INVESTIGATING LOCAL PROTECTION EFFORTS IN FOREST VEGETATION CHANGE IN ORISSA, INDIA, USING NOAA AVHRR DATA

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OSTWALD, M., KAMARUZAMAN, J. & LINDQVIST, S. 2000. Investigating local protection efforts in forest vegetation change in Orissa, India, using NOAA AVHRR data. Twenty-nine NOAA AVHRR images pre-produced in Normalized Difference Vegetation Index (NDVI) were used to detect vegetation changes in three areas: a forest under local protection, a reference forest and the total forest area in Ranapur area, Orissa state, India. The data were from April 1992 to January 1996, a period when changes in forest vegetation due to local protection initiatives could be expected. Rainfall data were used to correlate the vegetation change, but neither simultaneous rainfall nor rainfall at time lags of three months showed correlation. From analysis of the NDVI images, the reference forest showed the greatest vegetation growth of 7%, while the locally protected forest and the total forest had a growth of 4% each from 1992 to 1996. Analysing the areal extent of growth, unchanged and decreased forest vegetation through NDVI gave a mean growth of 68.5% in the reference forest followed by 63 and 61% for the total forest and the locally protected forest areas respectively. The locally protected forest was increasing its vegetation status without decreasing that of the adjacent forest; thus the total forest area was going through a stage of vegetation growth.

Key words: Local protection - natural forest - NDVI - NOAA AVHRR - vegetation change - Orissa - India

OSTWALD, M., KAMARUZAMAN, J. & LINDQVIST, S. 2000. Penyiasatan terhadap usaha-usaha perlindungan tempatan dalam perubahan pembiakan hutan di Orissa, India menggunakan data NOAA AVHRR. Dua puluh sembilan imej NOAA AVHRR yang diprahasilkan dalam Indeks Pembiakan Berbeza Dinormalkan (NDVI)

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digunakan untuk mengesan perubahan di tiga kawasan: hutan di bawah perlindungan tempatan, hutan yang dirujuk dan luas kawasan hutan di Ranapur, negeri Orissa, India. Data diambil dari April 1992 hingga Januari 1996, satu jangka masa iaitu apabila perubahan dalam pembiakan hutan daripada inisiatif perlindungan tempatan dijangkakan. Data hujan digunakan untuk mengaitkan dengan perubahan pembiakan, tetapi hujan serentak serta hujan pada selang masa tiga bulan tidak menunjukkan perkaitan. Daripada analisis imej NDVI, hutan yang dirujuk menunjukkan pertumbuhan pembiakan yang terbesar iaitu 7%, manakala hutan yang dilindungi tempatan dan jumlah hutan mempunyai pertumbuhan setiap satu sebanyak 4% dari 1992 hingga 1996. Penganalisisan tambahan kawasan pembiakan hutan melalui NDVI yang tidak berubah serta merosot memberikan min pertumbuhan sebanyak 68.5% di hutan yang dirujuk diikuti masing-masing oleh 63 dan 61% bagi luas kawasan hutan dan kawasan hutan tempatan. Hutan di bawah perlindungan tempatan menambahkan status pembiakan tanpa mengurangkan penambahan hutan; dengan itu luas kawasan hutan telah melalui peringkat pertumbuhan pembiakan.

Introduction

The annual rate of deforestation in the tropics has been claimed to be 15.4 million ha during the 1980s, with a rate of 1.2% in Asia and the Pacific. For India, the figure was 0.6% annually (FAO 1993, FAO 1998) or a conversion of 4.3 million ha of forest into non-forest during the period of 1951–80 (Forest Survey of India 1988). Degradation of forest, which includes forests converted to plantations, fragmentation of forest and closed canopy forest transformed to open canopy forest, affected 2.3% of the forest area in India during the 1980s (FAO 1998). The decline or degradation in the eastern state of Orissa has been calculated at 22% from the 1950s to 1980s (Poffenberger *et al.* 1996), indicating a great change in forest resources. In Orissa, 36% of the land was classified as forest in the early 1990s. Forest is of crucial importance to the poorer 45% of the population, of which 60% depends on the forest as a source of livelihood (Orissa Forest Department 1996). The population in Orissa grew from 26 to 31 million people from 1981 to 1991, which resulted in an increase of the pressure on forest resources in the state (Government of Orissa 1990–91) together with an increased commercial exploitation. However, the type of conventional figures on deforestation and degradation as the one used above has recently been challenged by studies both in Africa and Asia (e.g. Fairhead & Leach 1996, Forsyth 1996). In the case of Africa, a savanna landscape believed to be deforested was shown to be new forest, and in Asia, erosions believed to be caused by over-cultivation were proven to be mainly naturally caused. Recent environmental research is proposing a less one-minded view of environmental change and vegetation history where local practices are taken into account.

Since the 1970s, due to the growing scarcity of important forest products in Orissa, many communities have begun forming forest protection committees, which aimed at protecting and improving the state-owned natural forest through natural regeneration and thus provide more forest resource for the villagers' livelihoods without any proper legal rights. In India, these have been called informal protection committees or community forest management groups and they often started off without involvement or knowledge from the Forest Department (FD). By the late 1980s, foresters from the FD recognised these initiatives which started a debate and in 1988 a law was passed which gave the local communities the responsibility for theft and fire prevention as well as the right to extract firewood and small timber to meet local needs. In 1990, a second law was passed which gave the local protection groups the right to 50% of all harvested timber from the protected forest (Poffenberger *et al.* 1996).

These developments produced a scenario where an increasing number of communities became interested in protecting natural forest. In some cases, this was done as a consequence of demonstration effect where visible examples of improved and more accessible forest products in neighbouring villages had taken place. In other cases, the motives came out of hope of future revenue or other benefits from the FD, and still yet in some other cases where availability of non-protected natural forest areas decreased, therefore increasing the fear of diminished forest resources in the future. According to the FD, several thousand communities are protecting forest areas ranging from 20 to 1000 ha each (Scandiaconsult Natura AB/Asia Forest Network 1998). Many more initiatives of local protection have been taken in Orissa, which have not been recorded.

The effect of protection efforts has shown an increase in the *in situ* protected forest vegetation (Ravindranath *et al.* 1991, Ostwald & Näslund 1999). One form of rehabilitation of degraded forest is through assisted natural regeneration (ANR), which has been suggested as a potentially rapid, efficient and cost effective means of reforestation from studies in Indonesia (Kartawinata 1994). The assisting agent was, in the case of Indonesia as well as in Orissa, the local community involvement or the local protection. However, the succession is slow and it takes 250–500 years to return to the original forest condition. Yet, other studies have shown that local protection of a forest area has increased the pressure on adjacent forest areas (Kant *et al.* 1991, Jonsson & Rai 1994), i.e. a geographical move of forest degradation.

Theories related to vegetation change and the process of regeneration of *in situ* and adjacent forest associated with local protection are presented in Figure 1, and is a conceptual base for this paper. It is often assumed that the effect of local protection makes the *in situ* forest increase its vegetation at a steady pace with the time of the protection initiatives, while adjacent forest, on the other hand, degrades in the early stage of the protection (Kant *et al.* 1991, Jonsson & Rai 1994). The theory suggests that the adjacent forest starts to improve first after some time. This can be explained by either a natural regeneration due to the *in situ* protected forest or by the fact that one improved forest area stands as an example for others to follow in the adjacent areas. The forest regeneration model indicates the importance of a time variable when discussing vegetation changes in locally protected forests.

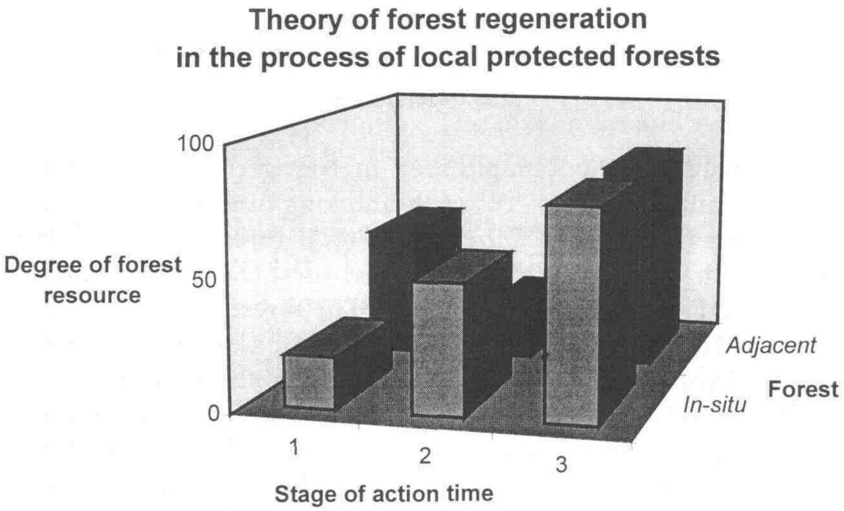

Figure 1. The process of vegetation change of *in situ* and adjacent forest areas of local protection in three different stages. Stage 1–start of the protection effort. Stage 2–early regenerating stage of the *in situ* forest giving pressure on the adjacent forest. Stage 3–a regenerating stage of the *in situ* forest where it can be used by people in a more sustainable way and where the adjacent forest area will increase.

It has also been proven that rainfall has a great impact on the regeneration of vegetation in a tropical environment with the importance of variation of precipitation over the year (Shinoda 1995, Eklundh 1998).

The vegetation index, Normalized Difference Vegetation Index (NDVI), has been widely used in correlation with biomass production (Dregne & Tucker 1988) and for tropical forest biophysical properties such as basal area (Foody *et al.* 1996) and crown cover (Apan 1997).

The objectives of this study are to investigate and examine the causal changes in forest vegetation in locally protected areas as well as their surrounding forest areas. The period considered is from April 1992 to January 1996. This is the time when considerable changes in forest vegetation due to local initiatives can be expected in the area. The questions posed are: Can NDVI produced NOAA AVHRR images be used to investigate vegetation change in locally protected forest areas? How is the vegetation changing interannually, annually and spatially? Why is it changing? Can it be explained in terms of variation in rainfall or is it caused by local forest-protection initiatives?

Materials and methods

Site description

The Reserved Forest in the Ranapur area in Nayagarh district in Orissa State, India, located at latitude 19° 45'– 20° 05' N and longitude 85° 00'– 85° 25' E, is the focus of this study (Figure 2). Of the state's total forest area, 50% is classified as dense forest (crown cover > 40%), 37% open forest (*c.* 10–40%) and 12% shrub (*c.* <10%) (Orissa Forest Department 1996). The forest in the area is classified as northern tropical dry deciduous forest (Padhi 1994). Common tree species in the region are *Madhuca indica, Emblica officinalis, Acacia nilotica, Dalbergia paniculata, Aegle marmelos, Vahunia purpurea, Diosyprus melanoxylon, Bridelia retusa* and *Butea monosperma* (Kant *et al.* 1991). A total of 250 different plant species are estimated to be present in the study area (Vasundhara 1997). The area is characterised by two mountain ridges: the Eastern Ghats (highly metamorphosed granulite and gneissic rock), cutting through the plains where paddies dominate. The main areas of natural forest are located on the ridges. The soils in the area are mainly Ferric Luvisols with some Eutric Nitosols (FAO 1977, Driessen & Dudal 1991).

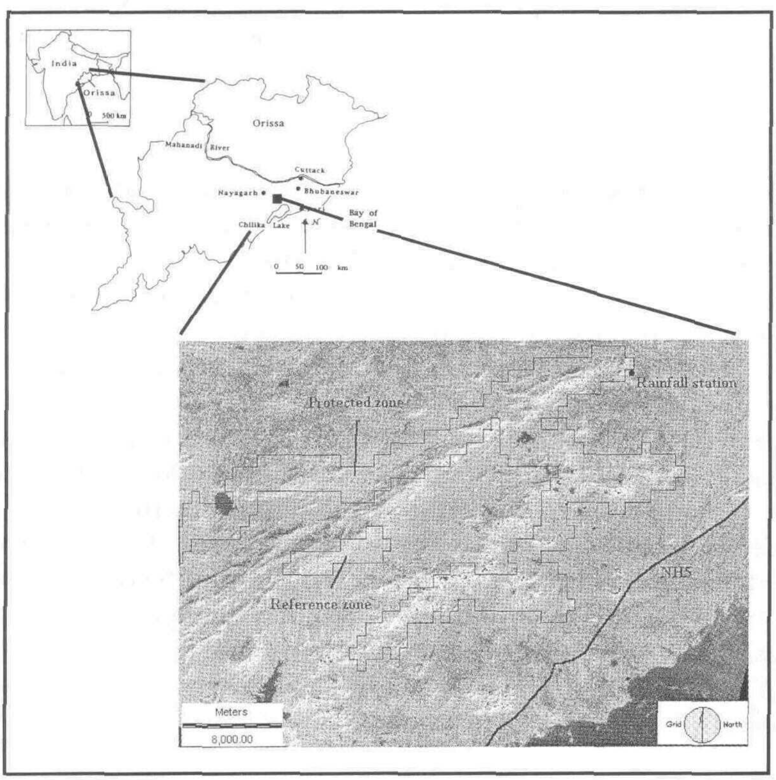

Figure 2. A map of India showing a SPOT X3 (DEC-94) image of the study area with the reference forest zone (17 km^2), local protected zone (323 km^2), rainfall station and NH5 - National Highway 5 between Calcutta and Madras

Orissa is located in the tropical belt and is under the influence of the southwest monsoon. Eighty percent of the total rainfall occurs during the monsoon season from the middle of June to the beginning of October. The annual precipitation in the area varies from 1058 to 1565 mm. The maximum and minimum monthly mean temperatures are 30.6 and 23.7 °C respectively, with maximum temperature between May and October and minimum temperature in January (Government of Orissa 1988). The population density in Orissa is 202 people km^{-2}, somewhat below the national average of 264 people km^{-2} (The Far East & Australia 1999). The population in the area increased by 140% between 1961 and 1991 (Census Data of Orissa 1961, 1971, 1981 and 1991). The state is predominantly rural with more than 80% of the population working in the agricultural sector.

The forest range of Tangi and Ranapur area in Nayagarh district is an area where local protection has been developing along the borders of the natural forest (state-owned Reserved Forest) and the plains of mainly cultivated land. According to forest officers, there are hardly any areas along the mountain slopes that have not been claimed as locally protected (Amin 1997, pers. com.).

A comparative study from the Ranapur area in Orissa, India, focusing on the forest regeneration from a locally protected and a non-protected forest area shows significant differences in physical features of trees such as diameter and height (Ostwald & Näslund 1999). From a reconstruction of the environmental history of the area, made from a comprehensive questionnaire survey focusing on people using the forest as well as data from maps and archives, Ostwald and Baral (1998) report that the study area has undergone similar types of vegetation change. According to the locals and older generation taking part in the survey, the mountain was characterised by dense diversified forest before 1967. In a biodiversity inventory made by a local non-governmental organisation, it was stated that with a growing population after independence (1947), the forest on the mountain was intensively used for local consumption of firewood and for the commercial pulp industry (Vasundhara 1997). The villagers claimed that about 30 years ago, the forest started to change due to over-exploitation, and by 1982, most of the mountains were bare.

For this study, areas covering the natural forest boundary around the Eastern Ghats in the area of Ranapur/Tangi are the focus (Figure 2), since these are the areas where local protection is taking place. One reference area of natural forest with poor accessibility by roads and low population pressure, located in the interior part of the forest, is used as a control area for monitoring vegetation change within more untouched or less stressed forests. This area has not been degraded and is therefore not undergoing regeneration at the present.

Materials

NOAA AVHRR data produced in NDVI were used, one image from every month, from the period of April to January 1996 giving a total set of 29 images. Images from October 1993 to January 1995 were not available. The conventional

NDVI was produced by the red and the near infrared (NIR) bands of the images as:

$$NDVI = (NIR\text{-}red)/(NIR+red)$$

The index represents a relative index of the condition of green vegetation (Lillesand & Kiefer 1994). The images were pre-processed by the distributor through radiometric calibration where raw digital counts are composed to radiance as described by Kidwell (1991). Atmospheric corrections were done for ozone and Rayleigh scattering (Teillet 1991), but not for water vapour or aerosols due to the lack of community agreement on a feasible method. NDVI computation was done and the formula that scales the NDVI from -1 to 1 was changed to 0–200, where each value represents one percent of the total possible range. The images were further geometrically corrected, including registration of solar and satellite zenith and relative azimuth viewing angle for each pixel, and finally composed into a 10-day mean with a resolution of 1 km at the Goddard Space Flight Centre. The 10-day mean images were produced by selecting the highest value of a particular pixel taken from the 10 last consecutive days of every month. This is done to decrease the effect of clouds. For further processing information, see Eidenshink & Faundeen (1994). For the scope of this study, the effects of bi-directional effect, use of different satellites and presence of clouds have not been further corrected. No further consideration was taken for the saturation effect of NDVI over 0.7 (equals 170 in this data set), since only one month (November 1995) has a value over 170. A SPOT-3 HRV image (20 m resolution) was acquired on 29 December 1994 (228–309) to support the 1 km resolution NOAA images. This image was geometrically corrected by ground truth points using a linear nearest neighbour transformation with a standard error of less than one pixel (i.e. <20 m). Radiometric correction of satellite sensor data to spectral radiance ($mWcm^{-2}\ sr^{-1}\ \mu m^{-1}$) was performed (Lillesand & Kiefer 1994). IDRISI software (Eastman 1997) was used for the enhancement and analyses of the images. Daily precipitation data for the period 1987 to 1997 from Ranapur weather station (Figure 2) were used to indicate the trend of monsoon and rainfall distribution over the years.

Methods

The data used were processed and analysed in several steps (Figure 3). The NOAA image data were originally produced in Interrupted Good Homolosine (Eidenshink & Faundeen 1994) and later converted to Universal Transverse Mercator (UTM) grid system to be compatible with the SPOT image.

Rainfall and its correlation to vegetation have been studied on a large scale in Africa (Shinoda 1995, Eklundh 1998). Seasonal phase lag between rainfall and vegetation has been suggested for tropical situations and is therefore included in the analyses. Eklundh (1998) states that rainfall is not an efficient indicator to determine vegetation through NDVI produced satellite imagery. The annual rainfall variations in Ranapur area are large and all months are therefore included in the analyses.

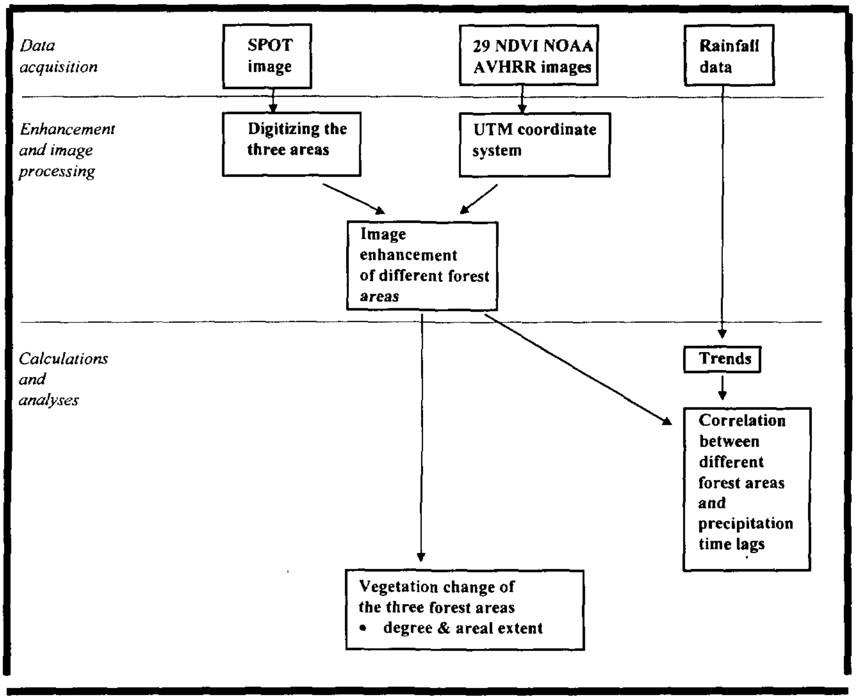

Figure 3. Flow chart of the study

From the SPOT image, the area subject to protection was digitised along the edge of the natural forest giving an area of 323 km² (Figure 2). One interior forest area of 17 km², which was used as a control to represent the less affected or more stable forest, was digitised. The whole forest area, including both locally protected and reference forest areas as well as the area between the two, was also digitised and used in the analyses. The changes in vegetation occurring in the total forest, reference forest and locally protected forest areas were analysed to investigate the impact of rainfall and local forest protection efforts based on NDVI over natural forest.

Results and discussion

The mean NDVI from the area (Figure 4) showed that the forest area as a whole had improved its vegetation status from April 1992 to January 1996. The slope was low and the correlation weak and non-significant ($R^2 = 0.0855$) even though still indicating an increase. The values were fluctuating greatly between the years, indicating an uncertainty in moist availability for vegetation from year to year. However, even if the three late months of high NDVI values, i.e. October, November and December in 1995, were excluded the slope was still showing a slight increase in NDVI ($R^2 = 0.0015$).

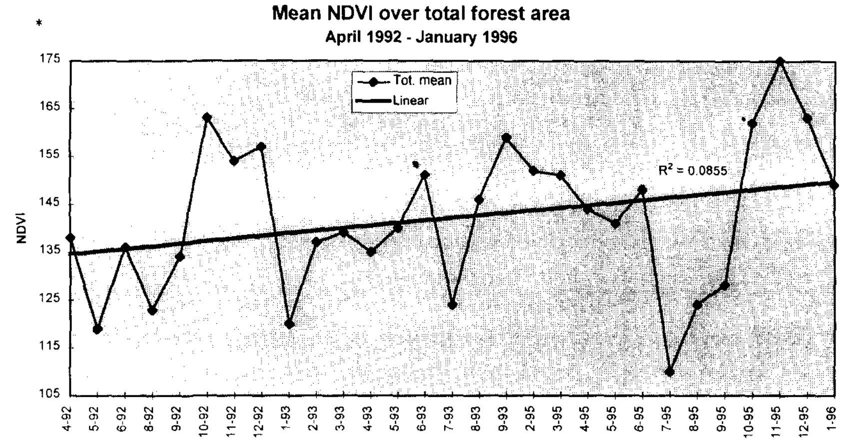

Figure 4. Mean NDVI from total forest area. *The producers routinely uses a formula that scales the NDVI from -1 to 1 as 0 to 200, where each value represents one percent of the total possible image.

Impact of rainfall

The possible correlation between increase of vegetation and rainfall was explored. The yearly rainfall totals from 1987 to 1997 (Figure 5) showed great interannual variation with a standard deviation of 640 mm and a maximum variation of 1295 mm. The mean was calculated to be 1542 mm. The annual variation was largest between May and November, i.e. during and in association with the monsoon period (Figure 6), and is of importance when choosing monthly NDVI images.

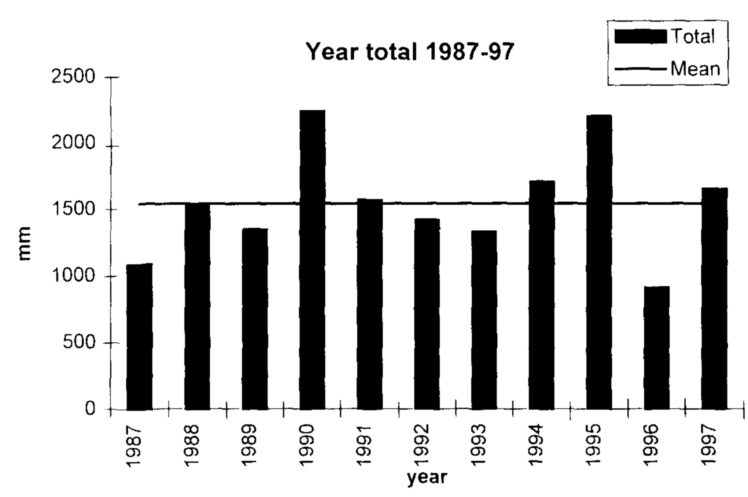

Figure 5. Yearly rainfall totals from 1987–97 with a maximum variation of 1295 mm and a standard deviation of 640 mm

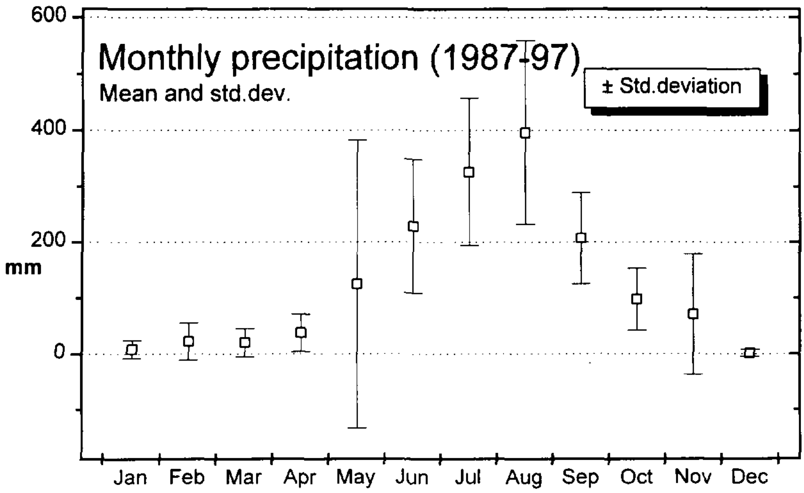

Figure 6. Monthly mean rainfall and standard deviation from Ranapur weather station

A correlation between the monthly rainfall and the mean and maximum NDVI for the different forest areas showed low correlation without significance (Table 1). Shinoda (1995) suggested that there is a time lag between rainfall and vegetation through NDVI. This time lag increases with distance from the equator and is associated with the change in and built-up of soil moisture available to the vegetation. The lag correlation is presented in Table 2. The result showed no clear correlation with regards to NDVI and rainfall time lag. The strongest correlation between rainfall and NDVI from the same month was found in the reference area followed by the locally protected forest area, yet with uneven significance. However, the rainfall distribution pattern did not explain the vegetation increase.

Table 1. Correlation coefficients and standard deviation between rainfall and mean and maximum NDVI from total forest area, reference forest area and locally protected forest area

	Total forest		Reference forest		Locally protected forest	
	Mean	Max	Mean	Max	Mean	Max
R^2	0.90	0.11	0.09	0.1	0.05	0.06
Std. dev.	16	13	17	17	14	13

N = 29.

Table 2. Correlation coefficients between NDVI and rainfall from simultaneous, 1-, 2-, 3- month lap rainfall and total rainfall from 3 previous months

	Simultaneous rainfall N = 29	1-month lap rainfall N = 26	2-month lap rainfall N = 24	3-month lap rainfall N = 22	3 previous months total rainfall N = 21
Total forest NDVI					
maximum	- 0.11	0.08	- 0.1	0.25	0.04
mean	- 0.23	0.03	- 0.13	0.14	- 0.01
Reference forest NDVI					
maximum	- 0.32**	0.04	- 0.28*	0.36**	- 0.04
mean	- 0.3*	0.0	- 0.26	0.22	0.05
Locally prot. forest NDVI					
maximum	- 0.17	0.14	- 0.1	0.29*	0
mean	- 0.27*	- 0.01	- 0.09	0.17	0.07

*p <0.1 and **p < 0.05, Pearson two-tailed test.

Impact of local protection

The change in vegetation status through NDVI between the different forest areas was further explored over the three-year time period available by calculating the total NDVI for every pixel from the three different forest areas divided by the area of concern (Figure 7). An increase in vegetation from 1992 to 1995 (1993 and 1996 for January) was experienced in all the areas and most of the months, except for the month of April which represents the end of the dry season and the month of November that showed an almost unchanged situation. The increase was greatest in the reference area (7%) while the total forest and the locally protected areas had a growth of 4% each. This result showed that the eventual decrease in forest areas (geographical move of pressure represented by stage 2 in Figure 1) outside the locally protected areas that has been suggested (Kant *et al.* 1991, Jonsson & Rai 1994) was not taking place in this area, since the whole forest area was showing an increase in vegetation status through NDVI. This can be represented as the third stage in Figure 1.

By looking at the spatial extent of forest vegetation change, i.e. extent of areas affected, rather than degree of change, the 29 NDVI images were classified to show the size of areas of growth, unchanged as well as decreased vegetation. This was done for the three forest areas: total, reference and locally protected forest areas from 1992 to 1995 (Table 3). The table shows evidence of the variation over the year, indicating a biannual growing season pattern, the first in November-December (directly after the monsoon period) and the second one from April to June (the hottest period in the end of the dry season and the commencement of the monsoon). The means of the three different vegetation change categories for the three forest areas show the highest growth in the reference forest (68.5%), followed by the total (63%) and locally protected forest (61%) areas. The

Table 3. Percentage of area affected through growth, unchanged and decreased forest vegetation from 1992 to 1995 (for January 1993–96) in total forest, reference forest and locally protected forest areas based on NDVI (Only months with available NOAA data for three years)

	Total forest			Reference forest			Locally protected forest		
	Growth	Unchanged	Decreased	Growth	Unchanged	Decreased	Growth	Unchanged	Decreased
October	33	15	52	24	36	40	34	14	52
November	99.7	0.1	0.2	100	-	-	99	-	1
December	87	9	4	96	4	-	88	8	4
January	11	11	78	-	4	96	15	15	70
April	70	15	15	52	20	28	71	14	15
May	100	-	-	100	-	-	99	0.5	0.5
June	95	2	3	100	-	-	89	4	7
August	41	6	53	88	4	8	31	5	64
September	32	5	63	56	8	36	23	8	69
Mean	63	7	29	68.5	8.5	23	61	8	31
Standard deviation	34	6	31	37	12	32	35	6	31

areas with decreasing forest vegetation status varied from 23 to 31% for reference and locally protected forest areas respectively. The vegetation changes detected through NDVI in the locally protected forest area are behaving similarly to those of the total forest area, while the reference forest area is showing a greater increase. This again indicates that there has not been a shift of forest degradation to adjacent forest areas due to local protection and that the locally protected areas are regenerating in the same pattern as the forest as a whole, yet not with the same intensity as an untouched forest. The time series chosen for this study could be representing the third stage in the theory model (Figure 1), while the second stage with visual degradation effects on the adjacent forest was previous to 1992 or did not exist at all.

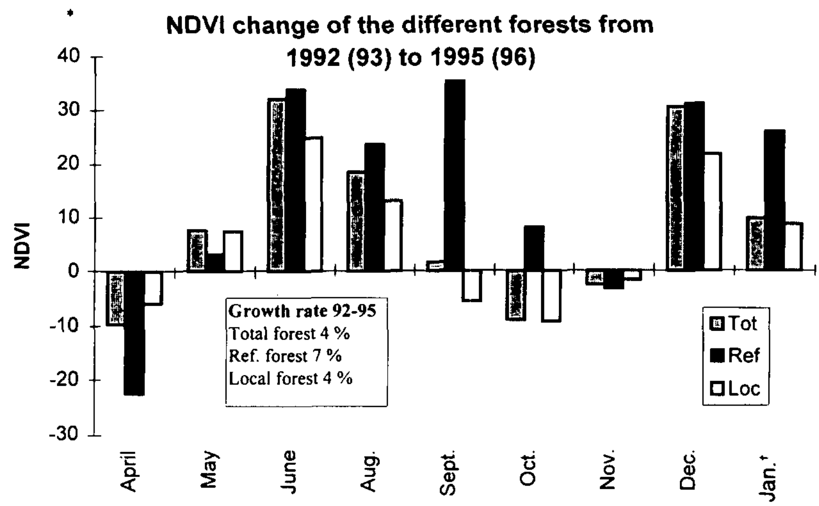

Figure 7. NDVI changes from total, reference and locally protected forest areas between 1992 and 1995, († based on 1993–96 data). * The producers routinely uses a formula that scales the NDVI from -1 to 1 as 0 to 200, where each value represents one percent of the total possible image.

Conclusion

The following conclusions with regard to NDVI usage for vegetation change in forest areas subject to local protection can be drawn:

- The use of NDVI from NOAA AVHRR data to monitor and map vegetation changes provides a useful, time efficient and economically sound tool for forest managers in estimating the large scale vegetation effects on natural forest which can indicate locally protected efforts.

- Local protection along the forest fringes has not produced a geographical move of the static degradation to adjacent forest areas, since the whole forest area has increased in vegetation status from April 1992 to January 1996.

- It is crucial to have local knowledge of the natural vegetation over the years when using NDVI to quantify change pattern of a tropical forest, since there is a substantial difference between dry and wet situations.

- The rainfall pattern did not seem to be directly related to change of status in the forest vegetation.

Recommendations

Further research on vegetation change in forest subject to local protection should be encouraged and based on the results from this study, some recommendations can be given as follows:

- Higher resolution data could give more detailed information at the local level.

- When the area and data permit, higher size equality of the comparative areas should be sought.

- A longer time series of images would give a greater understanding of the historical vegetation changes in these forest areas that are being subject to drastic and fast changes.

- With more detailed and site specific village data on local control mechanisms of the forest, the cause of vegetation increase seen from the NOAA images can be explored, thus leading to a discourse on scientific and local knowledge.

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References

AMIN, N. 1997. Forest Range Officer Tangi. Personal communication.

APAN, A. A. 1997. Land cover mapping for tropical forest rehabilitation planning using remotely-sensed data. *International Journal of Remote Sensing* 18:1029–1049.

CENSUS DATA OF ORISSA. 1961, 1971, 1981 and 1991. Census Office, Bhubaneswar.

DREGNE, H. E. & TUCKER, C. J. 1988. Green biomass and rainfall in semi-arid sub-Saharan Africa. *Journal of Arid Environments* 15:245–252.

DRIESSEN, P. M. & DUDAL, R. 1991. *The Major Soils of the World.* Agricultural University of Wageningen, Katholieke Univesity, Leuven. 310 pp.

EASTMAN, J. R. 1997. *Idrisi for Windows, Version 2.0.* Clark University. 315 pp.

EIDENSHINK, J. C. & FAUNDEEN, J. L. 1994. The 1-km AVHRR global land data set: first stages in implementation. *International Journal of Remote Sensing* 15: 3443–3462.

EKLUNDH, L. 1998. Estimating relations between AVHRR NDVI and rainfall in East Africa at 10-day and monthly time scale. *International Journal of Remote Sensing* 19:563–568.

FAIRHEAD, J. & LEACH, M. 1996. *Misreading the African Landscape.* Cambridge University Press. 326 pp.

FAO. 1977. *Soil Map Booklet, Vol. VII, Asia South.* FAO-UNESCO, Paris. 117 pp.

FAO. 1993. *Forest Resources Assessment 1990 —Tropical Countries.* FAO Forestry Paper 112. 59 pp.

FAO. 1998. *Asia-Pacific Forestry towards 2010.* Rome. 238 pp.

(The) FAR EAST & AUSTRALIA. 1999. 30th edition. Europa Publication Limited, England: 366.

FOODY, G. M., BOYS, D. S. & CURRAN, P. J. 1996. Relations between tropical forest biophysical properties and data acquired in AVHRR channels 1–5. *International Journal of Remote Sensing* 17:1341–1355.

FOREST SURVEY of INDIA. 1988. *State of Forest Report.* Ministry of Environment and Forest, Dehra Dun.

FORSYTH, T. 1996. Science, myth and knowledge: testing Himalayan environmental degradation in Thailand. *Geoforum* 27:375–392.

GOVERNMENT OF ORISSA. 1988. *Climatological Data of Orissa 1977–1986.* Directorate of Economics and Statistics, Bhubaneswar. 131 pp.

GOVERNMENT OF ORISSA. 1990–91. *Municipal Statistical Year Book.* Directorate of Economics and Statistics, Bhubaneswar. 87 pp.

JONSSON, S. & RAI, A. 1994. *Forest, People and Protection.* ISO/Swedforest, SIDA, Bhubaneswar. 54 pp.

KANT, S., SINGH, N. M. & SINGH, K. K. 1991. *Community Based Forest Management Systems.* ISO/Swedforest, SIDA, Bhubaneswar. 70 pp.

KARTAWINATA, K. 1994. The use of secondary forest species in rehabilititation of degraded forest lands. *Journal of Tropical Forest Science* 7:76–86.

KIDWELL, K. B. 1991. *NOAA Polar Orbiter Data Users' Guide.* National Oceanic and Atmospheric Administration, Washington D.C.

LILLESAND, T. M. & KIEFER, R. W. 1994. *Remote Sensing and Image Interpretation.* John Wiley & Sons, Inc., New York. 750 pp.

ORISSA FOREST DEPARTMENT. 1996. *Capacity Building for Participatory and Sustainable Management of Degraded Forests in Orissa.* Project Document. 10 pp.

OSTWALD, M. & BARAL, R. 1998. *Perception, Knowledge and Attitudes towards Forest among People Involved in Forest Protection on Dhani Hill, Orissa, India.* Field Report. 6 pp.

OSTWALD, M. & NÄSLUND, B-Å. 1999. Effects on trees and soils from local protection of forest on Dhani Hill, Orissa, India. *Journal of Environmental Management.* (Submitted).

PADHI, G. S. 1994. *Forest Resources of Orissa.* BITS-Pilani, Bhubaneswar. 294 pp.

POFFENBERGER, M., BHATTACHARYA, P., KHARE, A., RAI, A., ROY, S. B., SINGH, N. & SINGH, K. 1996. *Grassroots Forest Protection: Eastern Indian Experiences.* Asia Forest Network Report 7. 84 pp.

RAVINDRANATH, N. H., MOHAN NAYAK, M., HIRIYUR, R. S. & DINESH, C. R. 1991. The status and use of tree biomass in a semi-arid village ecosystem. *Biomass and Bioenergy* 1:9–16.

SCANDIACONSULT NATURA AB/ASIA FOREST NETWORK. 1998. *Silviculture and Management Practices for Community Based Forest Management Initiatives.* Study Report. 30 pp.

SHINODA, M. 1995. Seasonal phase lag between rainfall and vegetation activity in tropical Africa as revealed by NOAA satellite data. *International Journal of Climatology* 15:639–656.

TEILLET, P. M. 1991. Radiometric and atmospheric correction procedures for AVHRR preprocessing in the solar reflective channels. Pp. 511–516 in *Proceedings of the 5th International Colloquium on Spectral Signature of Objects in Remote Sensing.* Courchevel, France.

VASUNDHARA. 1997. *Conserving Bio-diversity—A Decade's Experience of Dhani Panch Mouja People.* Vasundhara, Bhubaneswar. 37 pp.