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Detecting Trends in Landuse and Landcover Change of Nech Sar National Park, Ethiopia

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Abstract Nech Sar National Park (NSNP) is one of the most important biodiversity centers in Ethiopia. In recent years, a widespread decline of the terrestrial ecosystems has been reported, yet to date there is no comprehensive assessment on degradation across the park. In this study, changes in landcover were analyzed using 30 m spatial resolution Landsat imagery. Interannual variations of normalized difference vegetation index (NDVI) were examined and compared with climatic variables. The result presented seven landcover classes and five of the seven landcover classes (forest, bush/shrubland, wooded grassland, woodland and grassland) were related to natural vegetation and two landcover types (cultivated land and area under encroaching plants) were direct results of anthropogenic alterations of the landscape. The forest, grassland, and wooded grassland are the most threatened habitat types. A considerable area of the grassland has been replaced by encroaching plants, prominently by *Dichrostachys cinerea*, *Acacia mellifera*, *A. nilotica*, *A. oerfota,* and *A. seyal* and is greatly affected by expansion of herbaceous plants, most commonly the species of the family Malvaceae which include *Abutilon anglosomaliae*, *A.bidentatum* and *A.figarianu*. Thus, changes in vegetation of NSNP may be attributed to (i) degradation of existing vegetation through deforestation and (ii) replacement of existing vegetation by encroaching plants. While limited in local meteorological station, NDVI analysis indicated that climate related changes did not have major effects on park vegetation degradation, which suggests anthropogenic impacts as a major driver of observed disturbances.

Keywords Degradation · Landsat · Landcover · NDVI · Nech Sar · Terrestrial

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Introduction

Nech Sar National Park (NSNP) is one of the globally most important protected areas (PAs) serving as a refuge and providing habitat for numerous wildlife species including, Grant's zebra (*Equus quagga*) which yet widely erroneously called as 'Burchell's zebra' (Clark 2010), Grant's gazelle (*Gazella granti*), and specially for conserving the population of Swayne's hartebeest (*Alcellaphus buselaphus swaynei),* a highly threatened subspecies (Bolton 1969; Bolton 1973; Duckworth et al. 1992). NSNP lies within the Somali-Massai Regional Center of Endemism, one of the major floristic regions in Africa and falls within one of the International Union for Conservation of Nature (IUCN's) global biodiversity hotspots in the world, named the "Horn of Africa" (Blower 1968; Bolton 1970; Duckworth et al. 1992). As a result of abundant bird fauna that are held in the NSNP, Birdlife International has designated the park as an Important Bird Area (EWNHS 1996). While the importance of NSNP for nature conservation is well documented (White 1983; Duckworth et al. 1992) and widely considered as crucial to protect habitats, rehabilitate degraded areas and to improve local livelihoods (Blower 1968; Bolton 1970; Fetene et al. 2012a), the park is also considered as one of the most degraded in the world (Clark 2010). The habitat degradation of NSNP (Svialek 2008; Shimelse et al. 2010; Yusuf et al. 2011) is associated to long-lasting human activities to the natural habitats. For example, soil erosion in the Nech Sar Plain is a great problem arising from livestock overgrazing. In addition to degradation due to overgrazing, a large area of the grassland habitat is threatened by shrub encroachment (Yusuf et al. 2011) and is greatly affected by expansion of encroaching perennial herbs and shrubs (Andargie 2001; Svialek 2008).

The forest resources within the park have decreased in size due to over-harvesting and crop farming. The population of Arba Minch is growing rapidly with high demand of fuelwood and placing increasing pressure on the small, rare groundwater forest which is also attributed to be a direct consequence of the physical expansion of the town in the absence of any attempt to promote alternative sources of energy (Aregu and Demeke 2006).

Series of institutional change in the PAs governance is also cited as one of the main challenges for the conservation enforcement of NSNP. For instance, since its foundation in 1974, NSNP has been subject to several institutional changes (Table 1) and instability of the organizational structure has had a strong impact on the park's protection and its enforcement (Negera 2009; Debelo 2011, 2012; Kelboro and Stellmacher 2012).

These changes and institutional instability at national level have had negative effect on NSNP and other PAs in Ethiopia and subsequently have led to decline of wildlife population (Doku et al. 2007; Vymyslická et al. 2010; Fetene et al. 2011; Datiko and Bekele 2011; Mamo et al. 2012).

Therefore, conservation and restoration strategies for NSNP will require a detailed knowledge and understanding of the spatial and temporal patterns of landscape disturbance and degradation as these dynamics are closely linked to habitat quality, species fitness, and population persistence (Turner 1990; Hall et al. 1997; Block et al. 1998; Morris 2001). Estimates of vegetation dynamics in NSNP have traditionally been based on a few spatially and temporally discrete observations within the park area (e.g., Negussie 2008) but such observations cannot adequately reflect the rapid and numerous changes within the park area over recent decades. There is little historic data available to help understand the impact of human activity on park disturbance. Consequently, there is a need for temporally and spatially comprehensive mapping of disturbance and degradation in NSNP.

In addition, it is necessary to identify the drivers of change especially those regarded as negative forces as a prerequisite for a future park management plan (Scholte 2011). Proper understanding of key drivers of habitat disturbance has paramount importance in helping the main stakeholders particularly; wildlife managers, environmental planners, policy makers, and the community at large to formulate informed plans and policies for sustainable wildlife conservation (Meir et al. 2004; Watson et al. 2009).

As an alternative to field-based approaches, landscape disturbance and degradation in NSNP may be analyzed in space and time using satellite data (Kennedy et al. 2007, 2010). Remote sensing provides large area estimates of deforestation rates, habitat fragmentation, and habitat degradation in human-altered landscapes (Narumalani et al. 2004; Stickler and Southworth 2008) and may therefore be a useful tool for habitat conservation planning. It may also provide historic records of landscape disturbance, which will be useful for estimating the effect of policy changes on the status of ecosystems in NSNP.

The Landsat series of satellites has proven utility for mapping landcover change and disturbance (e.g., Wulder et al. 2007; Masek et al. 2008) since 1972. The Landsat TM and ETM + sensors on board of Landsat 5 and 7 platforms have a spatial resolution of 30 m, a spatial extent of 185 × 185 km per scene thereby representing landcover across large area (Wulder et al. 2007) at a revisit cycle of 16 days. The Landsat archive became freely available in early 2008 (Roy et al. 2010) providing new opportunities for mapping and analyzing previously underrepresented areas such as NSNP. In this study, satellite data from the Landsat TM and ETM + sensors were used to analyze both temporal and spatial patterns of disturbance and

Table 1 Park management and enforcement of NSNP protection

Period	Management
1974–1980	Ethiopian wildlife conservation organization (EWCO)
1980–1994	Forest and wildlife conservation and development authority (FaWCDA)
1995–2004	Southern nation nationalities and peoples regional state (SNNPRS)
2004–2008	African parks foundation (private–public management)
2008–present	Ethiopian wildlife conservation authority (EWCA)

landscape degradation in the terrestrial habitats of NSNP using historical to recent observations.

Therefore, the main objectives of this study are to answer the questions such as (i) what is the magnitude and direction of change in landuse/landcover within terrestrial area of the NSNP over time? (ii) Which landcover/habitat types are more affected by landscape disturbance? and (iii) what are the key drivers for land scape degradation and landcover change in the NSNP? Answering these questions will help identify root problems and enables to suggest alternative management strategies for NSNP and PAs elsewhere in Ethiopia.

Materials and Methods

Study Area

Nech Sar, meaning 'white grass' in Amharic language (Official language of Ethiopia), is an IUCN (International Union for Conservation of Nature) category II National park that was established in 1974. The name Nech Sar is derived from a creamy color of grass *Chrysopogon plumulosus* that whitens during the dry season at Nech Sar Plain (Duckworth et al. 1992). It is situated 510 km south of Addis Ababa with an altitudinal range of 1100–1650 m above sea level. The park combines different landscapes including savannah grasslands, hill areas, lakes, riparian and ground water forests, woodlands, shrub and thickets (White 1983; Duckworth et al. 1992). The ground water forest and Kulfo riparian forest dominate the western part of NSNP and the Sermele riparian forest is found in the eastern part of the park along the Sermele River (Fig. 1). NSNP covers 514 km^2 with 85 % terrestrial ecosystems and 15 % are aquatic formed by Lake Abaya and Lake Chamo, including 55 km of shoreline from Lake Abaya and 41 km of shoreline from Lake Chamo (Clark 2010). This study focuses on the park's terrestrial habitats and the park was selected as a study area due to its ecological significance and the multiple problems associated with its management and conservation (Fetene et al. 2014; Kelboro and Stellmacher 2012).

The climate of the study area is characterized by a relatively hot climatic condition with low and unevenly precipitation distribution. The annual pattern of precipitation around NSNP is bimodal. Monsoon winds from the Indian Ocean bring the majority of rain during the first rain season between March and May. Prevailing winds from the Atlantic Ocean are responsible for a second, shorter rain season between September and November (Clark 2010). Mean annual minimum and maximum temperatures between 1980 and 2010 were 17 and 30 °C, respectively, and the mean annual precipitation was 907 mm (Metrological Agency of Ethiopia).

Field Data Collection

Ground truth points were established at random locations to validate observations obtained from remotely sensed images. During the field work, photographs were taken at different landcover types and spatial locations were recorded using a Global Positioning System (GPS 60). Information on the historical landcover of the park was collected by interviewing senior native wildlife scouts who were engaged in the park since its establishment and assisted this field data collection. Further evidence of the historic distribution of species and landcover was available from previous works (Negussie 2008; Fetene et al. 2011). Based on field observations and local people knowledge, the terrestrial landcover of NSNP was categorized into seven different classes, including forest, bush/shrubland, wooded grassland, woodland, grassland, cultivated land and areas dominated by encroaching plants. Although it is difficult to identify encroaching plants from remotely sensed data at species level, our field observation and experience supported by information from senior wildlife scouts of NSNP help define area under encroaching plants separately as it showed a unique form of structure relative to the other dominant vegetation types. As a result of occupying a large portion of land by these plants in the NSNP, a landcover class under encroaching plants is warranted. The vegetation description was based on the classification provided by FAO (2012) and White (1983) and other relevant literatures (e.g., Pratt et al. 1966; Lind and Morrison 1974; Pratt and Gwynne 1977).

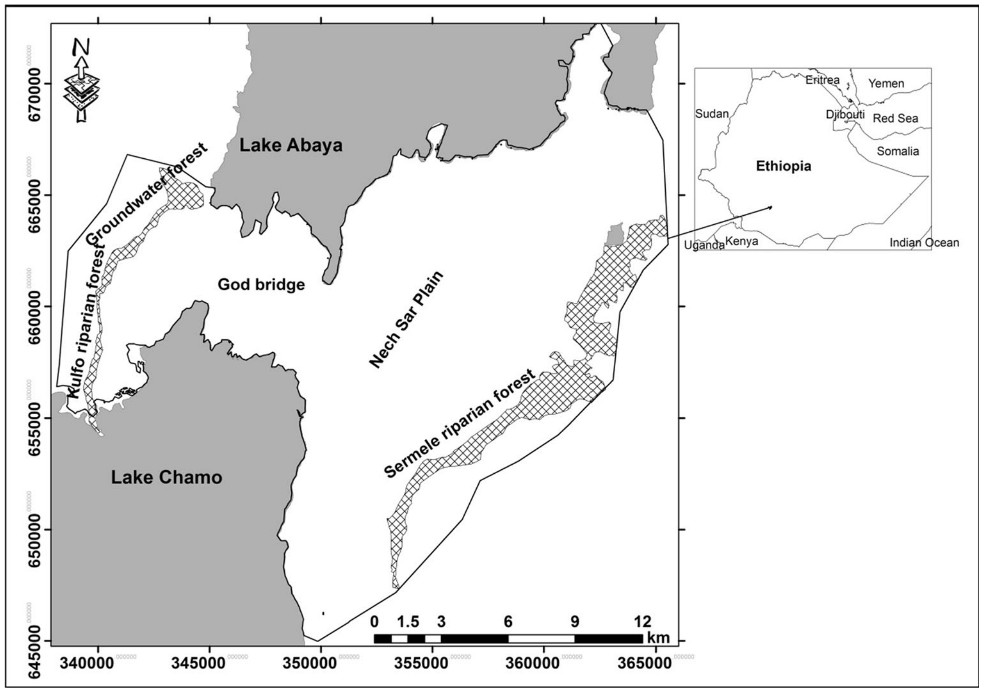
Forest land spanning more than 0.5 ha, with a tree canopy cover of more than 10 %, which are not primarily under agricultural or urban landuse and includes forest in national parks, nature reserves and other protected areas such as those of specific environmental, scientific, historical, cultural, or spiritual interest.

Bushland densely growing woody vegetation of shrubby habit, with a canopy cover of 40 % or more, low stature between 3 and 7 m in height, and when it mixed with climbers termed as thicket.

Shrubland area covered by woody perennial plant, generally more than 0.5 m and less than 5 m in height at maturity and without a definite crown. The height limits for trees and shrubs should be interpreted with flexibility, particularly the minimum tree and maximum shrub height, which may vary between 5 and 7 m.

Wooded grassland land covered with grasses and other herbs, with woody plants covering between 10 and 40 % of the ground.

Fig. 1 Map of study area



Woodland consists of trees that are branched, deciduous and range from 8 to 20 m in height, canopy cover >20 %, crowns may touch grasses and herbs present.

Grassland land covered by grasses and other herbs, either without woody plants or if present not covering more than 10 % of the ground.

Cultivated land areas where the natural vegetation has been removed or modified and replaced by other types of vegetative cover of anthropogenic origin (UNEP/FAO 1994).

Encroaching plants Distinctive plants which are common causes of grassland loss in dry savannas and are responsible for a decline in range condition (Scholes and Walker 1993; Oba et al. 2000).

Remote Sensing Data

Landsat images were used to detect changes in landcover and landuse between 1985 and 2013. Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images with less than 80 % cloud cover were downloaded for the park area (Path/Row 169/56) from USGS/GLOVIS using the Landsat image selector developed by the US Forest Service Pacific North West Research station in Corvallis, OR (http://staticweb.fsl.orst.edu/larse/ts/index.html). A total of 137 images (67 from the dry season and 70 from the rain season), on average six images per year were downloaded. For the purpose of this study, rain season in the study area was defined as the periods from March 1 to May 31 and September 1 to November 30 and dry season was defined as the periods between December 1 to February 28 and June 1 to August 31. No Landsat images were available for the years 1991–1993 and 1996–1998 of the study area.

Landsat images were atmospherically corrected using Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) algorithm (Masek et al. 2013). LEDAPS is based on a Dark Object Subtraction (DOS) to correct for additive noise caused by aerosols. In addition to atmospheric correction, cloud and cloud shadow were removed from all images using *fmask*, an automated cloud mask algorithm (Zhu and Woodcock 2012).

Landcover Classification and Change Detection

Changes in landcover between 1985 and 2013 were determined using a supervised classification method based on a combination of Landsat TM bands 1–5 and 7 (maximum likelihood approach) with the information generated from ground control points and based on local peoples' knowledge of field observation information about vegetation types. To mitigate misclassification of individual pixels, majority analysis using kernel size of 3 by 3 was employed to change spurious pixels within a large single class and smoothing the landcover results.

In order to minimize errors in landcover classification resulting from reflectance differences in the dry and rain seasons, landcover analysis was based only on rain season images with reasonable cloud cover (see "Remote Sensing Data" section). Rain season imagery has the advantage that crop cultivation and encroaching plants are easier to identify than during the dry season. Following the supervised classification of imagery post-classification change detection algorithm was performed to determine changes in landcover (Yang 2002; Yuan et al. 2005; Lindquist et al. 2008). This post-classification approach provides statistical evidence on how landcover has changed and is used to calculate and map landcover changes over time.

The accuracy of the landcover classification was assessed using a confusion matrix to compare the 2011 classification results to the ground observations. For each landcover class, a contingency matrix was generated and the overall accuracy, the Kappa statistic, and the producer and user accuracy for each class were calculated (Congalton and Green 2009). The total accuracy was calculated by dividing the number of correctly classified elements (i.e., the sum of the diagonal elements in an error matrix) by the total number of pixels included in the evaluation process. The Kappa statistic is an alternative measure of the classification accuracy that subtracts the effect of random accuracy and it quantifies how much better a particular classification is compared to a random classification.

Validation of historic landcover results is inherently more difficult due to the lack of comprehensive field observations at different periods. It is, however, reasonable to assume that accuracies of those classifications are comparable to that achieved in 2011 as image quality and landscape structure are comparable. Additional evidences about historic landuse were collected from local expert information and previous vegetation studies (e.g., Bolton 1970; Duckworth et al. 1992; Negussie 2008; Svialek 2008; Fetene et al. 2012b).

Interannual Variations of Normalized Difference Vegetation Index

In addition to changes in the spatial extent of vegetation types, interannual variations of normalized difference vegetation index (NDVI) and their relationships with climatic variables (temperature and precipitation) were also examined to assess vegetation degradation over time. The landsat-based detection of trends in disturbance and recovery (LandTrendr) algorithm, a trajectory-based change detection method (Kennedy et al. 2010), was used to determine changes in Landsat TM and ETM + satellite images.

The physical characteristics of the vegetation detected by the NDVI are likely related to some measure of canopy density (i.e., leaf area or percent cover) (Verhulst and Govaerts 2010). NDVI value ranges from −1 to 1. The highest the value, the highest would be the proportion of green vegetation in the pixel. NDVI is sensitive to the presence, density and condition of vegetation and is found to be a good predictor of vegetation vigor (dense to bare) and degradation of ecosystem (Hurbert and Haskell 2003). Value of −1 to 0 is usually assumed as non-vegetation and when the value approaches to 1 indicates dense vegetation. To minimize cloud contamination and optimize image quality for noise, best pixel NDVI composites were generated by averaging cloud free observations for each year and season. In this study, NDVI values are scaled between 0 and 1000 to fit with the precipitation and temperature measurements. However, since there is no a continuous data of remotely sensed images in the 1990s, the NDVI analysis was conducted between 2000 and 2010. In these periods, there is a continuous remote sensing data that can fit with the measurement of climate variables of the same years and seasons.

Assessment of Human Activities

Modes human activities in the park (e.g., livestock grazing, wood and grass collections and crop farming) were documented with respect to the distinguished landcover types. Using secondary data on the livestock trend and landcover changes, in the eastern part of the park particularly at the Nech Sar Plain and Sermele Valley, the existing livestock grazing and crop farming activities were assessed in relation to their effects on the natural vegetation.

Group discussion was conducted with relevant stakeholders of two administrative regions (Gelana from Oromia region and Amaro from Southern Nation, Nationalities and Peoples' region) and with two communities ('Guji' communities at NSNP and 'Kore' communities at 'Abulo-Alfecho'). Each group was composed of about ten to twenty individuals and the discussion was related to the resource use by the communities. The group discussion was conducted for about 2 h for each group and the results were checked with the information provided by the park management team. Moreover, collection of wood from Arba Minch groundwater forest and Kulfo riparian areas by residents of Arba Minch town were recorded during the study period.

Results

Changes in Landcover

A confusion matrix of landcover types using field observations showed that the accuracy of landcover change analysis was 90 % with a Kappa statistic of 0.878 (Table 2). User's accuracies ranged from 73 % for cultivated land to 97 % for forest and producer's accuracies

Table 2 Confusion Matrix for the Landsat TM 2011 image classification

Classified	Reference								
	Forest	Grass-land	Encroaching plants	Wooded grassland	Woodland	Cultivated land	Bush/shrubland	Row total	UA (%)
Forest	**146**	0	0	0	1	3	0	150	97
Grassland	0	**118**	1	4	0	0	0	123	96
Encroaching plants	0	2	**24**	1	0	0	0	27	89
Wooded grassland	0	5	0	**64**	5	2	0	76	84
Woodland	0	0	1	5	**80**	2	0	88	91
Cultivated land	9	0	0	2	2	**40**	2	55	73
Bush/shrubland	7	0	0	4	5	0	**88**	104	85
Column total	162	125	26	80	93	47	90	623	
PA (%)	90	94	92	80	86	85	98		

Overall accuracy = 90 %; Kappa statistic = 0.878

UA user's accuracy, *PA* producer's accuracy

Values along the matrix diagonal (correct classifications) are emphasized in bold

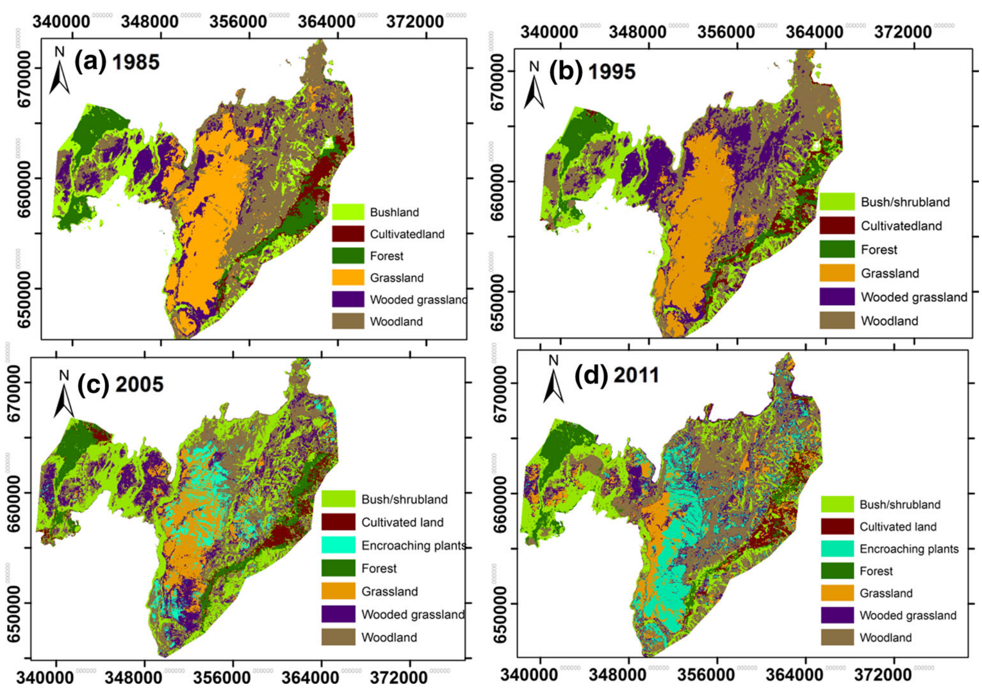


Fig. 2 a–d Terrestrial landcover maps of NSNP of 1985, 1995, 2005 and 2011

ranged from 80 % for wooded grassland to 98 % for bush/shrubland.

Magnitude and Direction of Landcover Change

A high magnitude and variety of landuse/landcover changes were recorded in NSNP. Among others habitat conversions were observed from forest to cultivated land and from grassland to bush/shrubland colonized by encroaching plants (Fig. 2).

Grassland areas remained relatively intact between 1985 and 1995, with some encroachment by woody species along the eastern edge of the park. However, the periods between 1995 and 2005 and then until 2011 saw a massive decline in the grassland where it reduced by 72 % of its 1985 extent (Table 3). Figure 3 illustrates the progressive

Table 3 Landcover area statistics and rate of change between 1985 and 2011

Landcover classes	1985 landcover (km^2)	Percentage of landcover 1985	1995 landcover (km^2)	Percentage of landcover 1995	2005 landcover (km^2)	Percentage of landcover 2005	2011 landcover (km^2)	Percentage of landcover 2011	Change in landcover 1985–2011 (%)
Forest	32	10	25	7	24	7	20	6	−38
Bush/shrubland	48	14	55	17	72	22	68	20	42
Wooded grassland	57	17	56	17	57	17	30	9	−47
Woodland	103	31	111	33	70	21	107	32	4
Grassland	79	24	69	21	55	16	22	7	−72
Encroaching plants[a]	–	–	–	–	35	10	51	15	46
Cultivated land	15	4	17	5	20	6	35	11	133

[a] Relative change detection was made between 2005 and 2011

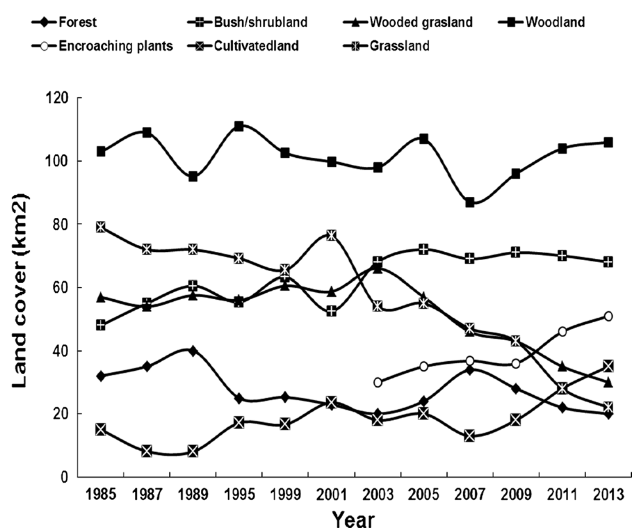


Fig. 3 Trends of landcover in Nech Sar National Park between 1985 and 2013

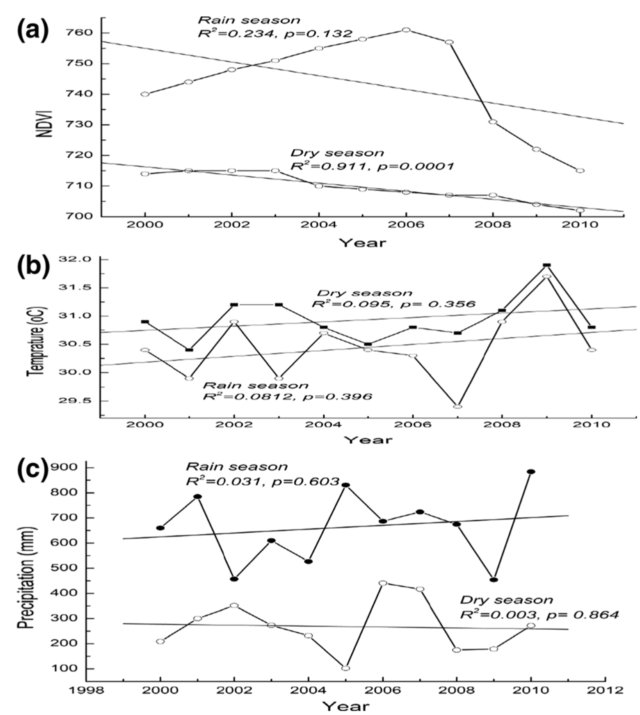


Fig. 4 Inter annual variations in **a** seasonal NDVI, **b** seasonal mean temperature, and **c** seasonal precipitation of NSNP

decrease in forest and grassland and replacement with new or previously less dominant landcover types. Forest areas were largely replaced by cultivated land particularly after 2005. Cultivated land expanded particularly in the Sermele Valley, the eastern part of the study area, and has more than doubled since the 1980s with a particular strong increase after 2007 (Fig. 3).

In addition to cultivated land, woody species have taken over some of the grassland, likely as a result of over grazing by domestic animals. Some landcover types, including the grassland ecosystems, have declined steadily, while changes in other landcover types have been slowed during certain times or were even temporarily reversed, such as in the case of the cultivated land area. The most dramatic reduction in landcover was seen in grasslands which declined from previously about 79 km^2 in 1985 to about 22 km^2 in the 2011(Table 3).

Trends of Seasonal NDVI in NSNP

The NDVI trends for dry seasons decreased significantly ($R^2 = 0.911$, $P = 0.0001$) between 2000 and 2010 (Fig. 4a) but the climatic variables (precipitation and temperature) did not show significant differences within that periods (Fig. 4b, c), indicating that results of NDVI did not show significant correlations with climate variables for the study periods (Fig. 5a–d).

Despite the pronounced NDVI decrease in the dry season of the study area, the analysis showed little effects of precipitation and temperature on the vegetation change. In this study, changes in seasonal precipitation and mean seasonal temperature trends were not consistent with those of NDVI, indicating that climatic parameters were not significant drivers for the contribution of vegetation activity to seasonal plant growth of the study area. In fact, these results are based on local meteorological data and may not apply for large-scale landscape interpretation.

Effects of Human Activities

The result showed that human activity is dominantly observed in the three habitats (the forest, the wooded grassland and the grassland), which are the most preferred habitats by wild animals. As a result of livestock and human pressure, the Nech Sar Plain is degraded by overgrazing and the grassland is invaded by undesirable plant species which are unusual for the area. The wooded grassland is severely disturbed by human settlement. The Sermele riparian forest is deforested and the area is converted into crop farm. In the Arba Minch groundwater forest collection of fuel wood was observed as a daily activity by the people from Arba Minch town. Thus a number of men and women, young and children were observed while collecting wood resources from the forest. Observation of human and livestock is much more recorded in the forest and grasslands as compared to other habitat types of NSNP (Fig. 6).

Results of group discussion also showed that a large portion of the communities within and the surrounding areas have been excessively utilized the park resources directly or indirectly.

Discussion

The results have shown dramatic shifts in both vegetation type and vegetation density, which coincided well with changes in organization structures and related changes in anthropogenic landuse. These results are in agreement with previous findings (Negussie 2008; Clark 2010; Yusuf et al. 2011), suggesting that anthropogenic use is a major factor of landscape degradation in NSNP. At the same time, the results also suggest that precipitation as the major meteorological driver of vegetation growth (e.g., Svialek 2008) played only a minor or insignificant role in the observed changes. Classification accuracies of >90 % indicate that satellite remote sensing was successfully used to analyze vegetation types across the NSNP (Ridd and Liu 1998).

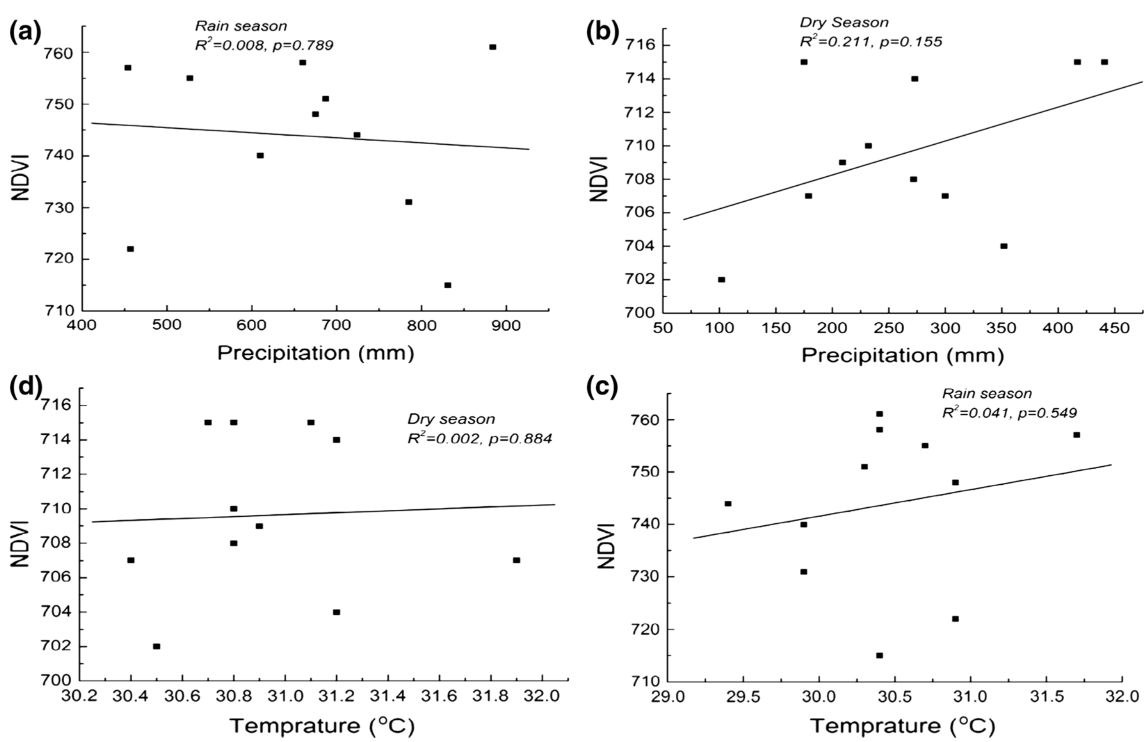


Fig. 5 Mean seasonal NDVI—precipitation and temperature relations of NSNP

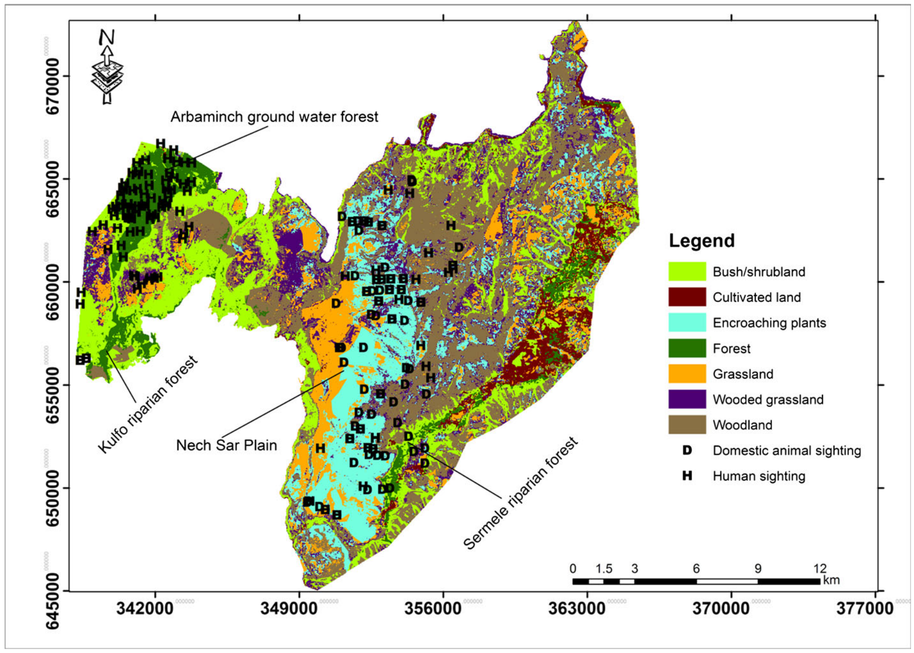


Fig. 6 Human and domestic animal sightings at different habitats of NSNP

Landscape disturbance in the early 1990s coincides well with poor PA governance in the country, where many PAs were affected by open access extraction of natural resources. During that time, neither formal organizations nor traditional institutions were active in natural resource conservation (Tenasaw et al. 2009).

Debelo (2011) reported that in 1982 the community had been forcefully displaced from the NSNP during the military regime, which may account for some of the forest recovery observed during the beginning of the study period. The depletion of forested area observed in the Sermele riparian forest since the early 1990s and simultaneous increase in cultivated land could be explained by the government transition in 1991 which allowed the communities to return to their previous settlement areas and inhabited in the eastern part of the national park. Due to the forceful displacement in the decade before, the population maintained a very hostile attitude towards the park, killing the wildlife in an attempt to secure their settlement by eliminating the need for protection in the area. Mixed ethnic groups from Arba Minch town likely also caused the massive destruction of Kulfo riverine and Arba Minch groundwater forest for timber, charcoal, firewood, and construction materials (Aregu and Demeke 2006; Fetene et al. 2012b).

Overgrazing on the grassland and wooded grassland particularly after 1990s resulted in hosting plants which had not been a component of these habitats. As a result, a large area of the grassland habitat is threatened by shrub encroachment mainly by *Dichrostachys cinerea*, *Acacia mellifera*, *A. nilotica*, *A. oerfota,* and *A. seyal* (Yusuf et al. 2011) and is greatly affected by expansion of encroaching perennial herbs and shrubs, most commonly of the Malvaceae family which include *Abutilon anglosomaliae*, *A.bidentatum,* and *A. figarianu,* which are natives to tropical and sub-tropical regions in Africa (Andargie 2001; Svialek 2008). These encroaching plants have been expanded in NSNP in the 1990s and since early 2000s they have aggressively replaced the grassland (Fig. 2) thereby greatly reducing the forage of large mammals (Fetene et al. 2015). Svialek (2008) reported that none of these encroaching plants seems to be alien invasive species and there are no major findings from the previous researches about their spatial extent across the park.

Widespread decline in vegetation particularly the forest and the grassland after 2007 suggest that withdrawal of the African Parks foundation from the management of NSNP has had dramatic effects on the park's ecosystems. This decline can be linked to a rapid diminishment of wildlife reported in other studies. For instance, Swayne's hartebeest was reported to have declined from 130 individuals in 1967 (Blower 1968), 103 in 1973 (Bolton 1973), 40 in 1992 (Duckworth et al. 1992), 35 in 2008 (Vymyslická et al. 2010; Fetene et al. 2011; Datiko and Bekele 2011), to only 12 in 2010 (Mamo et al. 2012) and four (4) in 2012 (Fetene et al. 2014). Similarly, anthropogenic disturbance and landscape degradation have been reported as a broader problem also across other protected areas elsewhere in the country (Mekonnen 2012) and are attributed to increasing human pressure resulting from lack of support from highly impoverished local communities and a lack of socio-economic and ecological linkages in protected area management.

The results have shown that changes in vegetation of NSNP could be attributed to (i) degradation of existing vegetation through deforestation and (ii) replacement of native vegetation by encroaching plants. For example, changes in vegetation cover across the Nech Sar Plain may be largely explained by expansion of herbaceous plants and woody species encroachment (Svialek 2008; Yusuf et al. 2011) following overgrazing of the grasslands by domestic animals. The encroaching species are not digestible by grazers, resulting in a widespread expansion across the plain.

While limited in local meteorological station, the analysis suggests that climate related changes did not have major effects on park vegetation change and that changes in vegetation degradation have largely been dominated by anthropogenic factors. Particularly the forested areas of NSNP are likely fairly independent of annual precipitation, as they have access to ground and surface water, particularly in the western part of the park and along the river sides.

Conclusions

The results of this study have shown that vegetation degradation is considerably higher in the forest and grassland habitats which are however the integral component of NSNP for wildlife conservation. The main observed degradation trends go from forest to cultivated land and from open grassland to bush/shrub encroachment. The observed change in the landuse/landcover was driven due to increasing anthropogenic pressure with poor PA governance related to unstable organizational structures.

Therefore, to restore NSNP to a condition of sustainable PA, it is absolutely important to ensure the social and economic sustainability of the local community out of the park through creating other means of livelihood, supply of alternative energy, and establishing basic infrastructure.

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