annual deforestation rates were 3.73 and 0.97% in two areas with high human population densities while for relatively unpopulated areas the rates were 0.31, 0.23, and 0.01%. At present similar information on the level of forest transition and forest landscape fragmentation is lacking for the Niger Delta.

The aim of this study was to investigate rates of forest transition in the Niger Delta region taking into consideration the patterns, causes and implications of landscape dynamics in the delta. The objectives were as follows:

i. to determine the spatial extent and rates of deforestation, afforestation and forest change in the Niger Delta using remotely sensed imagery,

ii. to investigate the effects of forest transition on the spatial structure of forest landscapes in the Niger Delta,

iii. to examine the extent to which socio-economic factors influence the processes of forest transition, and

iv. to simulate likely future changes in forest cover of the Niger Delta.

2. Materials and methods

2.1. Study area

The study area was the Niger Delta (Fig. 1). Geographically the Niger Delta is taken to have its apex at Aboh 5°33′49″N, 6°31′38″E which bifurcates into two main distributaries, the Nun and Forcados. The southernmost tip of the Delta is at Palm Point (4°16′22″N, 6°05′27″E) south of Akassa and at the estuary of Nun River. The Niger Delta region extends from the Benin river estuary (5°44′11″N, 5°03′49″E) in the west to the Imo river estuary (4°27′16″N, 7°35′27″E) in the east and has a total land area of approximately 25,900 km² or approximately 2.8% of Nigeria’s total land area (NDES, 1997). The natural vegetation of the Niger Delta is classified into five types which are as follows: moist lowland rainforests covering the upper riverine floodplains and Sombreiro-Warri plains; freshwater swamp forest covering the lower riverine floodplains and along the river valleys; the mangrove zone comprising the mangrove forests and mangrove swamps located in the upper tidal and lower tidal zones, respectively; saltmarsh and tidal mudflats along the shorelines; and coastal forests and thickets on the barrier sand ridges (NDES, 1997). In the Niger Delta population distribution and settlement pattern are determined by the availability of dry land within the mangrove swamp dominated zone. Most of the Niger Delta is characterized by massive and continuous swamps dotted by islands of dry land. Due to the narrow fringe-like islands dominant in the region land reclamation (through sand filling) is a common practice in order to accommodate the growing population (Moffat and Linden, 1995). Consequently, the largest settlements of the Niger Delta are locations further away from the mangroves such as Benin, Sapele, Warri, Port Harcourt and Ughelli (NDES, 1997).

2.2. Mapping deforestation and afforestation

For this study the analysis of remotely sensed data was undertaken in four stages namely: data acquisition and
processing, image classification, accuracy assessment and change detection. These are explained in the following sections.

2.2.1. Data acquisition and image pre-processing

The Landsat Thematic Mapper (TM) satellite imagery used for the study was obtained from the Global Land Cover Facility (GLCF) website (http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp) which is managed by the University of Maryland and funded by the National Aeronautics and Space Agency (NASA) in the United States. The Landsat TM data was acquired on the 19th of December 1986. A NigeriaSat1 image covering the same study area was acquired on the 20th of January 2007 by the Disaster Monitoring Constellation International Imaging (DMCii). The images were acquired during the dry season in order to limit cloud cover.

The rectification and restoration of the satellite image covering the study area was vital to the accuracy of the final product as the imagery in its raw state contained geometric distortions. The images were geometrically corrected using a polynomial geometric model in ERDAS Imagine (ERDAS Inc., 2008). To effectively maximise the information contained in the bands of the satellite imagery atmospheric correction was applied to remove the effects of atmospheric particles caused by absorption and scattering of radiation from the earth surface during acquisition (Lu et al., 2002). The presence of haze noise was observed and removed using the haze reduction command in ERDAS Imagine (ERDAS Inc., 2008). The pre-processing and further analysis was performed using ERDAS Imagine (version 9.2). The spectral radiance of each band contained in the imagery was calculated and converted to reflectance which was used as an input for image classification. All the bands of the imagery used in the study were resampled to a pixel value of 32.0 in order to normalize the spatial scale differences between the bands of both datasets.

The conversion of raw digital numbers to at-satellite reflectance values was done according to methods outlined in the Landsat 7 Science Data Users Handbook (Irish, 2000), similar to related projects (Huang et al., 2002). The raw digital numbers of the Landsat TM and NigeriaSat1 images were converted to at-satellite values to remove all forms of noise that were introduced due to atmospheric effects, change views and illumination geometry as well as instrument errors (Huang et al., 2002; Iqbal, 1983). This normalised the impact of illumination geometry. Eqs. (1)–(3) below were used in the computation.

\[
L_i = \frac{DN_i \times \text{gain}_i + \text{bias}_i}{E_{\text{sun}} \times \sin \theta} \quad (1)
\]

\[
L_u = \left( \frac{DN_u}{\text{gain}_u} \right) + \text{bias}_u \quad (2)
\]

\[
R_i = \frac{3.1415926 \times L_i \times d^2}{E_{\text{sun}} \times \sin \theta} \quad (3)
\]

where \(i\) is the Landsat TM band number; \(u\) is the NigeriaSat1 band number; \(L_i(u)\) are at-satellite radiance of Landsat and NigeriaSat1 images; \(\text{gain}_i(u)\) and \(\text{bias}_i(u)\) are band specific values obtained from the metadata or HDR files of both datasets; \(d\) is the normalised Sun-earth distance calculated from the eccentricity correction factor \(E_0 (d^2 = 1/E_0)\) (Iqbal, 1983), \(E_{\text{sun}}\) is the mean solar exoatmospheric irradiance (Irish, 2000), and \(\theta\) is the sun elevation as provided in the image metadata file.

2.2.2. Image classification

The Iterative Self Organising Data Analysis (ISODATA) algorithm in ERDAS Imagine software (version 9.2) was used to perform an unsupervised classification of both images. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set (ERDAS Inc., 2008). Each time the clustering repeats, the means of these clusters are shifted. The new
cluster means are used for the next iteration. The ISODATA utility repeats the clustering of the image until either a maximum number of iterations have been performed, or a maximum percentage of unchanged pixel assignments reached between two iterations. For this study the unsupervised ISODATA classification technique had 30 classes, confidence threshold of 0.99, and 200 maximum iterations. The 30 classes were subsequently categorised into five major landcover classes namely: water, forest, bare soil, settlement and sand deposits.

2.2.3. Accuracy assessment

Due to the difficulty of accessing certain swamp terrain of the Niger Delta, a preselected site named Onya situated in Delta state which had been visited by the researcher was selected. The data used for training and testing image classifications were collected using a combination of methods and sources namely: DGPS field surveys covering Onya, a digitised 1: 50,000 topographic sheet covering Onya dated April 1984 and a high resolution orthorectified 1 meter IKONOS image dated January 2006 (which was closest to the NigeriaSat1 image used). The accuracy assessment was applied to the classified maps showing the following land-uses: water, forest, bare soil, settlement and sand deposits. This was accomplished using Accuracy Assessment command in ERDAS Imagine software. The results of the accuracy assessment for NigeriaSat1 image was 90% for the overall classification accuracy and 0.87 for the Kappa statistic.

2.2.4. Change detection

In order to determine the spatial extent of changes in the forested areas the classified images were recoded to define the forested areas as one class and all other land covers types were combined into a non-forest class. A post-classification comparison was adopted to determine the changes using the Change detection tool in ERDAS Imagine software. The forest transition maps showing deforested, afforested and unchanged forest landscapes were based on the difference between the forested area cover in the baseline (1986) and assessment (2007) maps for the study area.

2.3. Computing average annual rates of forest cover transition

The average annual rates of deforestation, afforestation and change in total forest cover were evaluated using spatial details of the forest cover area in 1986 and 2007. This was based on the assumption that the rates of annual deforestation, afforestation and change in total forest cover will not be constant (Armenteras et al., 2006; Lele and Joshi, 2008). Annual forest transitions were computed using the equations below:

\[
\text{Annual deforestation rate} = \frac{(\log F_{t2} - \log F_{t1} - B)}{t2 - t1} \times 100
\]

\[
\text{Annual afforestation rate} = \frac{(\log F_{t2} - \log F_{t1} - C)}{t2 - t1} \times 100
\]

\[
\text{Annual rate of total forest cover change} = \frac{(\log F_{t2} - \log F_{t1})}{t2 - t1} \times 100
\]

where \(F\) is the forested area in hectares, at \(t1\) (1986) and \(t2\) (2007); \(B\) is the area deforested between 1986 and 2007; and \(C\) is the area afforested between 1986 and 2007.

2.4. Forest cover change analysis and predicted dynamics

The extent of forest fragmentation was determined using FRAGSTATS software, a computer software program designed to compute a wide variety of landscape metrics for categorical map patterns (McGarigal et al., 2002). The metrics used in the study included the total area, percentage of landscape, number of patches (NP), mean patch area (MPA) and patch density (PD). The PD is equivalent to the number of patches of a particular patch type (i.e. forest patches) divided by the total landscape area.

Markov chain analysis is a technique for predictive change modeling and is based on past occurrences. In this study the Markov chain and probabilities matrix was used to evaluate the future status of forest cover in the Niger Delta outputting as results the percentage and probability of forest land use converting to non-forest and vice versa in the future. The Markov module in IDRISI Andes 15 (Eastman, 2006) was used for this procedure to perform a 20-year forward simulation. The example cited by Eastman (2006) used two different time periods (1971 and 1985) to project land use change into the future (1999) using the MARKOV module in IDRISI Andes 15. The module analyses a pair of land cover images and outputs a transition probability matrix and a set of conditional probability images (Eastman, 2006). The transition probability matrix records the probability of each land cover type changing to another landcover type, while the transition areas matrix records the number of pixels that are expected to change from each land cover type to each other land cover type over the specified number of time units. In the present study the conditional probability values showed the probability of forest land-cover being converted to non-forest and vice versa. The Markov chain analysis was executed on a state by state basis and the results outputted into ArcGIS for further analysis.

Table 1

Landscape measures from 1986 to 2002/03 of eight states in the Niger Delta region of Nigeria.

<table>
<thead>
<tr>
<th>State</th>
<th>Forest landscape area (ha)</th>
<th>Percentage of forest landscape (%)</th>
<th>Number of patches</th>
<th>Patch Density (no. per 100 ha)</th>
<th>Mean patch area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abia</td>
<td>192,968</td>
<td>287,092</td>
<td>39.73</td>
<td>59.11</td>
<td>46,741</td>
</tr>
<tr>
<td>Akwa Ibom</td>
<td>383,829</td>
<td>533,071</td>
<td>58.54</td>
<td>81.30</td>
<td>36,525</td>
</tr>
<tr>
<td>Bayelsa</td>
<td>791,441</td>
<td>659,829</td>
<td>84.54</td>
<td>70.48</td>
<td>9,150</td>
</tr>
<tr>
<td>Cross River</td>
<td>467,276</td>
<td>460,433</td>
<td>70.67</td>
<td>69.63</td>
<td>19,426</td>
</tr>
<tr>
<td>Delta</td>
<td>834,676</td>
<td>615,956</td>
<td>56.08</td>
<td>34.74</td>
<td>106,942</td>
</tr>
<tr>
<td>Edo</td>
<td>176,804</td>
<td>31,104</td>
<td>34.96</td>
<td>6.15</td>
<td>71,228</td>
</tr>
<tr>
<td>Imo</td>
<td>267,720</td>
<td>364,085</td>
<td>52.14</td>
<td>70.90</td>
<td>42,986</td>
</tr>
<tr>
<td>Rivers</td>
<td>650,422</td>
<td>681,311</td>
<td>62.77</td>
<td>65.75</td>
<td>40,088</td>
</tr>
<tr>
<td>Niger delta</td>
<td>3,765,136</td>
<td>3,533,880</td>
<td>59.93</td>
<td>56.25</td>
<td>373,086</td>
</tr>
</tbody>
</table>


1440
3. Results and discussion

3.1. Changes in forest cover

The total forest cover of the Niger Delta after image classification was 3,765,136 ha in 1986 and 3,533,880 ha in 2007 (Table 1). The total area of the forest and non-forest areas was 6,282,574 ha. The percentage of total forest cover in the Niger Delta declined from 60% in 1986 to 56% in 2007. In terms of percentages, the states with the highest forest cover were Bayelsa in 1986 (85%) and Akwa Ibom in 2007 (81%) (Table 1). The lowest forest cover was recorded for Abia in 1986 (40%) and Edo in 2007 (6%). Between 1986 and 2007 the percentage of forest cover increased for Abia, Akwa Ibom, Imo and Rivers states and declined for the Bayelsa, Cross River, Delta, and Edo states. The results showed that all the states in the Niger Delta had some form of variation in forest loss and gain over the 21 years time interval. Table 2 shows the results of forest cover change (indicating the areas that were deforested, unchanged and afforested) and the annual rates of change in the forest cover. The greatest loss in forest cover was in Delta state with a massive loss of 469,731 ha, 8% of the entire study area. The annual rates of deforestation varied between 4.94 and 0.45% across states which are higher than the rates observed in the Columbian Amazon which ranged between 3.73 and 0.01% (Armenteras et al., 2006). The total forest cover lost to deforestation in the entire Niger Delta was 1,381,217 ha, representing a large transition across 22% of the total landscape area. The annual deforestation rate for the Niger Delta from 1986 to 2007 was 0.95% while the afforestation rate was 0.75%. These rates exceed those reported for humid tropical forests globally and in Latin America, Africa and Southeast Asia (Achard et al., 2002). The annual rate of change in forest cover for the entire Niger Delta from 1986 to 2007 was –0.13% indicative of a general trend in forest cover decline. Bayelsa, Cross River, Edo and Delta states experienced forest cover decline, with Edo and Delta being the highest, while Abia, Akwa Ibom, Imo and Rivers states experienced a forest cover increase. Table 1 shows the deforested and afforested landscape area for states in the Niger Delta from 1986 to 2007.

3.2. Changes in forest spatial structure

Changes in the forest landscape structure from 1986 to 2007 were observed in all eight states of the Niger Delta. The changes in NP, PD and MPA which are measures of the extent of subdivision or fragmentation of the forests are shown in Table 1. The total NP increased in Bayelsa, Cross River, Delta and Rivers states, while it decreased in Abia, Akwa Ibom, Edo and Imo states (Table 1). PD showed an opposite change to the NP results for each of the states. Overall the NP for forest cover in the Niger Delta for 1986 and 2007 were 373,086 and 384,240, respectively, which may not appear to be a large difference overall, but the changes in NP tend to be concentrated in particular states (Table 1). For Bayelsa, Cross River, Delta, Edo and Rivers states there was a decline in the MPA from 1986 to 2007, a further indication that fragmentation had occurred in the five states. However, Abia, Akwa Ibom, and Imo states had an increase in MPA indicating an overall expansion of existing forest patches. The MPA for the entire Niger Delta decreased from 10.1 ha to 9.2 ha between 1986 and 2007. Overall, these spatial metrics demonstrate that for most states in the Niger Delta, forest cover has declined and the remaining patches have become more fragmented. However, there is a group of states where forest cover has increased and this is mostly through the enlargement of forest stands rather than the creation of new patches. Such variations between states in the dynamics of forest spatial structure are likely to generate different environmental effects. Nevertheless, the dominant process of forest cover decline and fragmentation across the

<table>
<thead>
<tr>
<th>State</th>
<th>Deforested (ha)</th>
<th>Unchanged forest (ha)</th>
<th>Afforested (ha)</th>
<th>Annual rate of change in forest cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abia</td>
<td>100,165</td>
<td>94,803</td>
<td>192,289</td>
<td>1.51</td>
</tr>
<tr>
<td>Akwa Ibom</td>
<td>75,190</td>
<td>308,639</td>
<td>224,431</td>
<td>4.51</td>
</tr>
<tr>
<td>Cross River</td>
<td>178,722</td>
<td>612,719</td>
<td>47,110</td>
<td>0.53</td>
</tr>
<tr>
<td>Delta</td>
<td>132,159</td>
<td>335,117</td>
<td>125,315</td>
<td>0.69</td>
</tr>
<tr>
<td>Edo</td>
<td>160,544</td>
<td>16,260</td>
<td>14,844</td>
<td>4.94</td>
</tr>
<tr>
<td>Imo</td>
<td>81,902</td>
<td>185,819</td>
<td>178,267</td>
<td>2.27</td>
</tr>
<tr>
<td>Rivers</td>
<td>182,805</td>
<td>467,616</td>
<td>213,694</td>
<td>0.82</td>
</tr>
<tr>
<td>Niger Delta</td>
<td>1,381,217</td>
<td>2,385,919</td>
<td>1,147,961</td>
<td>0.95</td>
</tr>
</tbody>
</table>
delta as a whole is likely to have deleterious effects on the provision of a wide range of ecosystem services. While fragmentation can lead to greater habitat diversity, studies in other tropical forest environments, have clearly demonstrated that fragmentation leads to adverse effects on range-restricted endemic species (Martin and Blackburn, 2010), overall species diversity (Fahrig, 2003), carbon sequestration (Groeneveld et al., 2009) and controls on the hydrological cycle (Giambelluca, 2002).

3.3. Socioeconomic drivers and processes of forest landscape transitions

Part of this study aimed at investigating if there were relationships between specific socio-economic indicators and the characteristics of forest transition in the Niger Delta region. In this regard data on the poverty ratings percentage and population statistics for all eight states in the Niger Delta were obtained from the office of the National Bureau of Statistics in Nigeria. The concept of measuring poverty level has a number of factors contributing to the proper definition of this term. Poverty is not the lack of income alone but the absence of basic requirements such as health facilities, education and employment (NBS, 2005, 2006; NDES, 1997). Recently powerlessness, isolation, vulnerability and social exclusion have been included in having a proper definition of poverty. The poverty headcount percentages recorded by the Office of statistics (2004) indicate high levels of poverty across the Niger Delta but with considerable variations between states (Table 3). Having regressed the annual afforestation and deforestation rates against the poverty headcounts between states it was revealed that there was no direct relationship between poverty and the rates of deforestation or afforestation across the states, indicating that there are other significant drivers of forest transition in the region.

The population figures from the 1963, 1991 and 2006 censuses conducted by the National Population Commission indicate a steady increase in the population of states comprising the Niger Delta (Table 3). In 1963 Rivers and Bayelsa states (formerly known as Rivers state) had a population of about 1.7 million people compared to 2.5 million, 3.5 million and 3.7 million inhabitants of Delta and Edo (formerly Bendel), Cross River and Akwa Ibom (formerly Cross River) and Imo and Abia (formerly Imo) states, respectively (NBS, 2006). Results of the 1996 and 2006 censuses revealed a rapid increase in population for each state. The highest was recorded in Rivers state having an exponential growth rate of 3.4%, followed by Delta and Imo states each having 3.2%. Akwa Ibom, Bayelsa and Cross River each had growth rate values of 2.9% while Abia and Edo had the smallest growth rate of 2.7%. Again, our analysis showed that there was no direct statistical correlation between population dynamics and the variation in forest transitions between states. However, it is apparent that economically driven variations in population and forest practices are important.

Prior to the 1970s migration into the Niger Delta was determined by the agricultural, fishing and trading needs of inhabitants in and around the region (NDES, 1997). However, after the discovery of oil in the Niger Delta the rate of migration increased as people from all over the country came to the urban areas of the core states of the region (particularly Rivers and Delta states) seeking jobs in oil companies. This pattern of migration was responsible for the massive growth rate witnessed in Rivers state (Table 3). Most of the major oil companies in Nigeria have their headquarters in Port Harcourt, capital of Rivers state. The inhabitants of the state rely more on the revenue derivable from the oil industry and trading activities. Port Harcourt has a history of being a major merchant port and is the center of a variety of industry with exports such commodities as petroleum, coal, tin, palm produce, cocoa and groundnuts. Given the limited availability of land in the mangrove dominated region of the core states, the population density on the habitable areas has increased greatly resulting in intensified pressure and over exploitation of the forest resources in the region (WAD, 1990; Moffat and Linden, 1995). It should be noted that most of the states with high afforestation rates are further away from the core states of the Niger Delta, and lack the financial resources of the oil rich states. Fig. 2 shows the maps of forest cover derived from remotely sensed data in 1986 and 2007, together with map of forest transitions that have taken place in the Niger Delta over the 21 years period. At a glance one can see the high transition in forest cover in Delta and Edo states which were mostly affected by the trend of forest loss, while states such as Imo, Abia and Akwa Ibom have experienced considerable afforestation.

Using contemporary aerial photographs to provide greater spatial detail, Fig. 3 provides examples of forest transition hotspots, showing deforested and afforested sites. The influence of human activities such as construction activities and intensified logging without replacement of felled trees has lead to the fragmentation of forest landscapes in the region (Fig. 3a–c). The pattern of deforestation in the Niger Delta is influenced by access routes such as roads, tracks and water ways; settlement expansion and construction activities such as power base stations; intensified exploration of crude oil by oil companies and seismic companies; and exploitation of forest resources for building, furniture making and export. A similar situation was observed in the tropical forests of the Colombian Amazon where the patterns of deforestation were influenced by the river transportation network, demographic pressure, quality of life and population density (Armenteras et al., 2006). In the Niger Delta some states have embarked on conserving forests and growing forest and oil palm plantations (Fig. 3d–f).
Fig. 2. Classified forest cover and forest transition hotspot map of the Niger delta from 1986 to 2007 (a: classified forest map for 1986, b: classified forest map for 2007, c: afforested, unchanged and deforestation areas hotspot map of the study area).

Table 4
Results of the Markov chain analysis: transition probability and transition area matrix for the Niger Delta.

<table>
<thead>
<tr>
<th>State</th>
<th>Land cover</th>
<th>Transition probabilities</th>
<th>Transition areas (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Forest</td>
<td>Non-forest</td>
</tr>
<tr>
<td>Abia</td>
<td>Forest</td>
<td>0.47</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Non-forest</td>
<td>0.67</td>
<td>0.33</td>
</tr>
<tr>
<td>Akwa Ibom</td>
<td>Forest</td>
<td>0.80</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Non-forest</td>
<td>0.83</td>
<td>0.17</td>
</tr>
<tr>
<td>Bayelsa</td>
<td>Forest</td>
<td>0.77</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Non-forest</td>
<td>0.33</td>
<td>0.67</td>
</tr>
<tr>
<td>Cross River</td>
<td>Forest</td>
<td>0.72</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>Non-forest</td>
<td>0.64</td>
<td>0.36</td>
</tr>
<tr>
<td>Delta</td>
<td>Forest</td>
<td>0.44</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>Non-forest</td>
<td>0.23</td>
<td>0.77</td>
</tr>
<tr>
<td>Edo</td>
<td>Forest</td>
<td>0.09</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>Non-forest</td>
<td>0.05</td>
<td>0.95</td>
</tr>
<tr>
<td>Imo</td>
<td>Forest</td>
<td>0.69</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>Non-forest</td>
<td>0.73</td>
<td>0.27</td>
</tr>
<tr>
<td>Rivers</td>
<td>Forest</td>
<td>0.72</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>Non-forest</td>
<td>0.55</td>
<td>0.45</td>
</tr>
<tr>
<td>Niger Delta total transition of forest landscape:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Niger Delta total transition of non-forested landscape:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.4. Forward simulation of forest cover

A forward simulation was performed in order to model the future status of the forests in the Niger Delta taking into consideration the pattern of forest transition recorded between 1986 and 2007. Table 4 shows the transition probabilities for each of the states together with the predicted areas of each state that will remain forested or non-forested or undergo conversion to forest or non-forest. Table 4 demonstrates graphically the variations between states in (a) the transition probabilities and (b) the total area of deforestation and afforestation. Fig. 4 shows the transition probability maps of forest cover in 2027 derived from remotely sensed data in 1986 and 2007. The results indicate that the highest probability of deforestation is in Edo state but because of the small area of remaining forest in 2007, the spatial extent of deforestation predicted for 2027 is small. Delta state is predicted to experience the largest spatial extents of both deforestation and afforestation, while most other states will have approximately the same areas that undergo deforestation and afforestation. These changes will result in large rates of transition of the forested landscape across the Niger Delta as a whole. As shown in Table 4, the total area of deforestation is predicted to 1,154,410 ha which amounts to 18% of the total geographical area of the delta. The total area to become afforested landscape
is 1,004,414 ha which is 16% of area of the delta. Hence, under present forest management regimes, some 34% of the area of the delta is predicted to undergo some form of forest transition by 2027.

4. Conclusion

This study has identified the spatial extent of forest transition in the Niger Delta region of Nigeria using remotely sensed data. The annual rate of deforestation, afforestation and forest cover change for the entire Niger Delta region was determined as 0.95, 0.75 and −0.13 percent, respectively. These represent rates of forest transition which are high compared with those found in many previous studies in tropical forest environments. There were considerable variations between the different states of the delta region in the characteristics of forest transition. Deforestation hotspots were found in the states of Bayelsa, Cross River, Delta and Edo while Abia, Akwa Ibom, Imo and Rivers states experienced high rates of afforestation. Landscape spatial metrics indicated that the forests of the Niger Delta have undergone high levels of fragmentation, which, as observed in other tropical forest regions, is likely to result in the degradation of ecosystem services provided by the forests.

The results indicated that there were no direct relationships between the characteristics of forest transition and poverty headcounts or population growth across the states of the Niger Delta. However, forest transitions can be accounted for by the different means of managing forest resources implemented in the states in response to the variations in the balance between their economic dependence on oil or forest-based resources. Our simulations of future changes indicated that, based on current patterns of landscape management, a substantial proportion of the Niger Delta will undergo some form of forest transition over the coming decades. Given the likely ecological and environmental impacts of this large-scale trend, urgent attention needs to be given to the development and implementation of more sustainable management policies and practices.

Acknowledgements

This study was made possible by the sponsorship of the Petroleum Technology Development Fund (PTDF) provided by the Government of Nigeria. Special thanks to the DMCii for providing the NigeriaSat1 imagery used for the study.

References


Wang, C., Qi, J., Cochrane, M., 2005. Assessment of tropical forest degradation with canopy fractional cover from Landsat ETM+ and IKONOS imagery. Earth Interactions 9, 1–18.