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*Keywords:* *forest fire; spatial pattern; temporal pattern; remote sensing; GIS..*

*GJSFR-H Classification : FOR Code: 070503*

MONITORINGCHANGESINFORESTFIREPATTERNINMUDUMALAITIGERRESERVEWESTERNGHATSINDIAUSINGREMOTESENSINGANDGIS

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*Keywords: forest fire, spatial pattern, temporal pattern, remote sensing, GIS.*

## I. Introduction

Forest fire is an important constituent in many forest ecosystems in spite of its diverse effects. Increasing fire frequency is a matter of serious concerns in tropical forests (Kellman et al. 1996). In the tropics, large parts of the forest are burning as an unintended consequence of current land-use practices (Cochrane 2003). Its immediate effect depends on the intensity of fire, but long-term effects depend also on fire frequency and seasonality (Gill 1975). Fire has a wide range of impact on flora, fauna and soil dynamics. (Verma and Jayakumar, 2012; Certini, 2005) Recurrent fires can significantly alter the structure, composition and biomass of forests, which are not adapted to fire (Xaud et al. 2013). According to the FSI report on forest fire (2012) 8,645 forest fire incidences were reported in 2004-2005 and 13, 898 in 2010-2011 in the India.

Most of these fires were reported in dry deciduous forests. In India, accidental fires occur in the dry season accredited to human use of forests (Saha 2002). The northeastern part of the India suffers from fire, mainly because of age-old practice of shifting cultivation (Puri et al. 2011). Forest fires are also very frequent across the Western Ghats (Kodandapani et al. 2004) and played a significant role in the vegetation history of Western Ghats (Chandran 1997). Western Ghats is the biodiversity hotspot with highest human population density (Cincotta et al. 2000). The mean fire-return interval in Western Ghats shortened from 10 years in 1910-1921 to 3.3 years in 1990-2002 (Kodandapani et al. 2004; Renard et al. 2012).

Remote sensing and GIS played a foremost role in the study of factors influencing the occurrence of fire and understanding the dynamic behavior of fire (Jaiswal et al. 2002; Lentile et al. 2006). Remote sensing is used for a variety of aspects of fire studies, as fire risk prediction, spread modelling, active fire detection, burned area mapping and to check the regeneration status of forests. Burned area mapping has been carried out using a wide range of satellite sensors that exploits the differences observed in the spectral signatures between healthy forest canopy and forests destroyed or damaged by fire (Gerard et al. 2003). Burned area can be estimated by various methods that include visual interpretation, supervised classification and through normalized burn ratio (NBR) index. Images from MODIS and Landsat TM/ETM+ satellites are a common source of data and have potential to monitor forest fires (Benito and Torralbo, 2012).

Few researchers have attempted to study forest fire in the Mudumalai. For example, Kodandapani et al. (2004, 2008 and 2009) studied fire history, the fire return interval, ecological impact of fire and conservation threats of forest fire in the Western Ghats from 1989 to 2005 and Mudumalai Tiger reserve (MTR) was a part of their study area. Srivastava et al. (2014) mapped fire risk areas in MTR and Mondal and Sukumar (2014) studied characteristic weather pattern associated with fire. Verma and Jayakumar (2015) studied impact of fire on stand structure and regeneration of trees in MTR. This study was designed to assess the fire pattern in MTR between 1999 and 2014.

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## II. Material and Methods

*a) Study Area*

This study was carried out in Mudumalai Tiger reserve. MTR is located between $11^0$ 32' & $11^0$ 43' N and $76^0$ 22' & $76^0$ 45' E at the tri-junction of Kerala, Karnataka and Tamil Nadu states, in the state of Tamil Nadu and is a part of the Nilgiri Biosphere Reserve that covers 5500 $Km^2$. MTR stretch over an area of 321 $Km^2$ with an average altitude of 1000 m (Fig. 1). Based on the climate of the area, there are three distinct seasons recognized. January-May is a dry summer season. Annual rainfall ranges from about 800 to 2600 mm and represents a strong east-west gradient. The temperature ranges from $13^0$C in December to $34^0$ C in April. Mean temperature varies $21^0$ to $25^0$ C in different parts of the reserve. Forest fires are very common in MTR, which occur typically between January and April.

*b) Data Collection*

Toposheets (58 A6 and 58A10) were collected from the Survey of India in 1:50,000 scales. Burned area maps were collected from the forest department, Tamil Nadu that were accessible from 2001 to 2012. Burned area maps for 1999, 2000, 2013 and 2014 were prepared using Landsat images downloaded from USGS web site (Table 1). Fire location data was downloaded from NASA Fire Information for Resource Management System (FIRMS) from January 2001 to June 2014 and used to compute the number of fires and their proximity to the road, footpath, and settlements (Table 1). All the images were geometrically corrected based on Survey of India topographic maps using ERDAS Imagine 11.0 software.

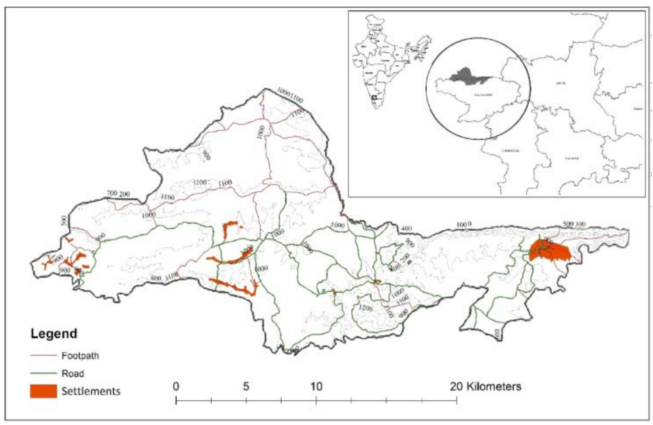


*Figure 1 :* Location map of the study area

*c) Data Analysis*

Fire locations were identified using NASA Fire Information for Resource Management System (FIRMS) data, from January 2001 to June 2014. Supervised Classification was performed, based on the shortwave infrared composite image (band combination 7-4-3 in Landsat ETM+) to delineate the burned area. SWIR bands are especially suited for camouflage detection, change detection, disturbed soils, soil type, and vegetation stress. Newly burned land reflects shortwave infrared light and appears red in this combination. Maximum likelihood classification technique was used for the supervised classification. Before the classification, representative training sites were extracted by visually selecting pixels representing burned and unburned surfaces. Fire maps for all years were transformed into raster data and combined using map algebra to prepare fire frequency maps. Vegetation map of MTR was prepared from recent satellite images LANDSAT 8, OLI-TIRS, p144 & r52 March 31, 2014) by supervised classification using Maximum likelihood classifier.

| Data used | Data types | Data sources | Temporal availability |
|---|---|---|---|
| Topography and burned area data | Toposheet 58 A6 & A10 | Survey of India | |
| | Burned Area Maps | Tamil Nadu Forest Department | 2001-2012 |
| | Fire Location data (MOD14/MYD14) | NASA Fire Information for Resource Management System (FIRMS) | January 2001– June 2014 |
| Remotely sensed data | LANDSAT 5, TM, p144 &r52 | USGS, EarthExplorer | Feb 02, 1999 & Apr 07, 1999 |
| | LANDSAT 7, ETM+, p144 &r52 | USGS, EarthExplorer | Jan 28, 2000, Apr 17, 2000, May 03, 2000 & Mar 2001 |
| | LANDSAT 8, OLI-TIRS, p144 &r52 | USGS, EarthExplorer | Apr 13, 2013, March 31, 2014,May 02, 2014 |

(Mean burned area, number of fire incidences and fire return interval (FRI) for each forest type were calculated.

Proximity analysis was carried out for roads, footpaths and settlements inside MTR to recognize their influence on forest fires. Roads, footpaths, settlements layers were prepared using the Survey of India toposheets (58A6 & 58A10). Regression analysis was done to see the relationship between total numbers of fires with increasing distance. All statistical analyses were done using IBM SPSS Statistics 20.

# III. Results

*a) Temporal Pattern of Fire*

Fire incidences in MTR ranged from 0 to 82 with an average of 22 incidences per year and maximum incidences of fire occurred in 2009. The forest was burning with an annual rate of 9.78% (3141.46 hectare) for 16 years. The total 29.91% area did not receive fire at all in past 16 years (1999-2014) (Table 2).

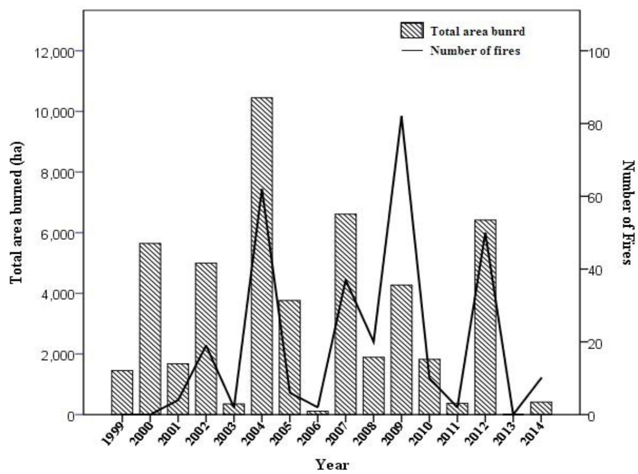


*Figure 2 :* Total area burned each year from 1999 to 2014 and the number of fires each year from 2001 to 2014

Whereas 26.49% area burned once, 18.62% twice, 14.00% thrice, 8.30% received four times, 2.40% five times and only 0.25% received six time fire. Maximum of 32.56% of the total forest area was burned in 2004. Fire occurrences were not detected in 2013.

*Table 2 :* Area burned in different fire frequency from 1999-2014

| Burn Frequency | Area (Ha) | Area (%) |
|---|---|---|
| 0 | 9601.11 | 29.91 |
| 1 | 8503.29 | 26.49 |
| 2 | 5977.02 | 18.62 |
| 3 | 4494.00 | 14.00 |
| 4 | 2664.30 | 8.30 |
| 5 | 770.40 | 2.40 |
| 6 | 80.25 | 0.25 |
| Total | | 100 |

During 2000, 2002, 2004, 2007, 2009 and 2012, the burned forest area ranged between 4000 and 8000 hectares, while in 2003, 2006, 2011 and 2014 fire burned less than 500 hectares (Fig. 2). Fire pattern in MTR was generally uniform for the period of analysis, where the higher occurrences of fire with more forest area burned in a year was followed by a few occurrences of fire with less area burned.

In our study, we recorded a maximum of six fire frequencies. Only 80.25 hectares of MTR received six-time fire in the 16 years of the study period between 1999 and 2014. Burned area decreased with increasing fire frequency. It is evident from the fire frequency map (Fig. 3) that majority of fires occurred in dry deciduous forest patches, which is in the middle and North Western side of the MTR. The moist deciduous forest on the southern side experienced least number of fires. Similarly, the scrub forest on the eastern side experienced a small number of fires during the analysis period.

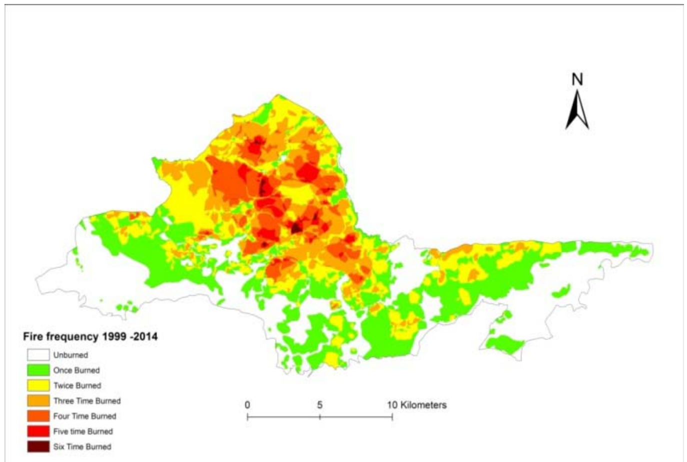


*Figure 3 :* Forest fire frequency map of Mudumalai Tiger Reserve (1999-2014)

*Table 3 :* Mean area burned, number of fires and fire return interval in different forest types in MTR from 1999-2014

| Vegetation type | Area burned (1999-2014) (%) | Mean annual area burned (Ha) | Number of fires | Fire return interval (Year) |
|---|---|---|---|---|
| Dry Deciduous | 88.23 | 2730.09 ± 2828.43 | 266 | 8.71 |
| Moist Deciduous | 23.15 | 86.78 ± 305.81 | 11 | 15.64 |
| Dry Thorn | 54.76 | 322.11 ± 825.93 | 22 | 13.25 |

Dry deciduous forest showed least fire return interval (FRI) of 8.71 year and was more prone to fires (Table 3), the moist deciduous forest was less prone to fire with a FRI of 15.64 year. FRI for the dry thorn forest was 13.25 years. Mean area burned between 1999 and 2014 was highest in dry deciduous forest (2730.09 ± 2828.43 hectares) followed by dry thorn forest (322.11 ± 825.93 hectares) and moist deciduous forest (86.78 ± 305.81 hectares). Most of the fires in MTR were recorded in February and March (Fig. 4). In our analysis, 4.68% of the fires were recorded in January, 58.86 % of fires in February, 34.78 % in March, 1% in April and fire occurrence was rare (0.66%) in May. Overall, 93.64% of fires were recorded in the months of February and March from 2001 to 2014.

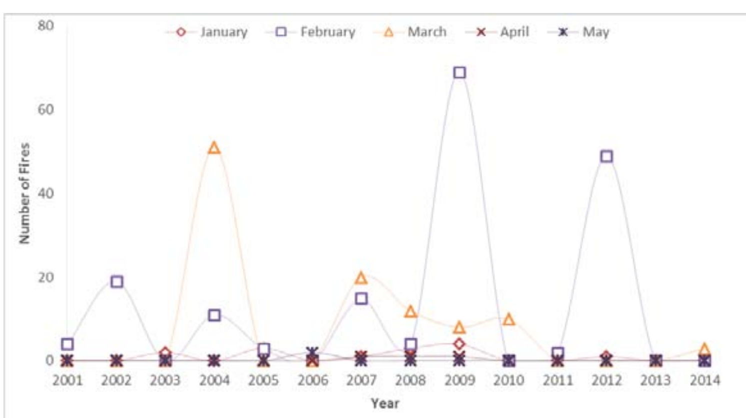


*Figure 4 :* Analysis of fire season in MTR from 2001 to 2014

*b) Spatial Pattern analysis*

We analyzed the spatial pattern of fire to determine proximity of forest fire to roads, footpaths and settlements. The roads ($R^2$= 0.849, p= 0.000) and footpaths ($R^2$= 0.729, p= 0.001) showed a strong association with fires (Fig. 5a & 5b).

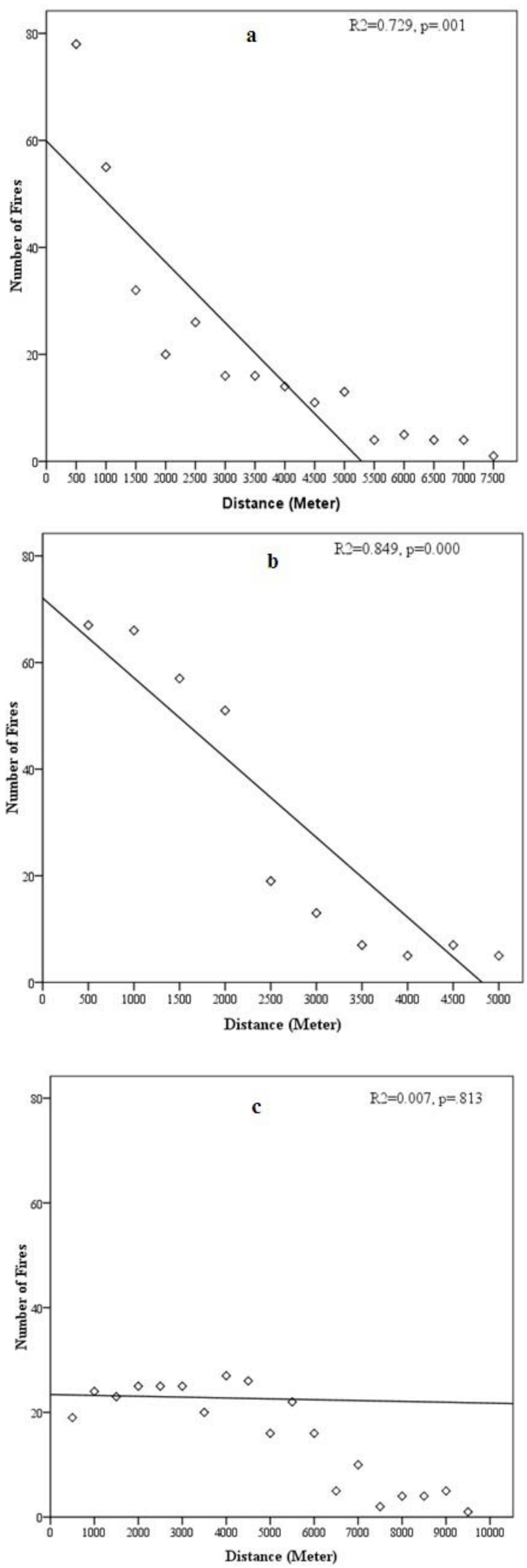


*Figure 5 :* Analysis of number of fire incidence from 2001 – 2014 with increasing distance from; a. Footpaths; b. Roads and C. Settlements

Fire incidences decreased with increasing distance from the roads and footpaths. Settlements ($R2= 0.007$, $p= 0.813$) did not show any noteworthy association with fire incidences (Fig. 5c). Numbers of fire occurrences within one km of footpaths and roads were 133 each and 43 around settlements in 16 years.

## IV. Discussion

Fire is a significant recurrent disturbance with potentially severe consequences in MTR. Forest fires have been a part of these ecosystems for many thousands of years (Chandran 1997; Gadgil and Chandran 1988) but fire frequency have been changed noticeably in the past 100 years, first increased due to growing human use of forest (Kodandapani et al. 2004) and later decreased in preceding decade owing to effective management practices and research conducted in past 25 Years in MTR. The causes of these fires are poaching, antler collection, grazing, tourism, estates and settlements in and around the reserve (Srivastava et al. 2014). The tribal's in these forest light fire to facilitate their hunt for shed antlers of 'Chital' (Axis axis) and Sambar (Cervus unicolor) (Johnsingh 1986). The poachers light fire for visibility. Fire incidences were recorded very high with a break of 1- 3 years. The same pattern is observed in the total burned area. Explanation for this could be the less availability of fuel for burning in the consecutive years. This reduction in flammability, however, may be short-lived if delayed tree mortality or tree fall increases surface fuels in future years (Balch et al. 2008).

In MTR, fire return interval was considerably declined (9.83 years) in past 16 years (1999- 2014) compared to previous decade. Kodandapani et al. (2004) reported 3.3 years mean fire return interval for MTR in 14 years of the study period (1989-2002). In a different study which included 7 years of data between 1996 and 2005, Kodandapani et al. (2009) recorded 7 years of mean fire return interval for Nilgiri landscape which includes MTR. The drastic reduction in the fire frequency could be ascribed to the anti-causative factors, particularly stationing of the anti-poaching-cum-fire camps in the year 2000, and ban on the operation of private vehicles as a consequence of restricted tourism (Srivastava et al. 2014). Other management practices include clearing of fire lines, removing lantana near the roads and prohibiting tourism in fire season. Annual rate of area burned was significantly reduced (9.78%) compared to earlier study of Kodandapani et al. (2004), who reported three time higher rate (30%) of burning between 1989 and 2002. Annual rate of burning in MTR was also less than Similipal Biosphere Reserve Odisha, India in the same decade, where 20.7% of burning rate was reported by Saranya et al. (2014).

The spatial pattern of forest fire locations is of interest for fire occurrence prediction and for understanding the role of fire in landscape processes. Fire occurrence could be affected by vegetation type, climate, topography and anthropogenic variables. There is variability in the susceptibility of fires across different vegetation types (Cochrane 2003; Cumming 2001). Dry deciduous forests are more vulnerable to the fire due to high fuel load, presence of grasses and low rainfall. Forest fires in the tropical dry deciduous forests have significantly changed the species diversity, structure and regeneration in MTR (Kodandapani et al. 2004). Almost whole central part of the reserve received more than five fire incidences in the past 16 years, which was principally covered by dry deciduous forest. Forest fires were rare in moist deciduous forest and very less in dry thorn forest.

Proximity of fire to roads, footpaths and settlements (Fig. 5a, b and c) was analyzed by assuming that most of these fires were deliberate or unintended, caused by the spark of the vehicle, poaching, antler collection or from settlements. Roads and footpaths provide quick and easy access to areas. Roads showed more noteworthy association with fires, and the number of fires was decreasing with increasing distance from roads. The study area is a tiger reserve, but few roads are used for tourism and local transport. One highway also passes all the way through the study area. Fire on both sides of the road could be unintentional by tourists or by the spark of the vehicles. We recorded the high number of fires around footpaths also, which considerably decreased with increasing distance. In MTR, the footpaths were used by tribes and burning along the footpaths suggests that most of these fires might be intended. Our results were supported by the study of Narayanaraj and Wimberly (2012), they studied influences of forest roads on the spatial patterns of human-and lightning-caused wildfire ignitions and found that fire incidences are declining with increasing distance from roads and footpath. The fire showed relatively less proximity to settlements, which may be owed to the presence of watch towers, forest guards and forest offices near the settlements. It suggests that area around roads and footpaths need special attention for fire fighting.

## V. Conclusion

In this study, we analyzed the pattern of forest fires in MTR in the past 16 years from 1999 to 2014. Analysis of spatial and temporal pattern of fire in the past will be vital to recognize and predict trends in fire pattern in the future. Compared to the previous studies conducted in and around the MTR, the fire frequency decreased evidently, but still forest is burning with an annual rate of 9.78%, which is the matter of vast apprehension. Results also showed that fires were more associated with footpaths and roads rather than settlements. This study can help the forest managers to improve management strategies to combat forest fires. Detrimental and beneficial impact of fire on flora, fauna and soil ecology needs to be thoroughly studied in shifting fire regime.

## VI. Acknowledgments

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## References Références Referencias

1. Balch, J. K., Nepstad, D. C., Brando, P. M., Curran, L. M., Portela, O., de Carvalho, O., & Lefebvre, P. (2008). Negative fire feedback in a transitional forest of southeastern Amazonia. *Global Change Biology*, *14*(10), 2276-2287.
2. Certini, G. (2005). Effects of fire on properties of forest soils: a review. *Oecologia*, *143*(1), 1-10.
3. Chandran, M. S. (1997). On the ecological history of the Western Ghats. *Current Science*, *73*(2), 146-155.
4. Cincotta, R. P., Wisnewski, J., & Engelman, R. (2000). Human population in the biodiversity hotspots. *Nature*, *404*(6781), 990-992.
5. Cochrane, M. A. (2003). Fire science for rainforests. *Nature*, *421*(6926), 913-919.
6. Cumming, S. G. (2001). Forest type and wildfire in the Alberta boreal mixedwood: what do fires burn?. *Ecological applications*, *11*(1), 97-110.
7. Forest survey of India (2012). Vulnerability of India's forests to fires. Ministry of Environment and Forests
8. Available on http://117.239.115.45/fire_report.pdf Accessed on 10 March, 2014
9. Gadgil, M., Chandran, M. D. S. (1988). On the history of Uttara Kannada forest. In Changing tropical forests (pp. 47-58). Centre for Resource and Environmental Studies, Canberra, Australian Capital Territory
10. Gerard, F., Plummer, S., Wadsworth, R., Sanfeliu, A. F., Iliffe, L., Balzter, H., & Wyatt, B. (2003). Forest fire scar detection in the boreal forest with multitemporal SPOT-VEGETATION data. *Geoscience and Remote Sensing, IEEE Transactions on*, *41*(11), 2575-2585.
11. Gill, A. M. (1975). Fire and the Australian flora: a review. *Australian forestry*,*38*(1), 4-25.
12. Jaiswal, R. K., Mukherjee, S., Raju, K. D., & Saxena, R. (2002). Forest fire risk zone mapping from satellite imagery and GIS. *International Journal of Applied Earth Observation and Geoinformation*, *4*(1), 1-10.

13. Johnsingh, A. J. T. (1986). Impact of fire on wildlife ecology in two dry deciduous forests in south India. *Indian Forester*, *112*(10), 933-938.
14. Kellman, M., Tackaberry, R., Meave, J. (1996). The consequences of prolonged fragmentation: Lessons from tropical gallery forest. In Forest patches in tropical landscapes (pp. 37-58). Island Publisher, Washingoton, USA
15. Kodandapani, N., Cochrane, M. A., & Sukumar, R. (2004). Conservation threat of increasing fire frequencies in the Western Ghats, India. *Conservation Biology*, *18*(6), 1553-1561.
16. Kodandapani, N., Cochrane, M. A., & Sukumar, R. (2008). A comparative analysis of spatial, temporal, and ecological characteristics of forest fires in seasonally dry tropical ecosystems in the Western Ghats, India. *Forest Ecology and Management*, *256*(4), 607-617.
17. Kodandapani, N., Cochrane, M. A., & Sukumar, R. (2009). Forest fire regimes and their ecological effects in seasonally dry tropical ecosystems in the Western Ghats, India. In *Tropical Fire Ecology* (pp. 335-354). Springer Berlin Heidelberg.
18. Lentile, L. B., Holden, Z. A., Smith, A. M., Falkowski, M. J., Hudak, A. T., Morgan, P., & Benson, N. C. (2006). Remote sensing techniques to assess active fire characteristics and post-fire effects. *International Journal of Wild land Fire*, *15*(3), 319-345.
19. Mazuelas Benito P, Fernández Torralbo A (2012). Landsat and MODIS Images for Burned Areas Mapping in Galicia, Spain http://www.divaportal.org /smash/get/diva2:553135/FULLTEXT01.pdf Accessed on 17 March 2014
20. Mondal, N., & Sukumar, R. (2014). Characterising weather patterns associated with fire in a seasonally dry tropical forest in southern India. *International journal of wildland fire*, *23*(2), 196-201.
21. Narayanaraj, G., & Wimberly, M. C. (2012). Influences of forest roads on the spatial patterns of human-and lightning-caused wildfire ignitions. *Applied geography*, *32*(2), 878-888.
22. Puri, K., Areendran, G., Raj, K., Mazumdar, S., & Joshi, P. K. (2011). Forest fire risk assessment in parts of Northeast India using geospatial tools. *Journal of Forestry Research*, *22*(4), 641-647.
23. Renard, Q., Pélissier, R., Ramesh, B. R., & Kodandapani, N. (2012). Environmental susceptibility model for predicting forest fire occurrence in the Western Ghats of India. *International Journal of Wildland Fire*, *21*(4), 368-379.
24. Saha, S. (2002). Anthropogenic fire regime in a deciduous forest of central India. *Current Science*, *82*(9).
25. Saranya, K. R. L., Reddy, C. S., Rao, P. P., & Jha, C. S. (2014). Decadal time-scale monitoring of forest fires in Similipal Biosphere Reserve, India using remote sensing and GIS. *Environmental monitoring and assessment*, *186*(5), 3283-3296.
26. Srivastava, S. K., Saran, S., de By, R. A., & Dadhwal, V. K. (2014). A geo-information system approach for forest fire likelihood based on causative and anti-causative factors. *International Journal of Geographical Information Science*, *28*(3), 427-454.
27. Verma, S., & Jayakumar, S. (2012). Impact of forest fire on physical, chemical and biological properties of soil: A Review. *Proceedings of the International Academy of Ecology and Environmental Sciences*, *2*(3), 168-176.
28. Verma, S., & Jayakumar, S. (2015). Post-fire regeneration dynamics of tree species in a tropical dry deciduous forest, Western Ghats, India. *Forest Ecology and Management*, *341*, 75-82.
29. Xaud, H. A. M., Martins, F. D. S. R. V., & dos Santos, J. R. (2013). Tropical forest degradation by mega-fires in the northern Brazilian Amazon. *Forest Ecology and Management*, *294*, 97-106.

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