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Burnt Area Mapping of Bandipur National Park, India using IRS 1C/1D LISS III Data

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Abstract The Bandipur National Park situated in the Western Ghats of Karnataka State, is one of the biodiversity hotspots of the world. During recent years, this park has witnessed repeated fires, affecting considerable areas under vegetation. The temporal satellite data from 1997 to 2006 have been analyzed to map the burnt areas using Remote Sensing (RS) and Geographic Information System (GIS) techniques. The vegetation cover is moist deciduous, dry deciduous, scrub forests and teak plantation. Information on extent of the burnt areas and the type of vegetation affected were derived forest range-wise. The fire prone regions have been identified by integrating vegetation type/density, road and settlement network and past history of forest fire occurrence, by assigning subjective weightage according to their fire-inducing capability or their sensitivity to fire. Comparison between each temporal dataset in terms of the extent of burnt area was also carried out to interpret fire incidence pattern. Three categories of fire risk regions such as Low, Moderate and High fire intensity zones were identified and it was found that almost 40% of the study area falls under low risk zone. An evaluation of the existing fire management systems and the implication of fire prevention programmes has been discussed, besides an assessment of causal factors for fire incidence in the park.

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Introduction

Disturbances are integral features of ecosystems, and most ecosystems are subject to several disturbance regimes that take place at different temporal and spatial scales (Holling *et al.*, 1995, Turner *et al.*, 1998). Fire is a vital and natural part of the functioning of numerous forest ecosystems, which is being used by human beings as a land management tool for thousands of years. Forest fires are considered to be a potential hazard with physical, biological, ecological and environmental consequences. Fire is one of the natural forces that influences plant communities as an ubiquitous disturbance factor in both space and time. Also, it serves an important function in maintaining the health of certain ecosystems. But as a result of changes in climate and with human use (and misuse) of fire, they are now a threat to protected areas rich in biodiversity. Smoke from fires can significantly reduce photosynthetic activity (Davies and Unam, 1999) and also cause health problems to wildlife. Although the ecological impact of fires on forest ecosystems has been investigated, comparatively little attention has been paid to the spatial data analysis to understand fire behavior and history. The occurrence and intensity of fire in a forest depends on the topography, weather (precipitation, humidity, temperature and winds), species composition and the forest type (Jaiswal *et al.*, 2002). The degree of recovery and need for rehabilitation interventions depends on the intensity of burning (Schindele *et al.*, 1989). Fire refuges are vital to the forest ecosystem in temperate regions because many species can survive only in such areas, and then supply a seed source to recolonize the burnt areas (Ohlson *et al.*, 1997). Burning is practised at the end of the dry season in order to renew grass to feed livestock and also to eliminate crop waste and to clean the soil before planting in tropical regions. Despite fire regulations, negligence in these activities and using fire in other land use systems frequently contribute to forest fires (Ramos, 2000).

Protected Area Management must take into account, the chance of natural disturbance by a variety of agents, including fire induced by humans residing in and around the forests. A major problem for forest management is that little is known of current fire frequencies and affected areas (Geldenhuys, 1996). It is essential to map forest fire risk zones to minimize frequency of fire by taking appropriate fire prevention measures, avert damage, etc. Satellite data play a vital role in identifying and understanding the extent of burnt areas and also the frequency at which different vegetation types/zones are affected. But, studies related to forest fire behaviour monitoring using remote sensing are a few in the Indian subcontinent. In this regard, the current study aims at using Remote Sensing (RS) and Geographic Information System (GIS) to detect fire prone areas and explore a fire regime over a decade period between 1997 and 2006 and to identify fire intensity zones by generating baseline information with respect to vegetation composition, soil characteristics, etc.

Study area

The Bandipur National Park covers parts of Mysore and Chamarajanagar districts of Karnataka, India. The study area lies between the latitudes 11° 35' 34" N and 11° 55' 02" N and between the longitude 76° 12' 17" E and 76° 51' 32" E (Fig. 1). This National Park was notified during 1974 which includes Venugopala Wildlife Sanctuary covering an area of 868.63 km^2. It was brought under Project Tiger during 1973 along with the adjacent Nagarahole National Park. The Bandipur National Park has been subdivided into nine wildlife ranges namely, Bandipur, Moliyur, N. Begu, Gundre, Hediyala, Maddur, Ainur Marigudi, Moolehole and Moyar (Table 1).

The study area has dry subtropical climatic regime with distinct dry (March to June), wet (Middle of June to September) and cold (November to mid

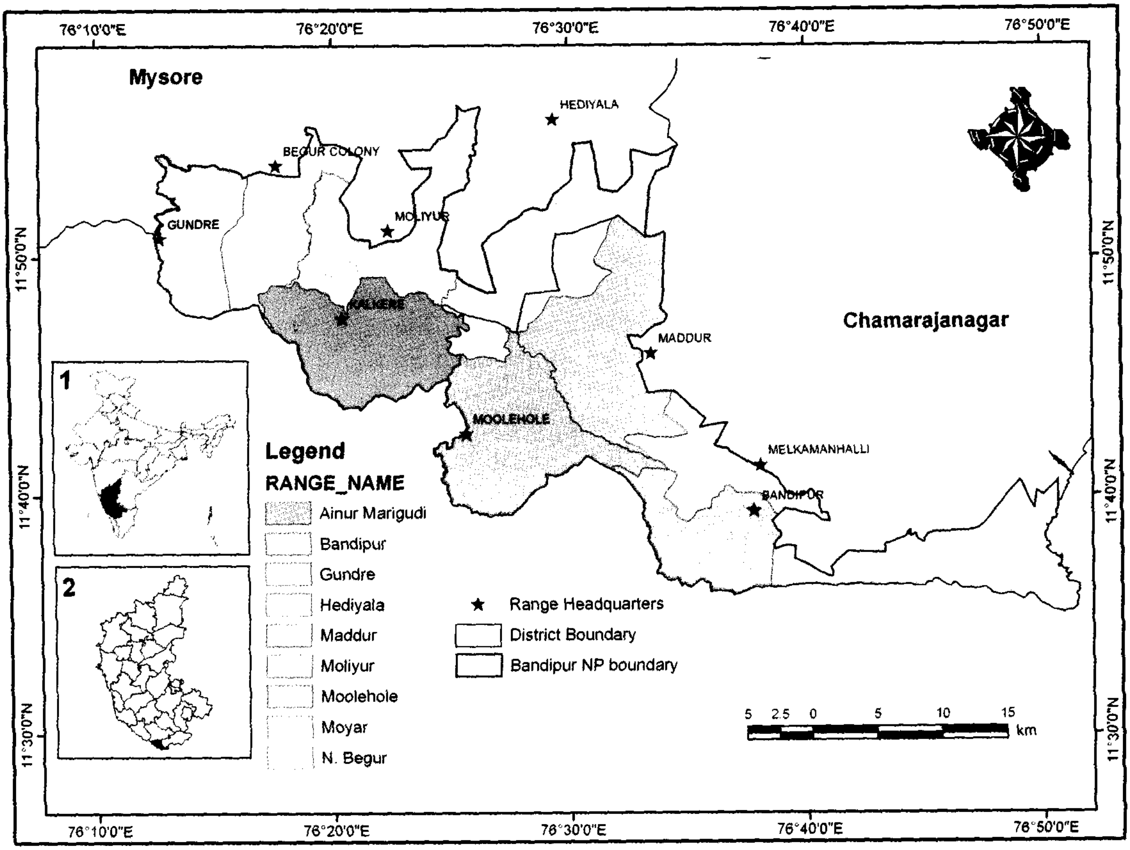

Fig. 1 Location map of Bandipur National Park.

Table 1 Wildlife range-wise area of the Bandipur National Park

Sl.No.	Range	Area (km^2)
1	Moliyur	87.41
2	N. Begur	64.01
3	Hediyala	112.92
4	Gundre	61.10
5	Maddur	114.82
6	Ainur Marigudi	103.41
7	Moolehole	111.57
8	Moyar	144.87
9	Bandipur	68.52
	Total	**868.63**

February) seasons. It is quite hot and dry in summer, receiving heavy showers from south-west monsoon and lighter rains from north-east monsoon. The coldest months are December and January and hottest months are March and April. The average annual rainfall ranges from 1270 mm (Kalkere) to 914 mm (Bandipur). Storms and cyclones are very rare and there is no record of damage caused by them. The temperature of the reserve is generally moderate, with a mean annual temperature of 24.16°C and maximum temperature of 29.66°C, rarely going beyond 30°C and minimum temperature is 18.66°C. The altitude varies from 780 m (Varanchi stream) to 1454.5 m (Gopalswamy hill) above MSL.

The forest of the park mainly has to moist deciduous, dry deciduous, semi evergreen and scrub type in addition to plantations and grass lands. The park is one of the richest wildlife areas in India having a very high ratio of predator and prey species, being populated by an intact assemblage of seven large angulate species (Mantijar, Chilala, Sambar, Chousingha, Gaur, Wild pig and Elephant) and three large predatory carnivores (Tiger, Leopard and Dholes), apart from a very rich avian species diversity.

Material and methods

The present study was conducted using satellite imageries, Survey of India maps and other collateral data obtained from various Government organizations as well as through ground truths. These data were analyzed and burnt areas have been mapped using Remote Sensing and Geographic Information Systems.

Materials

Survey of India topomaps

The Survey of India (SOI) toposheets (58A-1/5/6/9/10/13/14) of 1:50,000 scale pertaining to the study area were used for geo-referencing of satellite images, creation of cultural features and ground truth acquisition. The Forest administrative boundaries extracted from the working plan and wildlife management plan of the Forest Department were transferred onto topomaps and different wildlife administrative boundaries like division, range, section, beat, transportation network (roads and rails) and National Park boundary etc., were generated.

Satellite data

IRS-1C/D LISS III satellite data between 1997 and 2006 were obtained from National Remote Sensing Centre (NRSC), Hyderabad of the late summer season to ensure that all the fire events are covered. The geocoded sub-scene of selected study area (path 99 and row 65) was acquired for 1997 (March 2), 1998 (April 12), 1999 (April 8), 2000 (April 22), 2001 (March 29), 2002 (March 15), 2003 (March 9), 2004 (March 14), 2005 (March 4) and 2006 (February 26). The satellite data so procured were digitally rectified and processed using ERDAS (version 9.0). Later, for preparing different thematic maps viz., land use/land cover, drainage network, soils and forest type and vegetation mapping, etc., was done in GIS mode using ERDAS (version 8.7) and ARC GIS (version 9.0). Mapping has been done on 1: 50,000 scale.

Methodology

Preprocessing of images

The images were preprocessed using ERDAS (version 9.0). The toposheets pertaining to the study area were mosaiced to aid in further analysis. Subsetting was carried out for the images of 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004 2005 and 2006 specifying, the study area using the AOI tool. Map to image georectification process (Georectification) was adopted for geometrically correcting the satellite images with polyconic projection parameters, where ground control points were obtained from Survey of India (SOI) 1:50,000 scaled toposheets. Selection of points was done by referring to the image and choosing prominent landmarks.

Identification of burnt areas

In general, the reflectance of forests will be low in the visible part of the spectrum (except for the green region) and high in the near-infrared part. Thus, the spectral curve of the forest after burning becomes flat, differentiating highly contrast burnt areas from its surroundings. These observations were used in interpreting the satellite imagery of the study area for forest fire mapping and identification of fire-affected areas. The assessment of the extent of fire damage were carried out using VAX 11/780 based image processing system. The data have been georeferenced and the National Park boundary was digitized to generate the digital mask and extract the study area. A supervised approach is adopted for mapping of vegetation types. The map was further subjected to accuracy evaluation by selecting sample plots using simple random sampling, to assess the actual land cover versus digitally classified category. A slope map, settlement location and road map were also prepared using an SOI topographic sheet of the corresponding area. A two-way categorization table was formed and accuracy for each class was evaluated using:

$$C = [(Bj / Aj) * 100] \quad (1)$$

where,

j = 1, ... No. of classes.

Aj = No. of observations of class j from ground.

Bj = No. of observations on digitally classified image.

Identification of fire prone zones

Forest fire risk zones are locations where a fire is likely to start, and from where it can easily spread to other areas. The present study was confined to identification of the fire prone regions by integrating factors responsible for forest fire such as vegetation types/density, topography/slope, proximity to settlements and distance from roads. The fire prone regions have been identified and calculated by integrating vegetation type, density, proximity to road and settlements, slope and past history of forest fire occurrence along with their assigned weightages using the formula:

$$FP(I) = \Sigma ij\ Ci, Wij \quad (2)$$

where,

I = Fire prone categories

W = Weightage assigned to different parameters influencing fire proneness

C = Coefficients of weightages assigned to different parameters

I = No. of parameters considered

J = Subcategories of the parameters.

Assigning weightage to forest fire influencing factors

GIS analysis through computation and mathematical operations were also carried out by considering the forest fire influencing factors. The factors that influence fire risk in an area were analyzed in the following order of importance: vegetation, accessibility and distance, road network, slope, etc. The different classes among each factor were assigned suitable ratings based on their influence on the forest fire risk (Table 2). A higher rating indicates that the factor has a high degree of influence on the fire risk in an area.

- During analysis, vegetation types/density was given the second highest "weightage of 4" keeping in view the fact that a forest fire cannot occur unless inflammable material is present and accordingly, the vegetation types (with 1–7 classes) were rated on a scale of 25–100 based on its composition of species.
- Similarly, Data on Fire Incidences for the year between 2000 and 2004 was assigned the highest "weightage of 5" with rating of 70 (with 14–15 classes).
- Slope does not necessarily influence the probability of an ignition but has a strong influence on the behaviour of fire and also plays a role in the consequent suppression operation. Slope was assigned the third highest "weightage of 1" with rating from 30–100 (with 11–13 classes). The different slope classes were rated according to the likelihood that a fire ignited on the slope will spread.
- The proximity factor was assigned the third highest weightage, as man-made anthropogenic actions are the main causes for

Table 2 Weightages and ratings assigned to variables and classes for forest fire risk modelling

Sl. No.	Variables	Classes	Indices/ weightage	Fire sensitivity	Ratings/value
1	Vegetation type	(1) Dry deciduous 25-40	04	Highest	100
		(2) Dry deciduous 40-70		Highest	85
		(3) Dry deciduous 10-25		High	75
		(4) Moist deciduous 40-70		High	65
		(5) Teak plantation		Moderate	55
		(6) Scrub forest		Moderate	50
		(7) Others		Low	25
2	Foot path/Cart road/ Unmetelled road	(8) 2500-2000 m buffer	01	Low	5
		(9) 2000-1500 m		Medium	25
		(10) 1500 – 1000 m		High	50
		(11) 1000-500		High	75
		(10) 500-0		Highest	100
3	Slope (in degrees)	(11) 0-10	01	Low	30
		(12) 10 -35		Moderate	60
		(13) 35 and above		High	100
4	Habitation or Data on Fire Incidences from 2000—2004 (Source: Web Fire Mapper)	(14) Historical data with 1 km Grid	05	High	70
		(15) Historical data with 1.5 km buffer (For Moderate Risk Zone)		Moderate	70

initiating forest fires. Though this does not influence the behaviour of a fire, roads inside the forest provide possible access routes and hence road variables were assigned "weightages of 1" with ratings from 5–100 (with 8–10 classes). Since, the risk factor decreases farther from these features, a zone in close proximity to the settlement area / road network was assigned a higher rating.

- Surface water bodies which fall under no fire risk zone has been knocked out from the final map. Also, as the forest types in the study area vary with altitude, it is not considered as an important parameter in calculating fire risk index.

Finally, different classes in the thematic maps were labelled separately based on their sensitivity to forest fire as high, moderate or low. All the thematic maps (layers) were then integrated using the union process of GIS software and the fire risk index was calculated using the forest fire influencing factors along with the weightages assigned to the above parameters. Finally, forest fire risk zones were delineated by grouping the polygons of the integrated layer into different risk zones. A criterion-based analysis has been performed for demarcating the upper and lower limits of the forest fire index. The equation used for mapping the fire risk areas is as follows:

$$FR = [(VTI * wt) + (HDI*wt) + (HDIB* wt) + (SI * wt) + (RI * wt)] \quad (3)$$

where,

FR = Fire Risk Index/Numerical index of fire risk

VTI = Vegetation Type Index (1–7 classes)
HDI = Historical Data Index (4 years)
HDIB = Historical Data Index (4 years with 1.5 km buffer used for Moderate Risk Zone)
SI = Slope Index (with 1–3 classes)
RI = Road Index (with 1–5 classes).

Ground truthing

The park was surveyed to classify the vegetation types and land use patterns. Accordingly, different elements of vegetation and its structure were identified using differences in type of land cover/ land use, tree species composition, canopy cover, land feature description and the degree of disturbance using Global Positioning System. Based on the data collected from ground truthing, the images were classified into seven classes (Table 3). The ground truth analysis indicated that the major loss is on account of seasonal fire (man made) contributing to the consequent decrease in a regeneration pattern of vegetation.

Table 3 Details of the vegetation types under different fire sensitivity classes

Vegetation type & canopy class	Fire sensitivity classes
Dry deciduous 25-40	Highest
Dry deciduous 40-70	Highest
Dry deciduous 10-25	High
Moist deciduous 40-70	High
Teak plantation	Moderate
Scrub forest	Moderate
Others	Low

Results and discussion

Classification of Land use/Land cover

The spatial distribution of vegetation types in all the nine ranges of the Bandipur National Park has been broadly classified into four major forest types namely, dry deciduous forest which occupied the largest area (451.49 km^2) followed by moist deciduous forest (342.89 km^2), scrub forest (71.04 km^2) and semi evergreen forest (2.74 km^2) (Fig 2). Thus, dry deciduous forest covers a major portion of the National Park with 52 % distribution throughout the National Park followed by 39.48 % of moist deciduous forest, 8.18 % of the scrub forest and a patch of 0.32 % of semi evergreen forest. It is apparent that the fire occurrences are very high in dry deciduous forests as they shed all their leaves during winter season and serve as a major fuel source to promote fire.

The spatial extent of density was assessed and categorized into four density classes namely, 0–10, 10–30, >30 and miscellaneous. It was found that density class of 10–30 covered a larger area of 598.39 km^2 followed by class >30 (213.55 km^2). While class 0–10 (37.8 km^2) and miscellaneous (19.13 km^2) recorded lesser density.

Burnt area assessment

The type and characteristics of vegetation is considered as the main factor that affects the occurrence and spread of forest fire. The extent of burnt area (Fig. 3) in all the nine wildlife ranges of the National Park was assessed for the year 1997 to 2006 using IRS LISS-III data. Similarly, Khan *et al.* (1992) have mapped the fire affected areas in Bandhogarh National Park (MP) using IRS LISS-II data. It is evident that fire occurrences are less for 1997 and 1998. The fire had its heavy toll in 2005 accounting for 26 % of the total area when compared to the previous 10 years followed by the next higher values during 1999 and 2004 (Table 4). The results indicate significant variation in fire incidence and the area damaged in different ranges and it is apparent from the results that Bandipur National Park faces the risk of fire almost every year. Similar results were observed for Madumalai Wildlife Sanctuary for 1990 to 1995, which is also situated near the present study

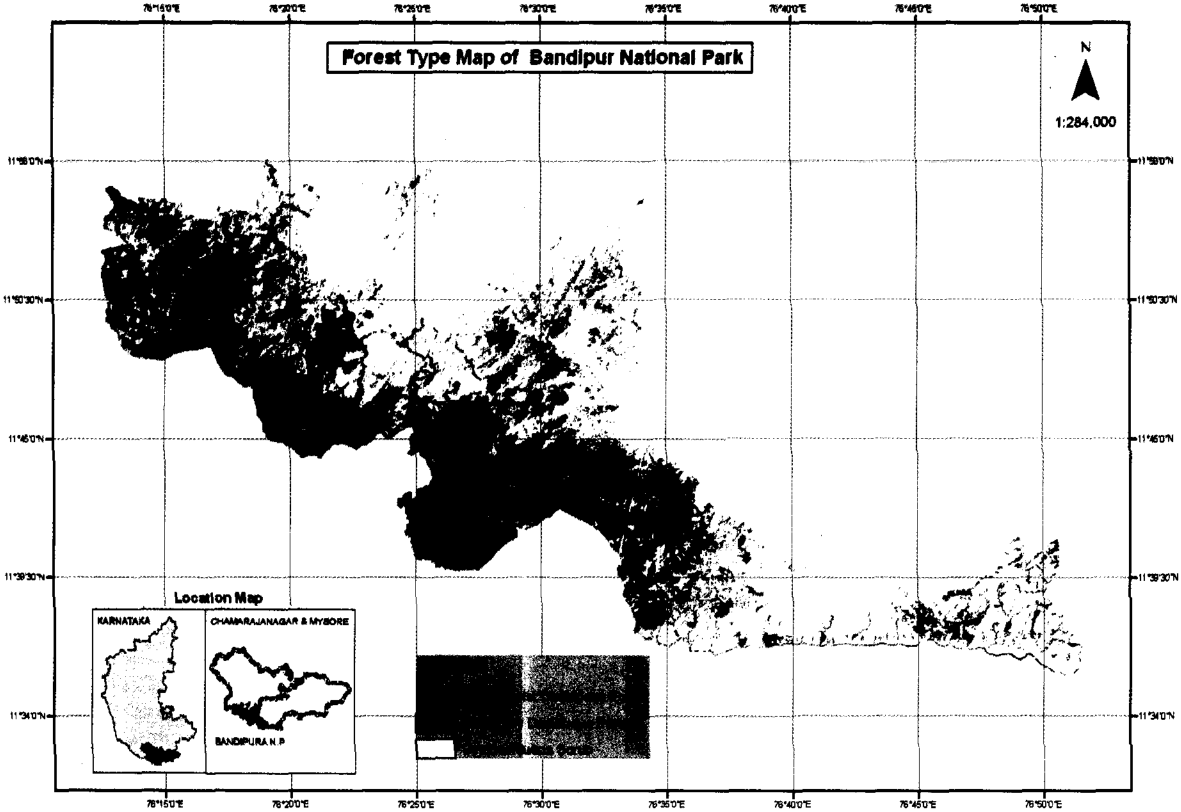

Fig. 2 Land use/land cover map of Bandipur National Park.

Table 4 The extent of fire damage in nine ranges of Bandipur National Park during 1997 to 2006

Sl.No.	Forest range	Area (km^2)									
		1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	Moliyur	0.00	0.00	5.46	3.02	1.02	23.32	23.89	7.19	56.15	26.48
2	N. Begur	0.00	0.00	43.05	2.01	9.03	12.56	14.62	9.57	15.63	2.71
3	Hediyala	3.98	0.00	3.74	3.52	0.00	14.03	13.23	22.42	9.57	10.84
4	Gundre	0.00	6.21	72.63	0.00	0.00	16.21	6.32	48.64	5.36	0.00
5	Maddur	4.53	0.00	2.53	4.02	0.00	5.02	2.51	5.26	12.36	13.49
6	Ainur Marigudi	4.73	0.00	21.45	0.00	1.30	4.02	6.76	13.62	16.56	0.00
7	Moolehole	0.00	0.00	2.86	5.23	1.24	2.00	0.20	10.54	2.56	13.13
8	Moyar	0.00	4.11	6.29	0.00	10.42	0.30	19.36	0.00	98.12	7.64
9	Bandipur	0.00	5.12	8.63	0.00	0.00	0.20	0.36	0.00	10.26	18.97
	Total	**13.24**	**15.44**	**166.64**	**17.80**	**23.01**	**77.66**	**87.25**	**117.24**	**226.57***	**93.26**

Note: * High fire damage occurrence.

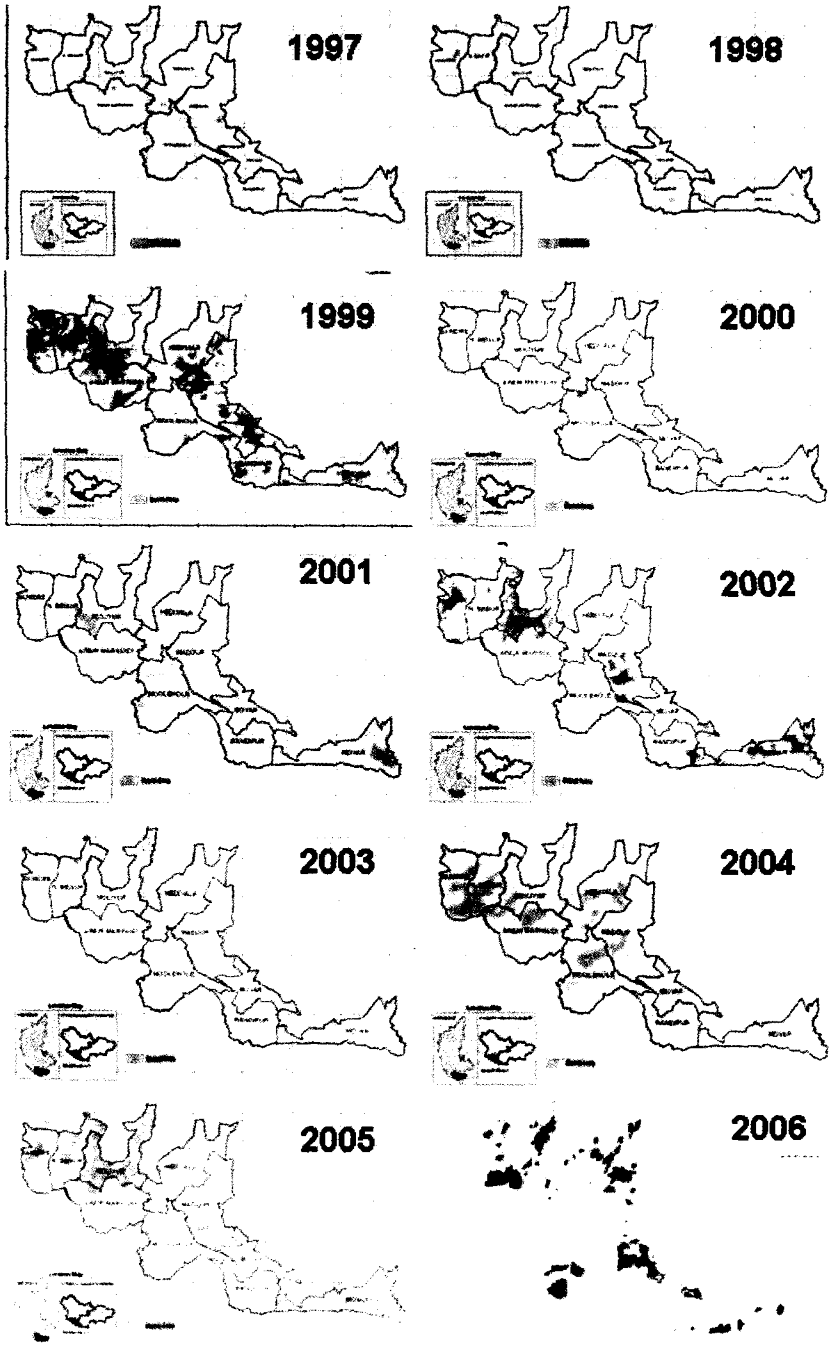

Fig. 3 Extent of burnt area for the years from 1997 to 2006.

area (Ranganath *et al.*, 1994). The forest fire events are of both surface (ground) and crown in nature, whereas the very less percentage of fire affected areas were reported for Bhadra Wildlife Sanctuary (Somashekar *et al.*, 2008).

Forest cover assessment and classification of fire intensity zones

It is evident from the study that vegetation types that come under high fire intensity zones belong to dry deciduous and moist deciduous forests, while teak plantation and scrub forests fall under moderate fire intensity zones (Table 5).

The low risk zones as indicated in the March 2002 data are spread over the northern and southern belt of the park leaving Maddur, Moyar, Mulehole and Ainur Marigudi ranges almost fire-free. As evident from the fire risk analysis map of 1999 and 2005, except high risk zones at Mavinahalla, Rampura and Hanghaithodu all the other high risk zones are located in the mixed deciduous and dry deciduous forests. Therefore, it can be concluded that mixed moist deciduous forests in the park comes under either no fire or low fire intensity zones.

An assessment of fire intensity zones was carried out to identify the areas experiencing repetitive fire at various intensities over a period of a decade and three zones of fire intensity were graded namely, (a) High intensity zones – areas experiencing high intensity fire damage and which are also in high risk status to fire damage in the near future, (b) Medium intensity zones – areas experiencing moderate intensity fire damage and which are also in moderate risk to fire damage in the near future and, (c) Low intensity zones - areas experiencing low intensity fire damage and which are also in moderate risk to fire damage in the near future (Fig. 4).

Table 5 Extent of fire risk zones

Fire risk zones	Degree of fire risk	Description of fire risk zones	Area (km^2)	Proportion of burnt area (%)
I	High	Areas dominated with mixed deciduous and dry deciduous forests bamboo; high ignition value on high slopes	78.25	25.64
II	Medium	Areas with teak plantation and scrub forests; moderate ignition value on moderate and high slopes	103.72	33.98
III	Low	Areas with less forests and a part of mixed moist deciduous forests; low ignition value and moderate slope	123.24	40.38
		Total	**305.21**	**100**

The high risk zones during 1999 were recorded in Mavinahole, Hanghatihodu, Kadamatturkatte, Karadikal Betta, Gopalswamy Betta (N), Hebbala, Kakankote betta and Ron Bridge beats. Similarly, high risk fire zones during 2005 are from Vadal (W), Kalkare, Chigarkaguvinahalla, Ukar, Moyar and Yalachatti.

Fire of both high and medium intensity was recorded in the sites having settlements, especially near Gundre, Hekkanahalla and Torangavikote during 1999; near Gidaganakote and Torangvikote during 2001 and 2005. However, around Nediyala and Moyur having settlements, fire of lesser intensity has been observed. It is therefore inferred that most of the fire around settlements belonged to either medium or high intensity in the last 10 years.

Accordingly, the fire intensity zones classification was carried out for all the nine ranges of the study area over a period of ten years. Evidently, the results of the fire intensity zonation indicate that out of a total area of 868 km^2, the fire incidence has spread in an area of around 305 km^2 (35.14 % of the total area) all over the National Park over the period of a decade (Table 5). It is apparent that out of 35.14 % fire incidence, nearly 14.19 % are low intensity fires followed by 11.94 % of medium and 9.01 % of high intensity. Also, the type of soil in the three fire affected zones was found to be loamy skeletal, clayey skeletal and clayey soils respectively.

Most of the fires representing burnt areas were located in the low and medium fire risk zones in the study area. Whereas in Madhya Pradesh, more percentage of area is under very high and high risk zone categories for a bamboo dominated forest type. However, they too attributed that repeated fire occurrences are due to proximity to human activity, road network, slope and vegetation type (Jaiswal *et al.*, 2002).

Assessment of causal factors of fire incidence in the park

The observed causes for fire incidences and causal information collected from the forest staff illustrated that most of the forest fires are not accidental and are in fact set by the villagers residing in the fringe of the park to get good grass growth in the ensuing season to feed their livestock. Also, some Gowlis and owners of low lying paddy fields set fire to get fresh shoots of grass or ash into their fields.

Comparatively, the fire incidence appears to be more predominant in the tourism zones perhaps due to their ignorance and negligence. Besides, people living in thatched houses burn the surrounding land to keep accidental fires away and to destroy bushes

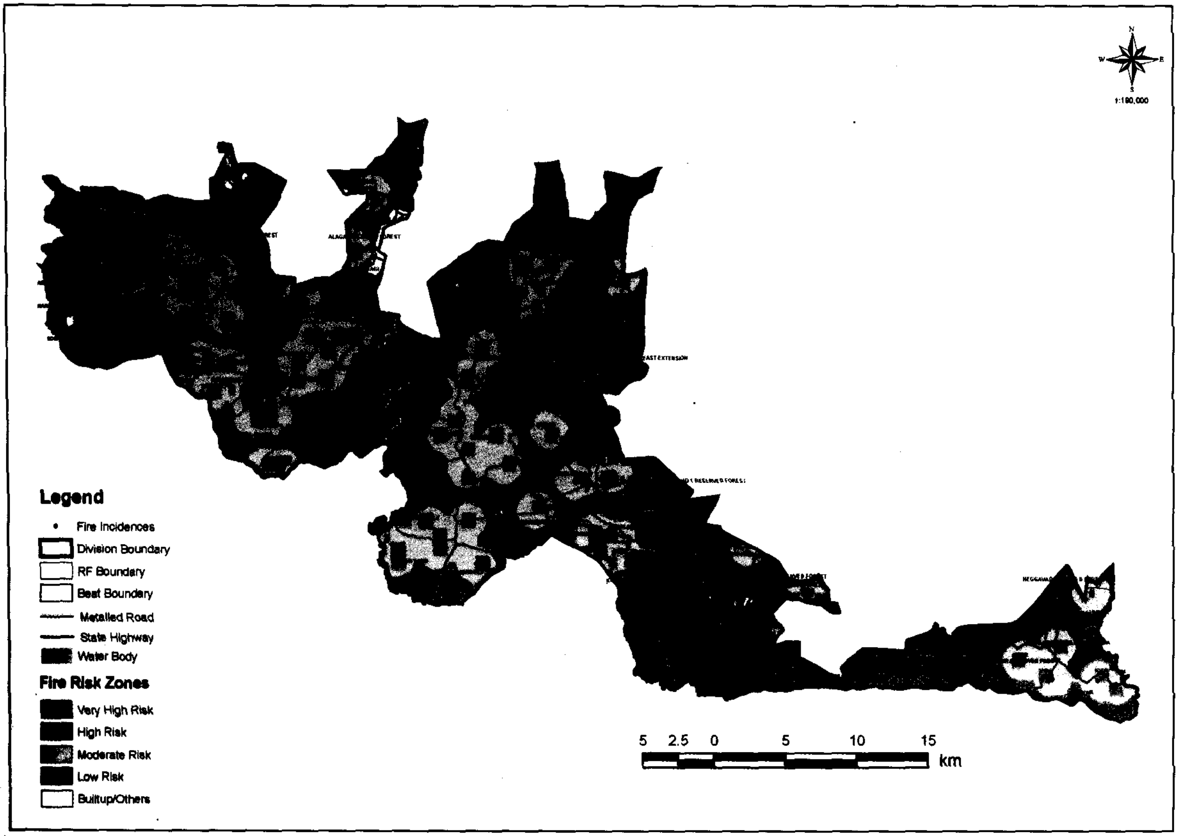

Fig. 4 Fire risk zonation map of Bandipur National Park.

and wildlife hideouts. Fire is also lit accidentally due to ignorance of labourers employed for bamboo extraction and eco-development works.

Increase in fire hazards was also due to the entry of people residing in the fringe villages into the forest for various purposes, such as collection of the antlers of deer, as these are not clearly visible in the presence of bushes. Fires are also lit to keep leeches and ticks away from the interior foot paths as the ticks carry monkey fever. Poachers set fire to avoid the sound of dry leaves. Some times after fire, half burnt trees are left smoldering, which may allow fire to start again and be spread by wind. Bamboo debris left out after extraction is also a fire hazard.

Conclusions and suggestions

Global concern over the fate of the world's forests as well as specific concern over the frequency and intensity of forest fires have increased dramatically as a result of human activities in recent years. Traditional forest fire management regimes with prescribed burning and proactive prevention approaches should be implemented, so that effective measures such as tampering unwanted fires more beneficial to local ecosystems and less costly in the long term are adopted. The information collected from the public within and outside the park and from the Forest Department on the causal factors for fire revealed that approximately 95% of the fire is connected with human activities that are mostly of intentional nature. Some of the management strategies currently adopted by the Forest Department are the fire lines and fire breaks, being maintained throughout the park, thereby making the inspection paths and forest roads themselves to act as barriers. Fire isolation trenches are maintained inside the park especially in areas having litter accumulation. Forest staff opine that beating fire with green bushes is the best method. Fire watch towers have been erected in the high altitudinal areas. A fire fighting team of 15–20 members has been given a vehicle for the task of fire fighting as well as walkie-talkie sets.

Since, fire problem cannot be solved without the full co-operation of local people, imparting prevention education to the tribal communities, giving employment as fire watchers for every 4 km or even encouraging them to participate in fire prevention works like establishment and maintenance of fire breaks, etc., should be undertaken. The eco-development committees of the park should be involved in fire prevention and control activity. In addition to this, in-service training and short courses must be organized not only for the forestry personnel at all levels but also the extension workers, voluntary organizations, electricity employees, engineers and others who may have time and interest to work in forest areas.

It is also necessary to encourage integration of agriculture and grazing land-use into fuel break systems through incentive mechanisms (e.g., through cost-free leasing of fuel break lands). Establishment of demonstration modules/practices for non-traditional harvesting of secondary forests with a view to offend the pressure exerted by agricultural burning and alternatives for the preparation of agricultural lands other than the burning of fossil fuels should be undertaken.

Precautionary measures to reduce fire hazard risk

Fire prevention must form the backbone of forest fire protection strategy in the National Park, but it is difficult to say with certainty as to what method of hazard reduction is ideal. It can be concluded that properly maintained fire lines can just help in breaking the continuity of the fires, but they cannot be relied upon to contain and localize fire itself. Identification and planting of the fire resistant species in covered firebreaks holds greater promise in preventing the occurrence of fire. The practice of agri-silviculture may often be found to be useful in reducing fire hazard, apart from its other advantage as a combined production system. Weeding, cleaning, climber cutting, thinning, etc., should be carried out from time to time as these operations reduce the hazard by breaking the vertical continuity of the fuels.

Fire lines serve a useful purpose in fire prevention by breaking the horizontal continuity of the fuel and the existing natural and artificial features. Direction of prevailing winds, fuel characteristics, fire behaviour, possible source of ignition etc., should be kept in mind while deciding their size and alignment, in order to be effective the fire lines have to be properly maintained. Evergreen firebreaks may be found useful in certain localities. Fire resistant species for planting as evergreen firebreaks need to be identified for different areas.

Detailed studies need to be conducted on the fire behaviour for different degrees and types of accumulated fuel under varying conditions of climate and topography in order to provide a scientific basis for hazard reduction through prescribed burning but also, for prediction of fire damage, guidance in fire suppression etc. Detailed plan for prescribed burning needs to be prepared in advance of operation where such burning may be prescribed for hazard reduction or other specific purposes. Close supervision of the operation by responsible officers is also necessary to ensure success. Requisite skills in prescribed burning as a measure of hazard reduction need to be developed through intensive training.

We hope that our suggestions will prove useful to those responsible for formulating and implementing fire management policies and programs in better understanding the key issues and challenges involving local people as effective partners in managing forest fires. Also, the study finds that LISS III data are useful in delineation of various thematic maps like forest type, density and forest fire risk zonation for better management of forest resources in Bandipur Wildlife Division. Large-scale fires throughout the world in recent times have demonstrated the social, economic and ecological costs of uncontrolled fires and have received unprecedented coverage to combat the negative impacts and for improvement in controlling forest fires.

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